GPS/GNSS課程

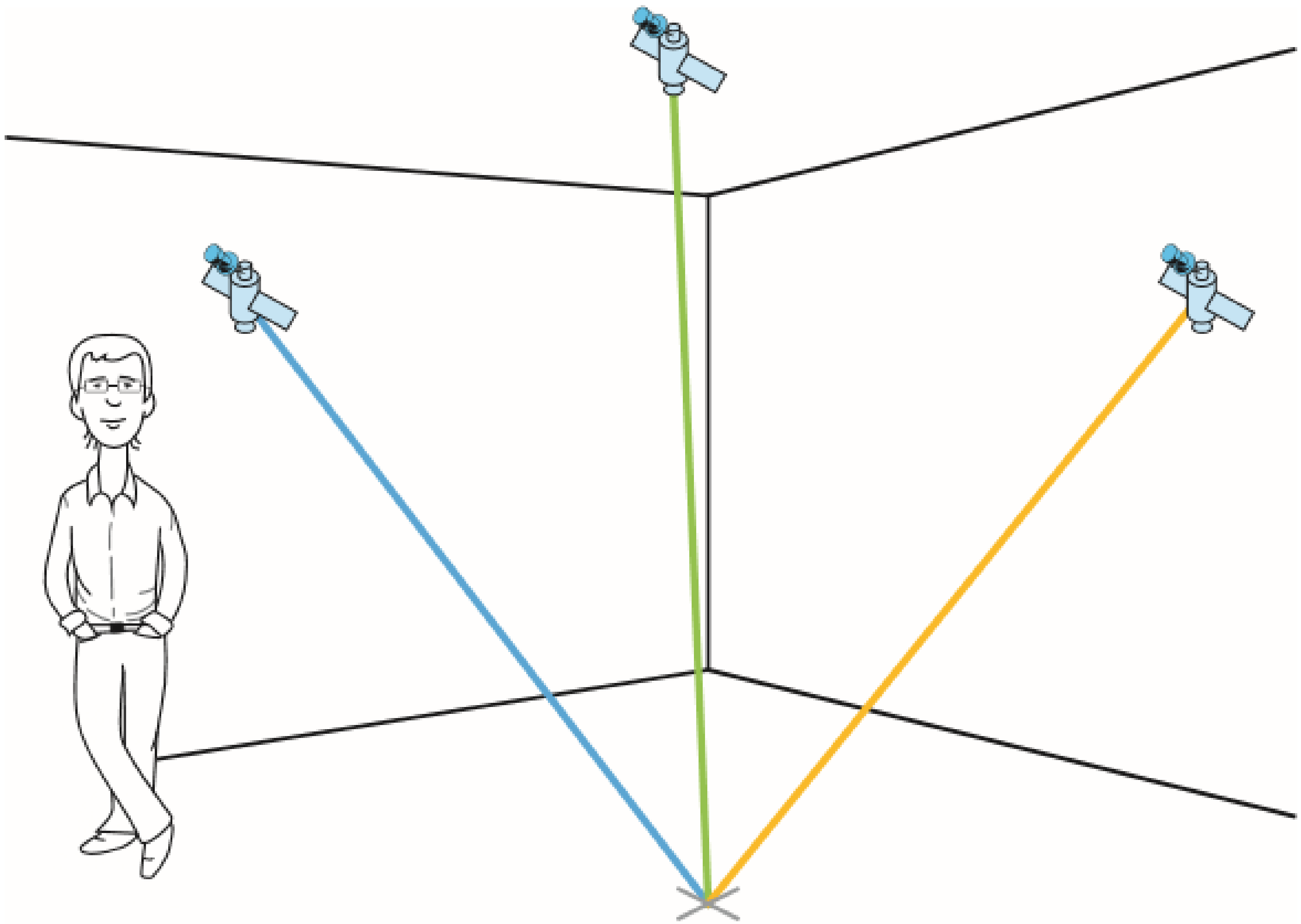
衛星定位基本原理
(Basics of Satellite Positioning)

張嘉強

健行科技大學

應用空間資訊系

距離交會原理



GPS/GNSS多樣化的應用

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GPS基本介紹

- 英文全名 NAVSTAR GPS (NAVigation Satellite with Time And Ranging Global Positioning System)
- 全球性、全天候、24小時運作之衛星導航定位系統
- 美國國防部為軍事目的所發展之系統
- 被動式接收衛星信號以決定使用者之時間、三維坐標及速度
- 依接收儀種類、運動型態、觀測方法及處理技術之不同，其定位精度於1 cm至5 m不等

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GPS發展歷程

- Phase 1: 1973-1979

  觀念驗證

  1978- First Launch of Block 1 SV

  1978年傳送第一筆訊號

- Phase 2: 1979-1985

  發展及測試

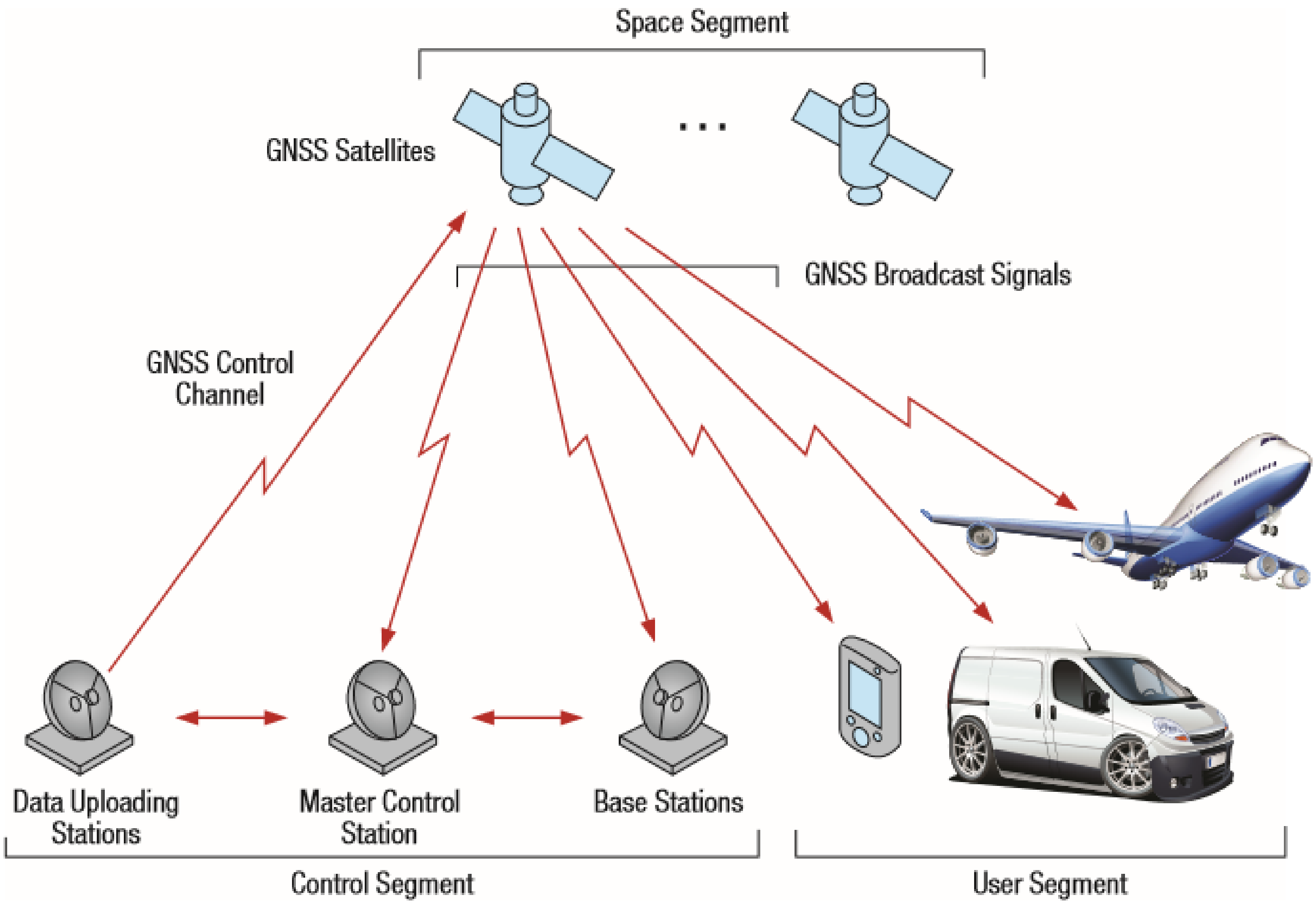
- Phase 3: 1985-Present

  製造及部署

  1993-IOC 1995-FOC

  目前每秒用戶數達40億

GPS系統架構(三個運作單元)



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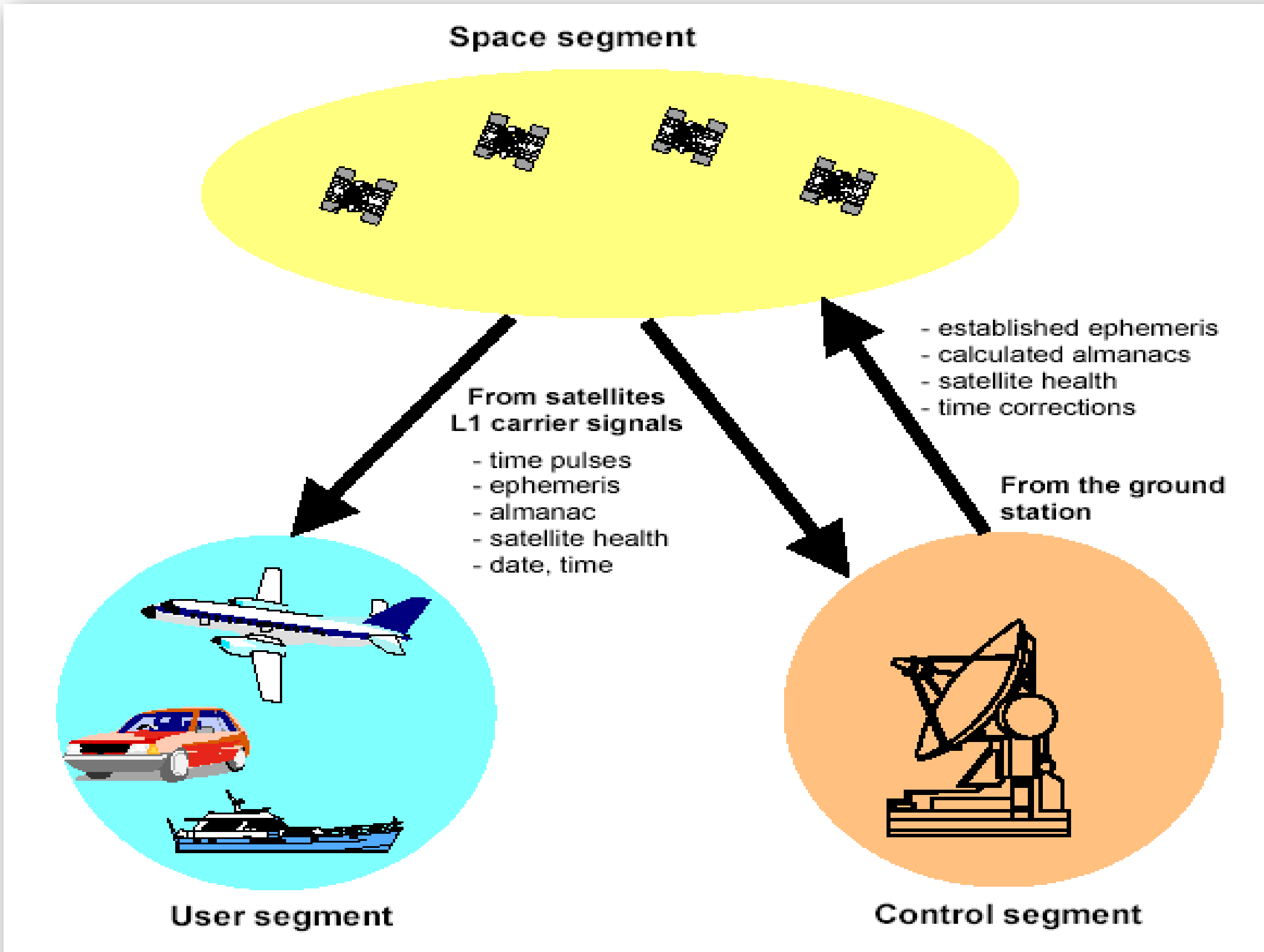
運作單元之關聯性



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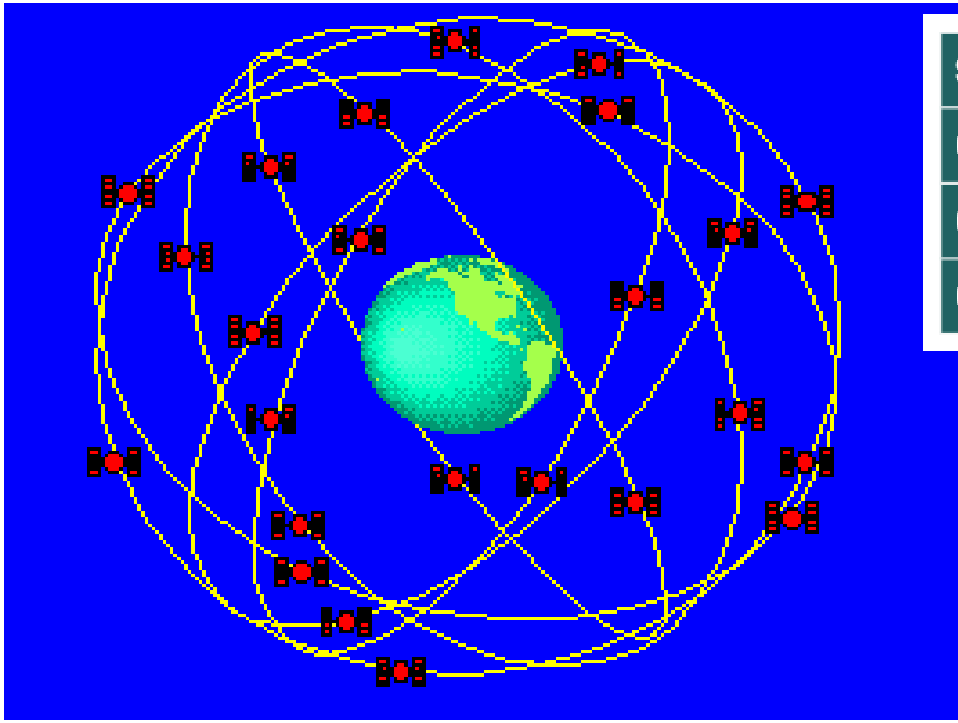
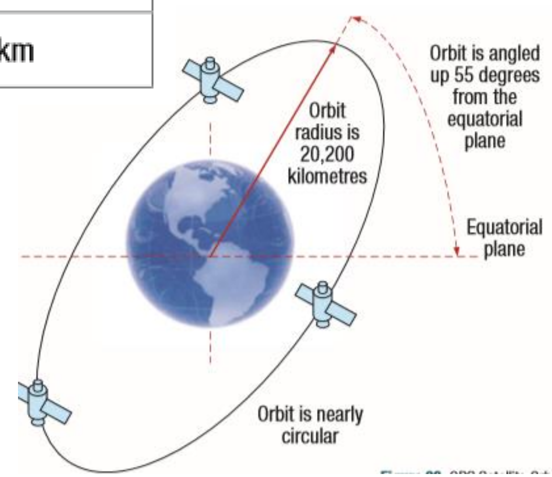
GPS衛星分布



Satellites	27 plus 4 spares
Orbital Planes	6
Orbit Inclination	55 degrees
Orbit Radius	20,200 km

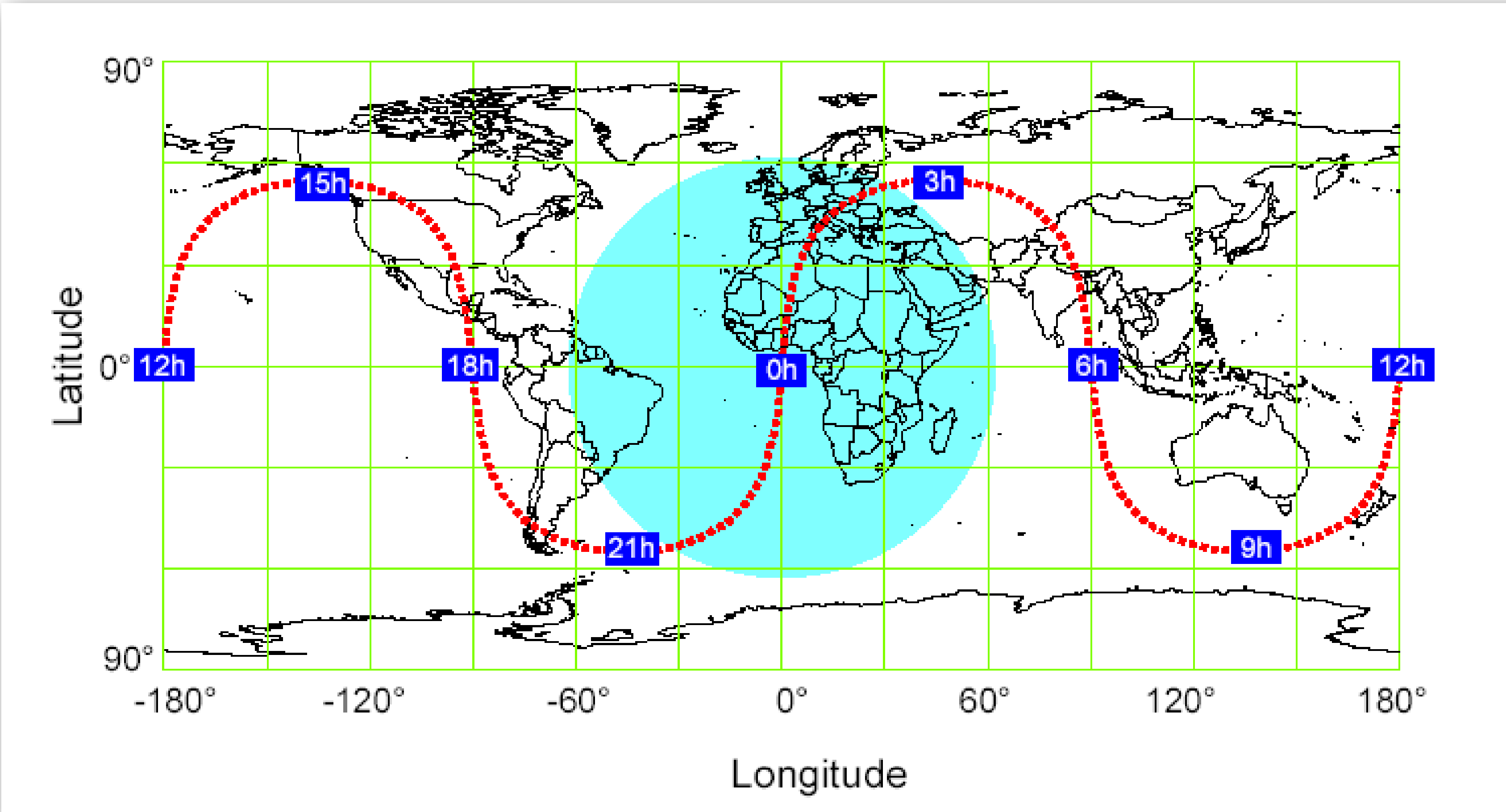


21+3(**24+3**)顆衛星　6個軌道面　55度軌道傾角

20200公里高度　12小時週期　地平面以上5小時

全球3-D分佈　每一時刻至少4顆衛星

GPS衛星軌跡及覆蓋面



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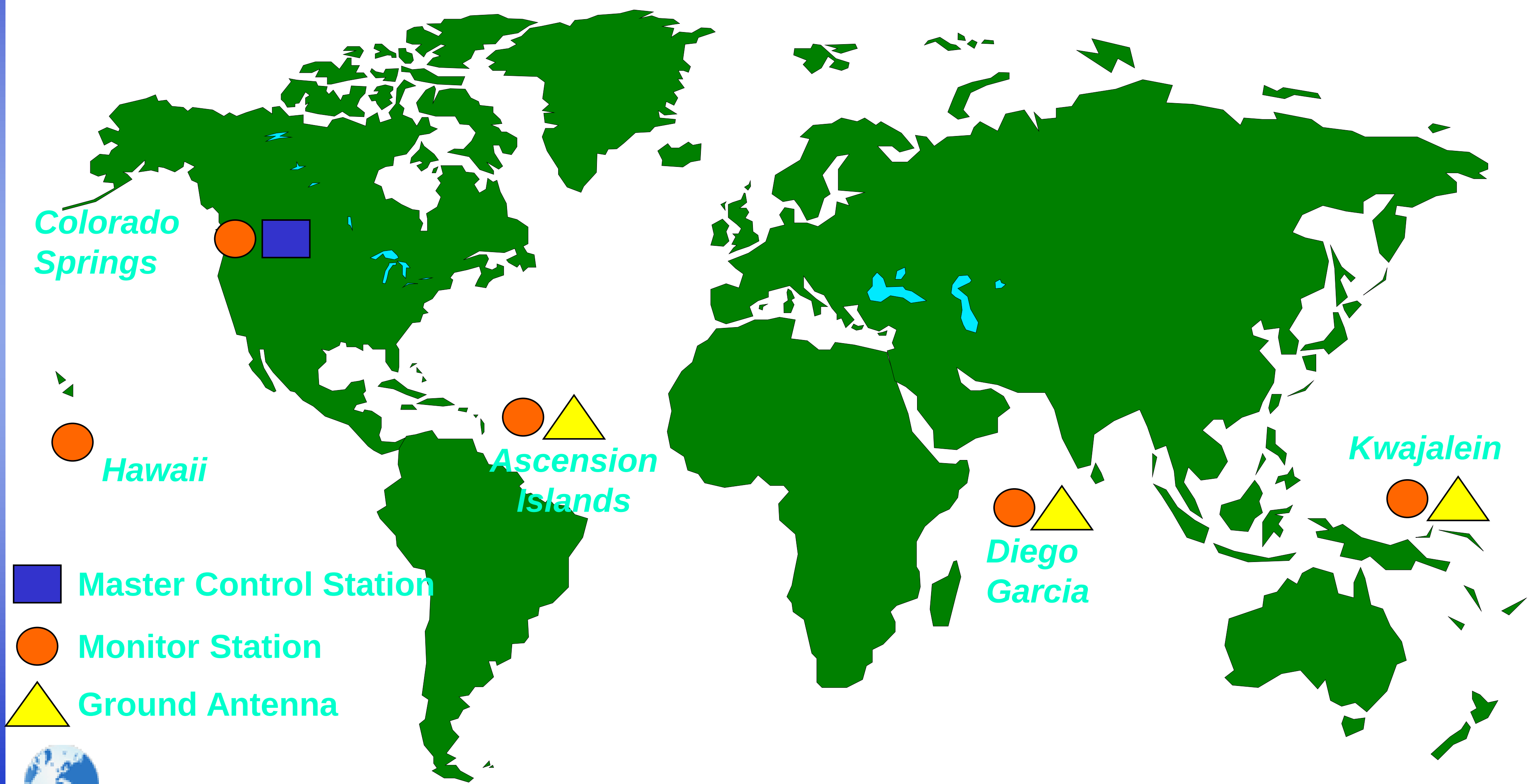
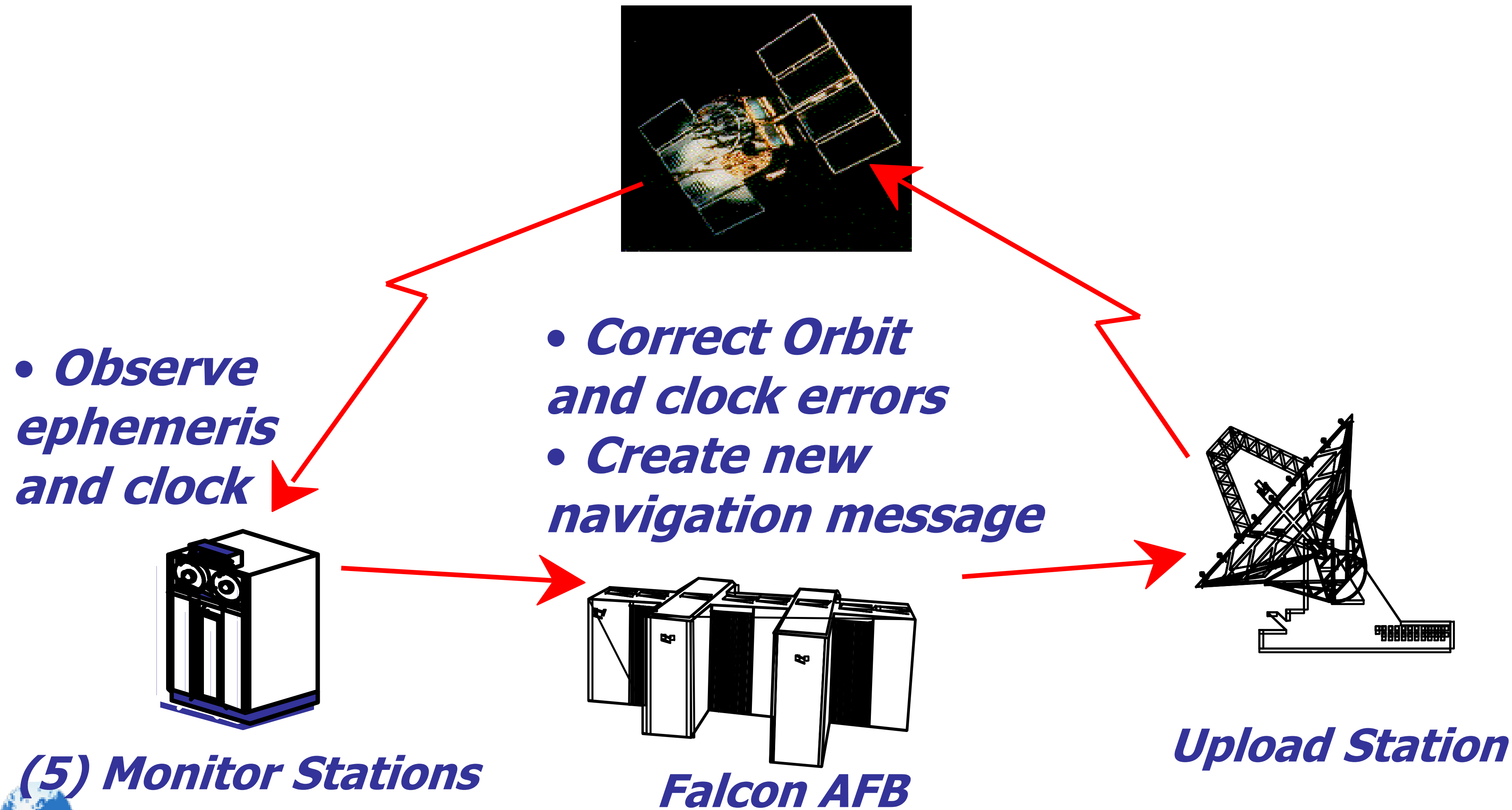
GPS地面監控站(原5站)



監控站運作程序


• Observe
ephemeris
and clock
• Correct Orbit
and clock errors
• Create new
navigation message
(5) Monitor Stations
Falcon AFB
Upload Station

監控站分類及功能

- 監視站(Monitor Station, MS)
  - 位於 Hawaii, Ascension, Diego Garcia, Kwajalien, Colorado Spring
  - 追蹤並接收GPS衛星信號
  - 傳送觀測資料至主控站
- 主控站(Master Control Station, MCS)
  - 位於 Colorado Spring 的 Falcon Air Force Base
  - 收集並處理監視站之觀測量
  - 產生衛星星曆及時間之估計值與預估量
  - 建構及發送導航廣播訊息
- 天線站(Ground Antenna, GA)
  - 除Hawaii及Colorado Spring之外的其它監視站
  - 利用S頻道將更新之衛星導航資料上傳至GPS本身

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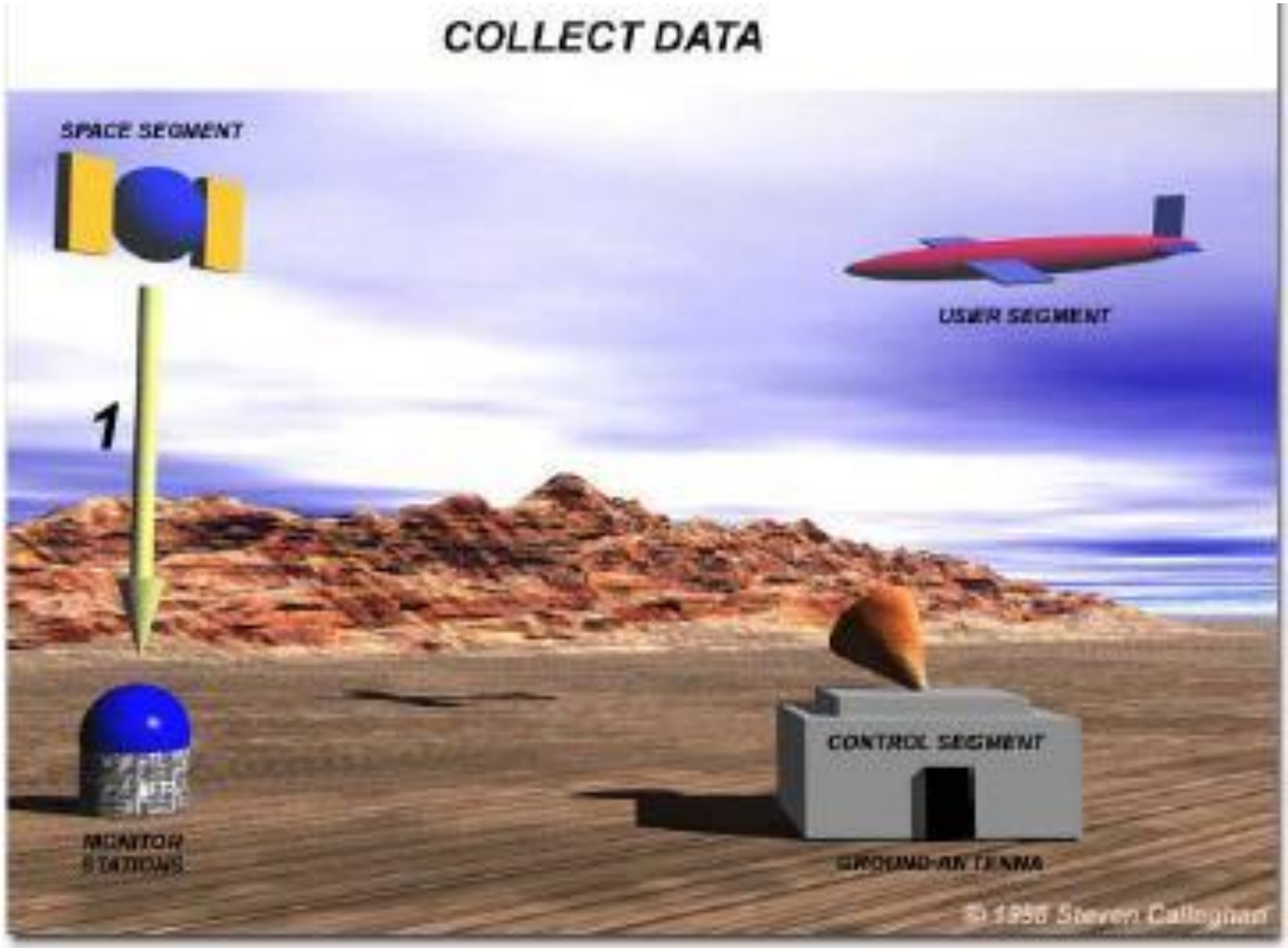
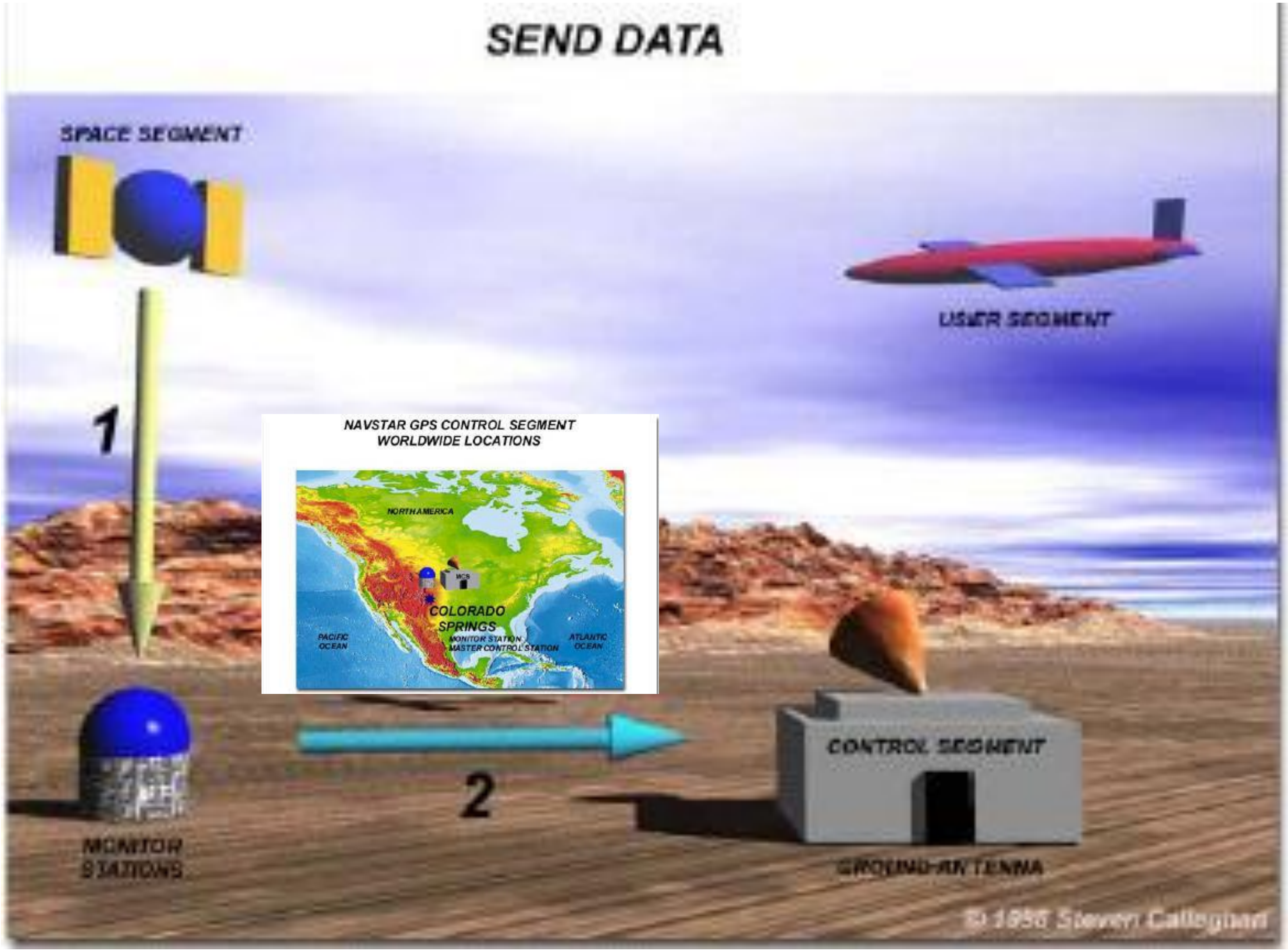
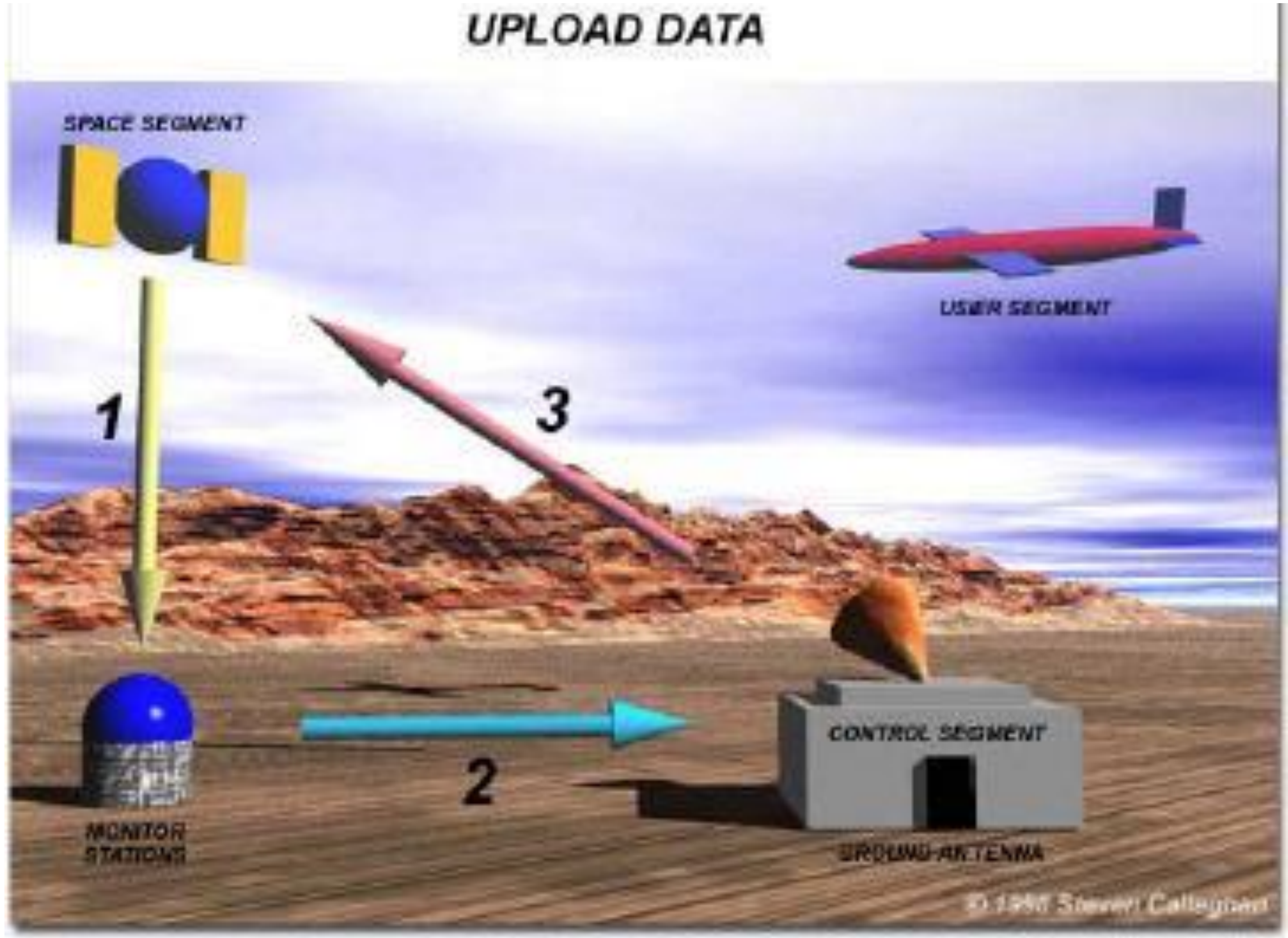
GPS監控站運作程序-1



GPS監控站運作程序-2



GPS監控站運作程序-3



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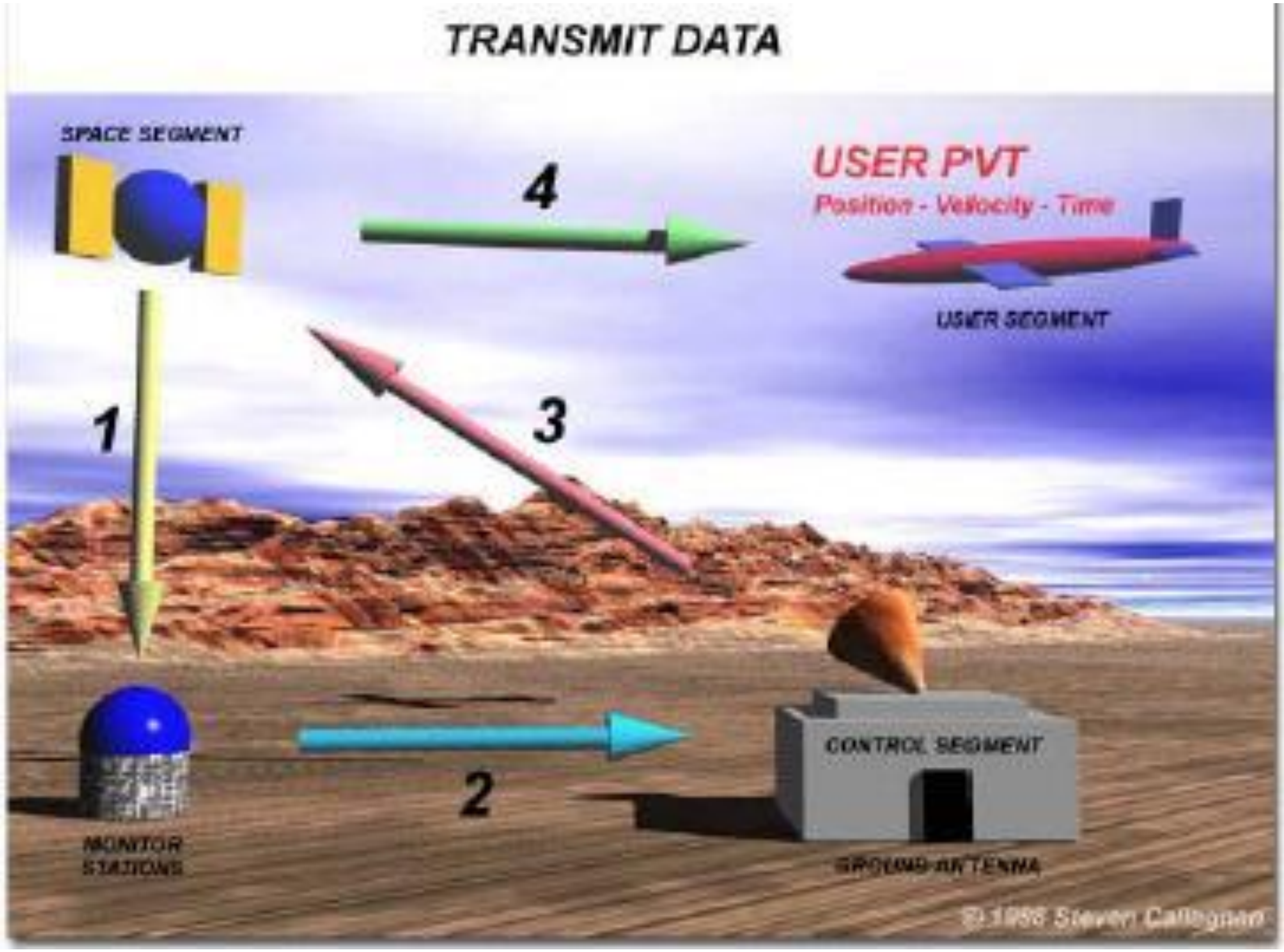
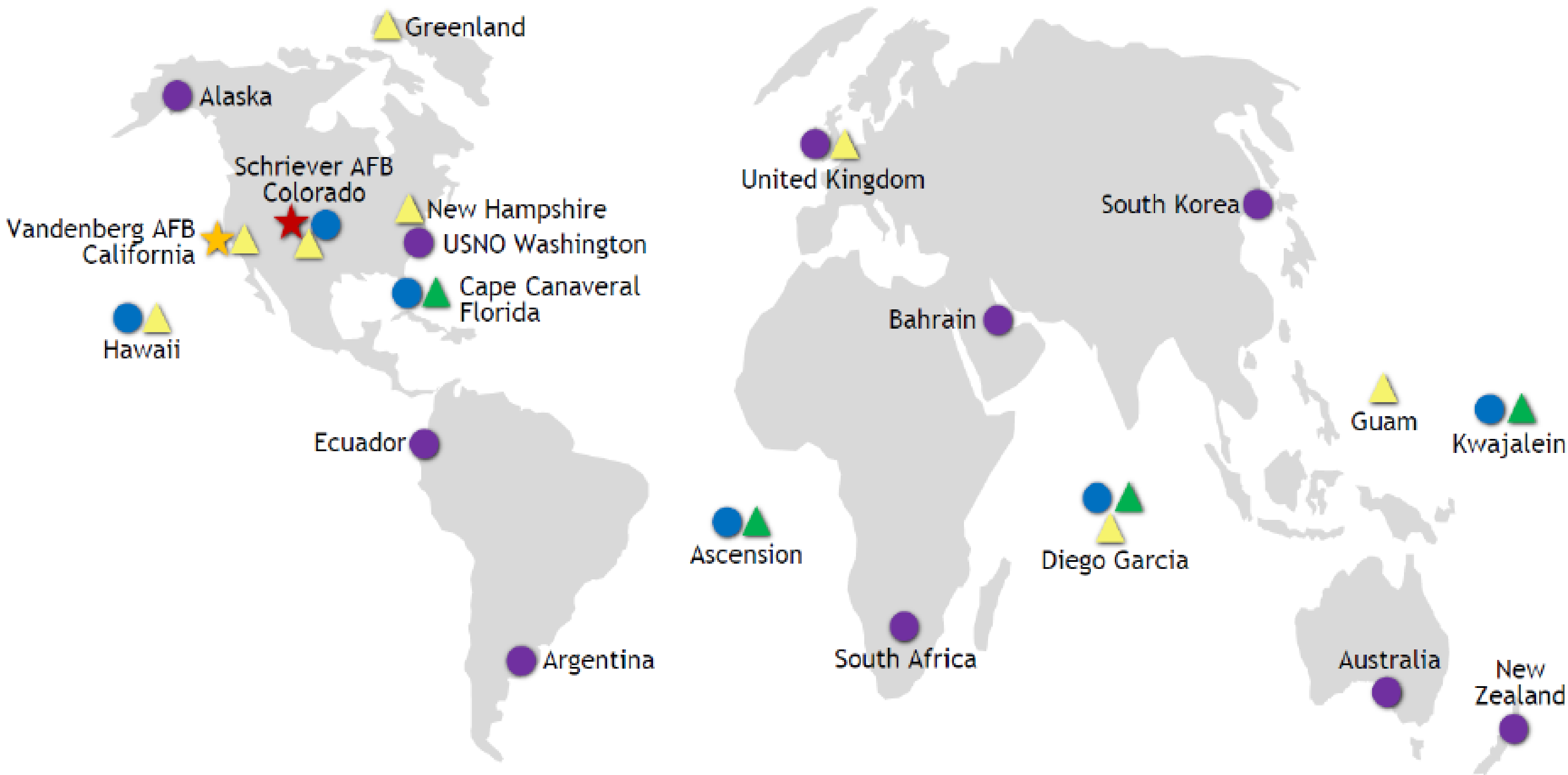
GPS監控站運作程序-4



GPS地面監控站(新19站)



★ Master Control Station
▲ Ground Antenna
● Air Force Monitor Station
★ Alternate Master Control Station
▲ AFSCN Remote Tracking Station
● NGA Monitor Station

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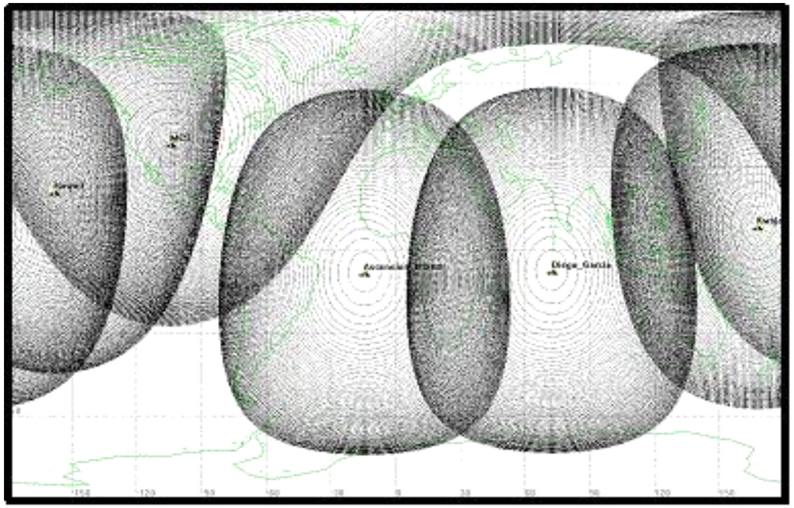
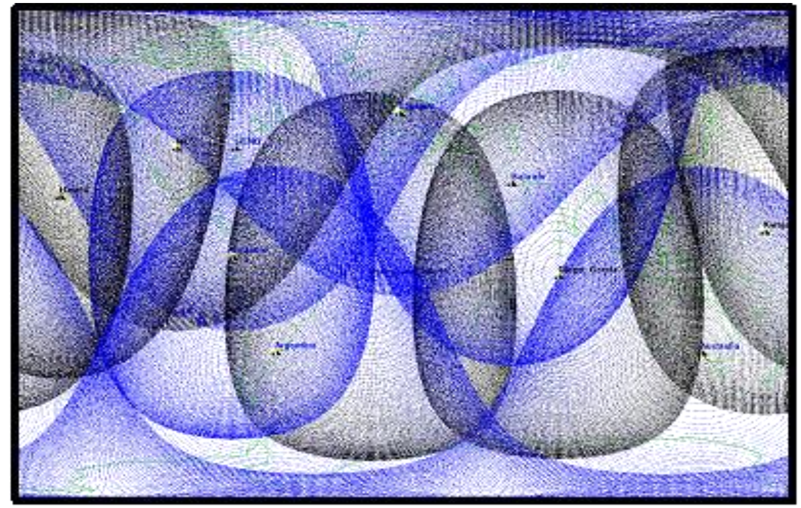
監控站可視範圍



USAF

+

NGA

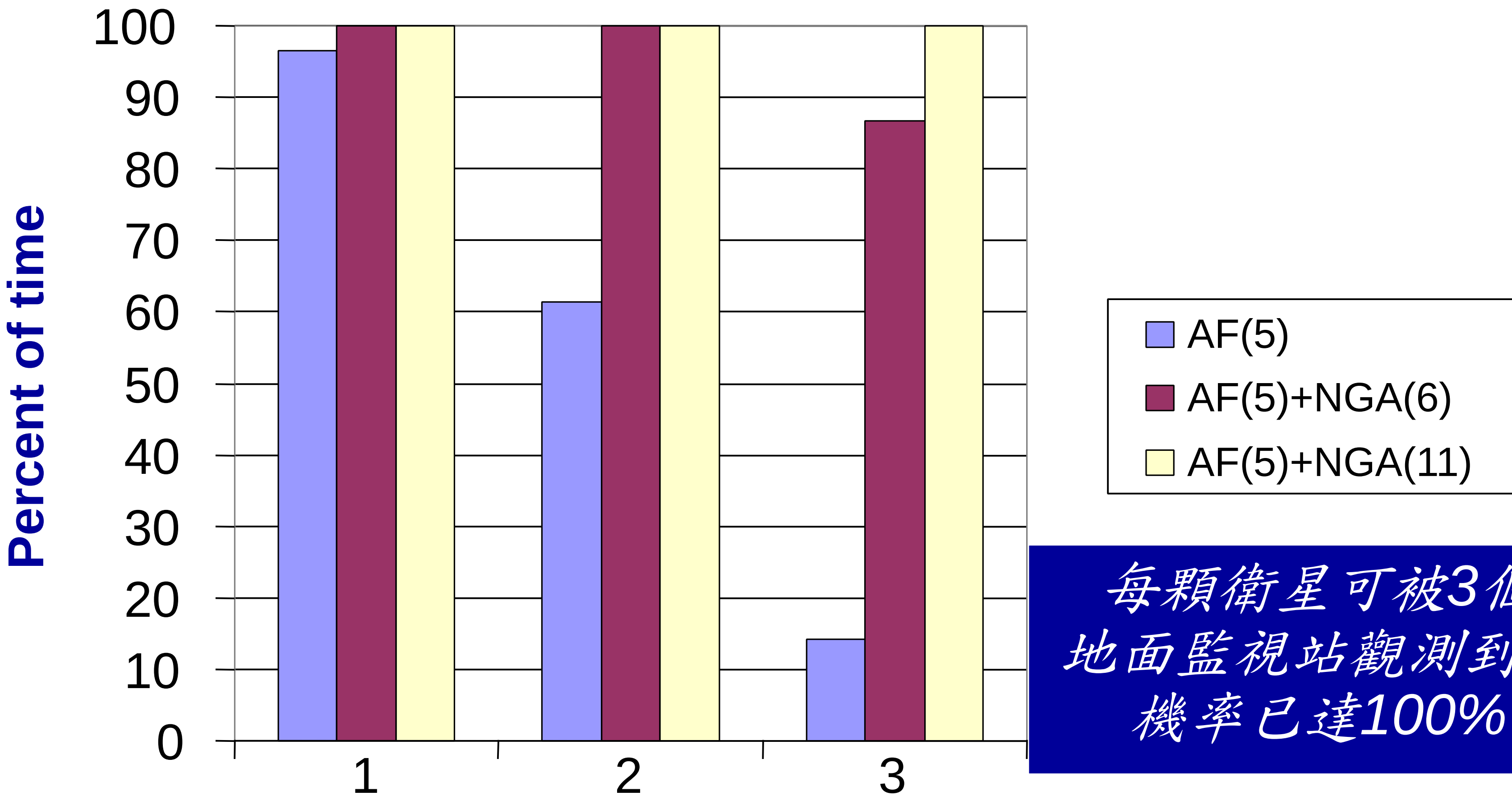


5 USAF stations

5 USAF + 6 NGA stations

Increased accuracy with double visibility for safety of navigation – Mission Success!

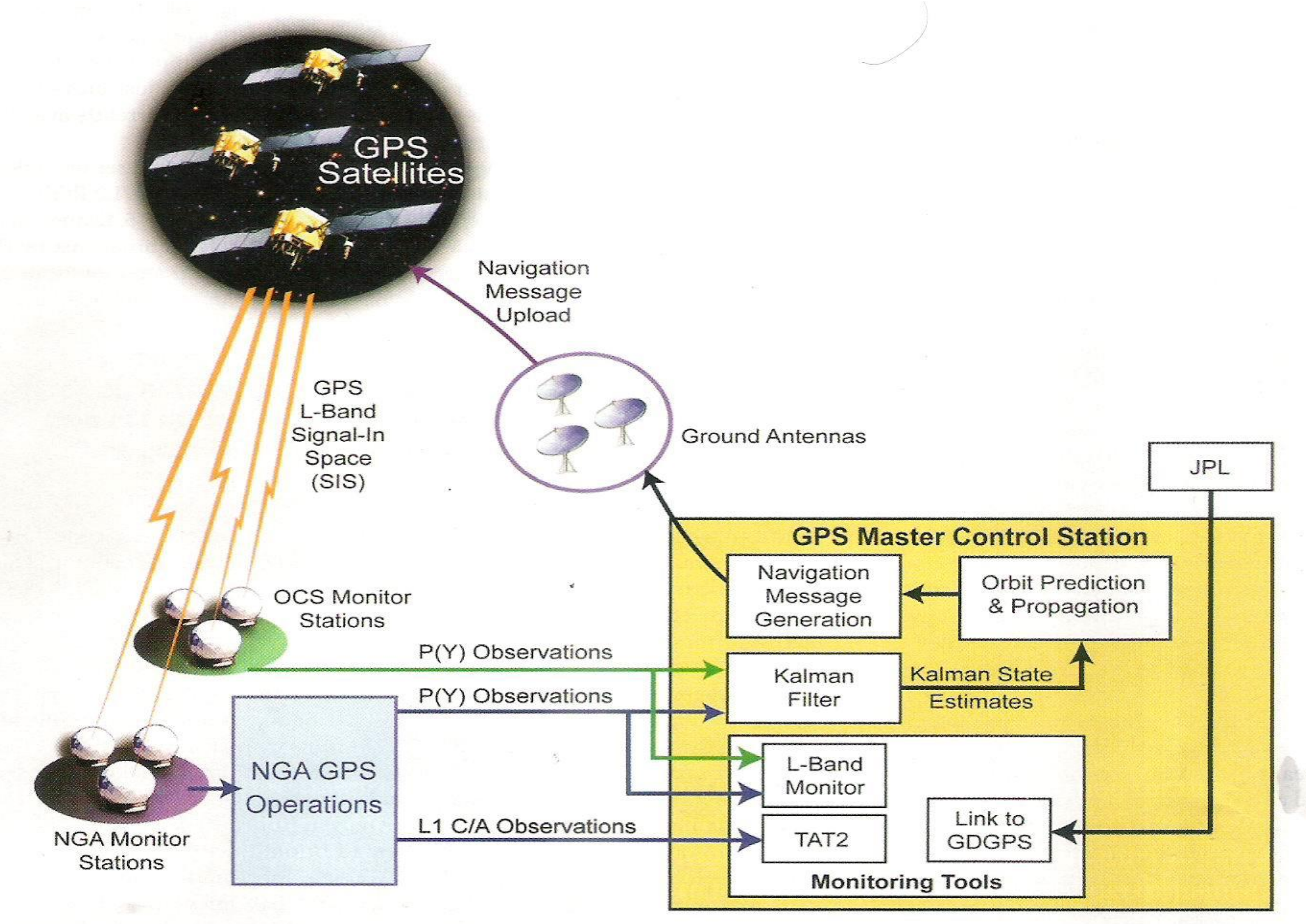
地面站接收數



Minimum number of stations in view
5 degree mask

每顆衛星可被3個地面監視站觀測到之機率已達100%

GPS衛星導航資料處理流程



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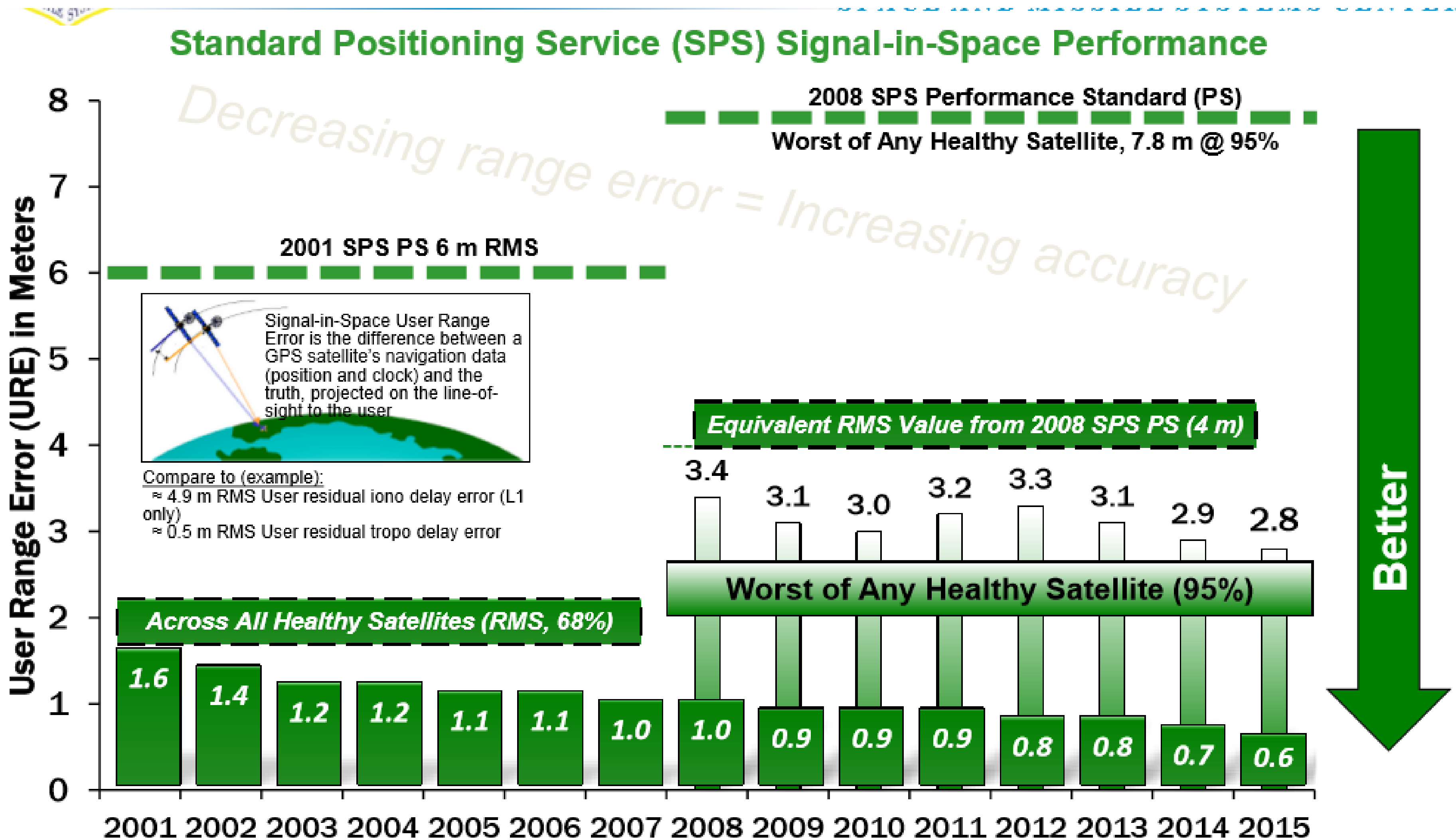
URE精度表現歷程



2016/5/11達0.635 m

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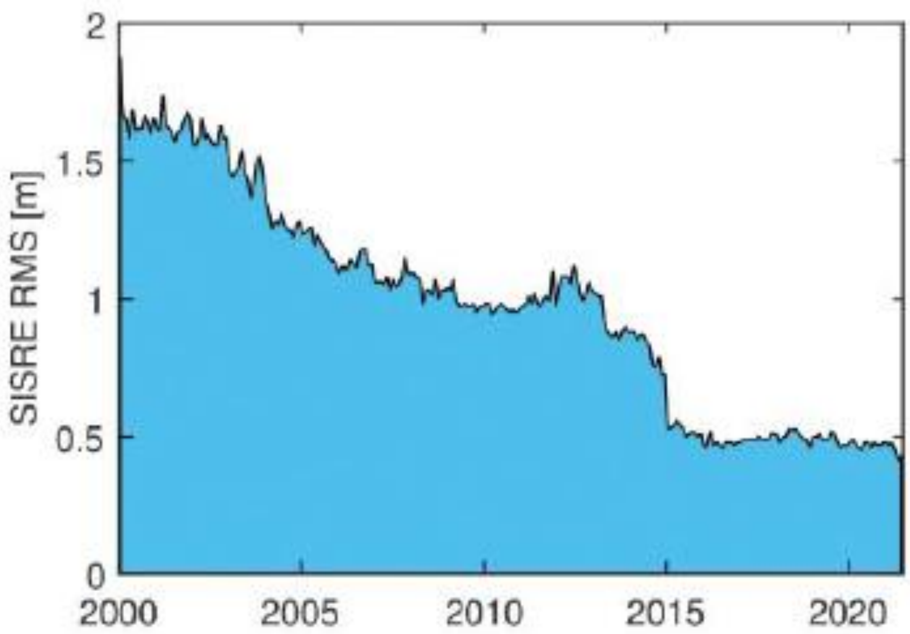
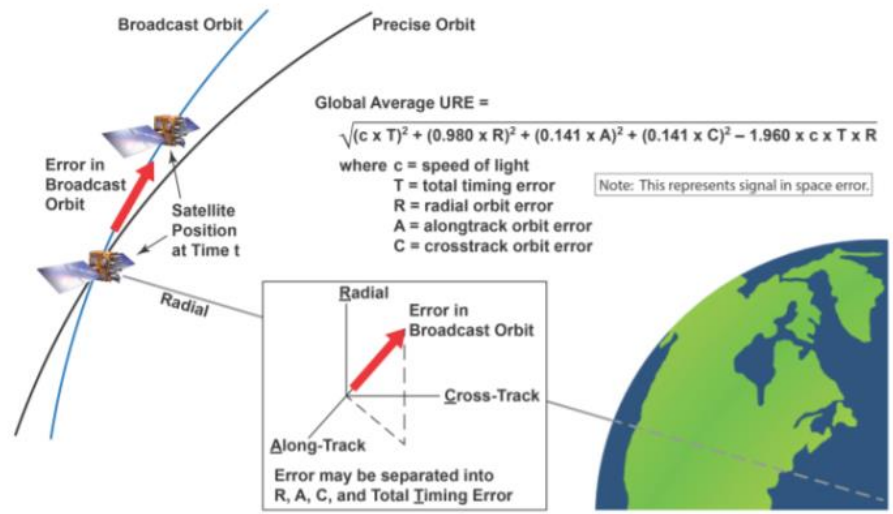
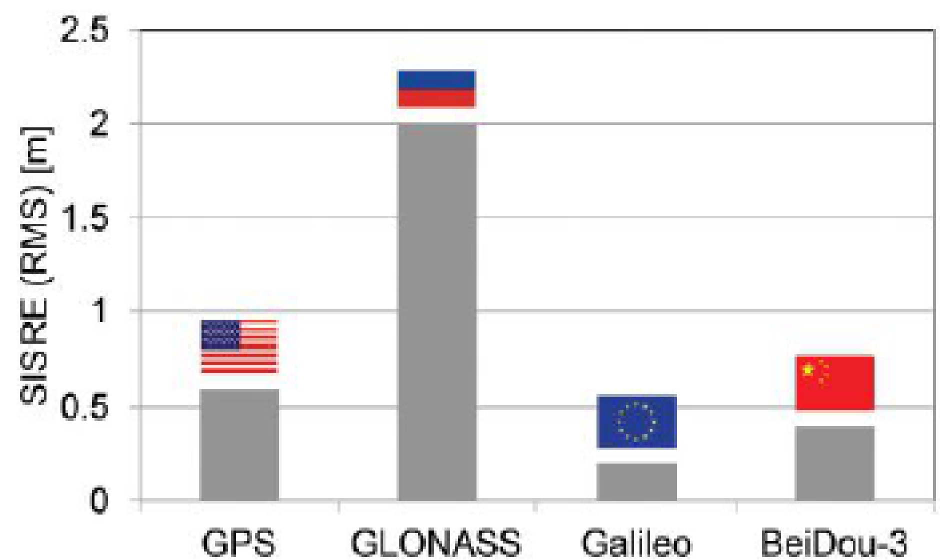
URE精度監測



GPS 2020/8-9達0.525 m





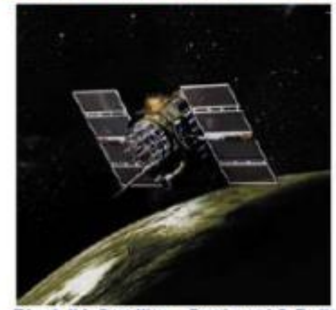
GPS歷代衛星型式

4 Generations of Operational Satellites

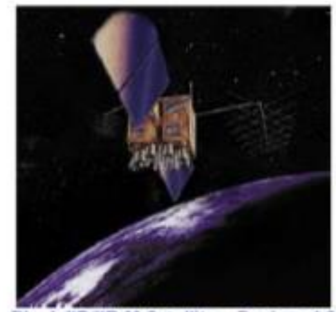
- Block IIA - 6 Residual
  - 7.5 year design life
  - Launched 1990-1997
- Block IIR - 12 Operational
  - 7.5 year design life
    (oldest operational satellite will be 19 years old in Jul)
  - Launched 1997-2004
- Block IIR-M - 7 Operational, 1 Residual
  - 7.5 year design life
  - Launched 2005-2009
  - Added 2nd civil navigation signal (L2C)
- Block IIF - 12 Operational
  - 12 year design life
  - Launched 2010-2016
  - Added 3rd civil navigation signal (L5)

目前已無

2016/2/5已發射完成



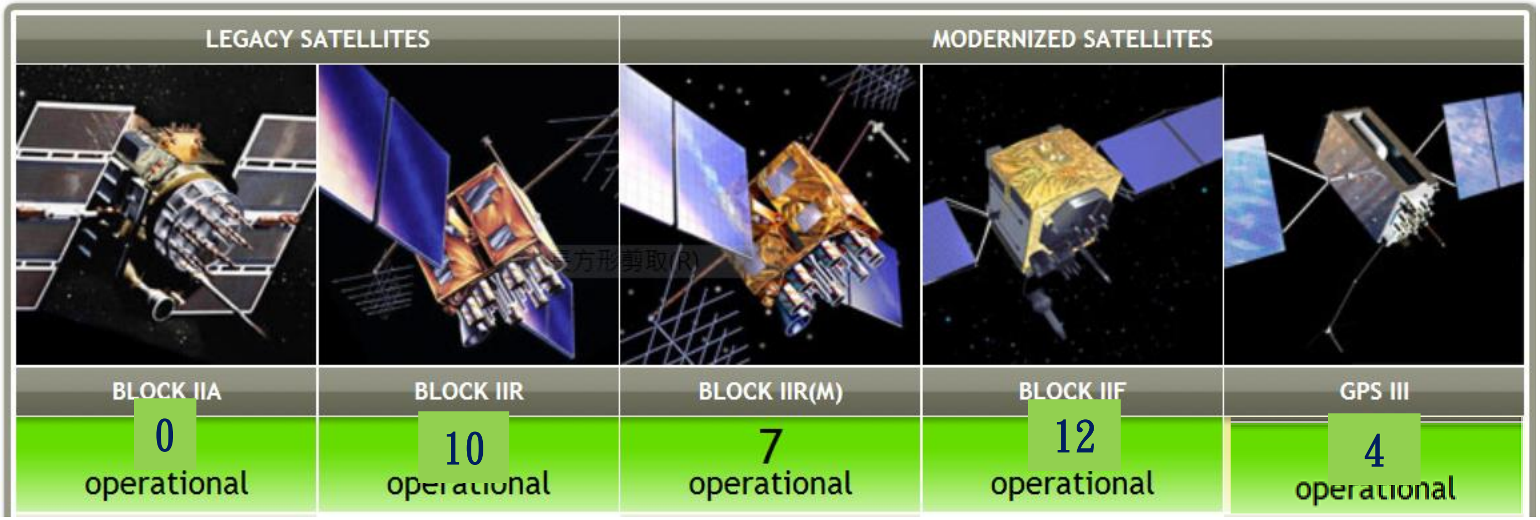
Block IIA Satellite – Designed & Built by Rockwell International



Block IIR/IIR-M Satellite – Designed & Built by Lockheed Martin

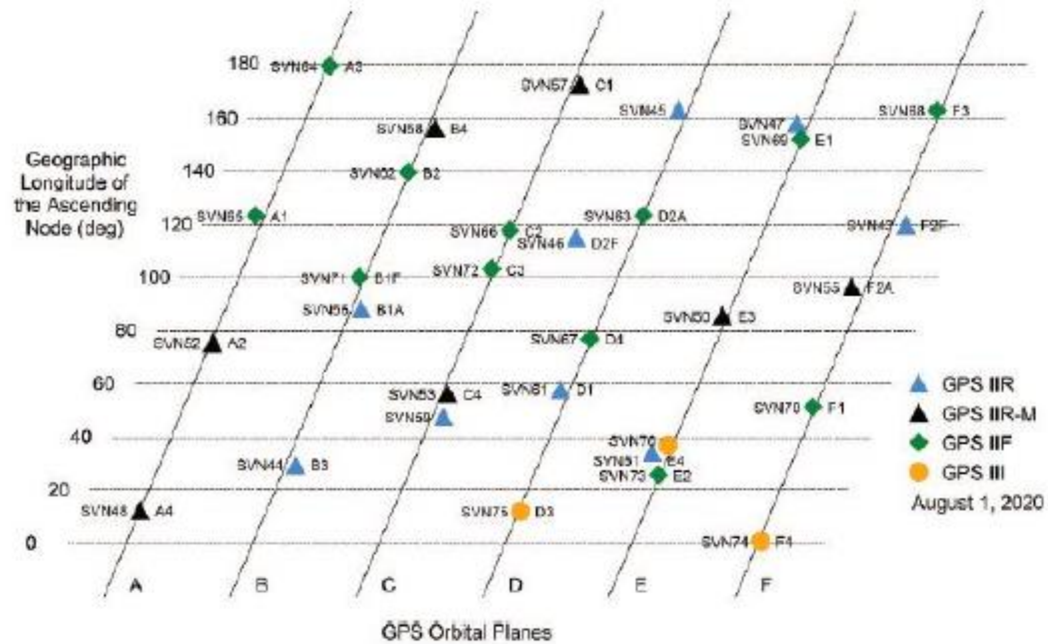
Block IIF Satellite – Designed & Built by Boeing

GPS在軌衛星

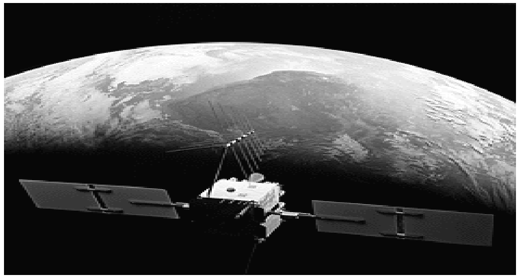


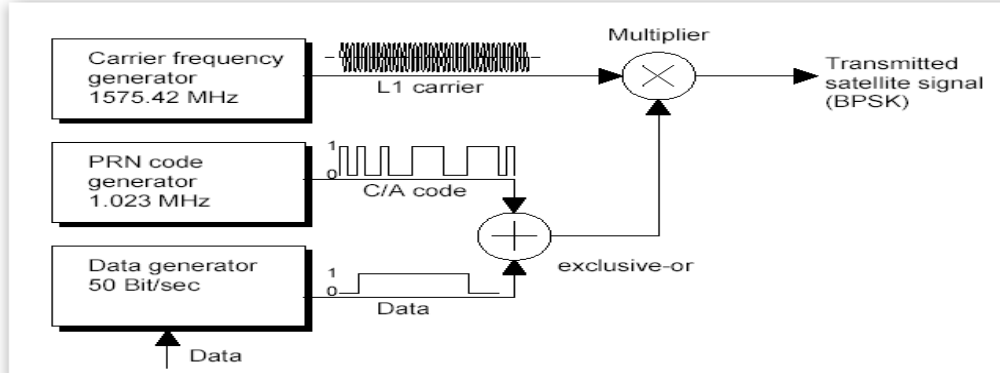
31（健康）/35（在軌）顆

- FOC (Full Operational Capability)
- 24+3 (or "Expandable 24") configuration



GPS信號結構(原設計)



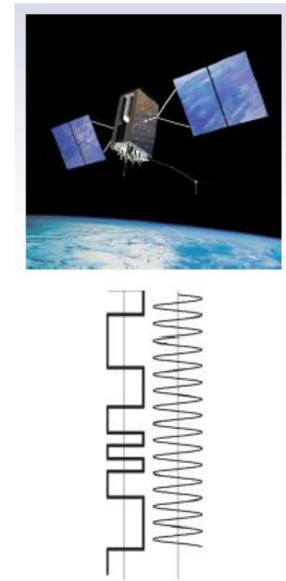


基本頻率
10.23 MHz

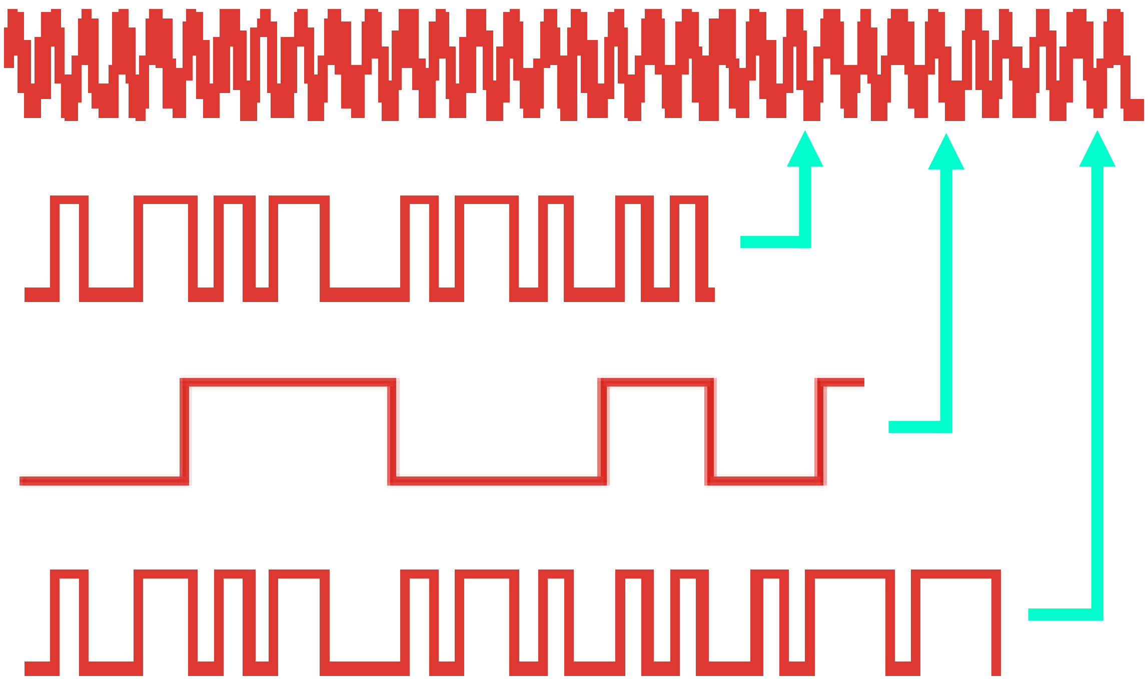
x0.1 → C/A 電碼
x1 → P 電碼
x154 → L1
x120 → L2

L1 1575.42 MHz	C/A 電碼 1.023 MHz	P 電碼 10.23 MHz	導航訊息 50 BPS
L2 1227.60 MHz		P 電碼 10.23 MHz	導航訊息 50 BPS

GPS信號調製



L1 Carrier Wave 1575.42MHz



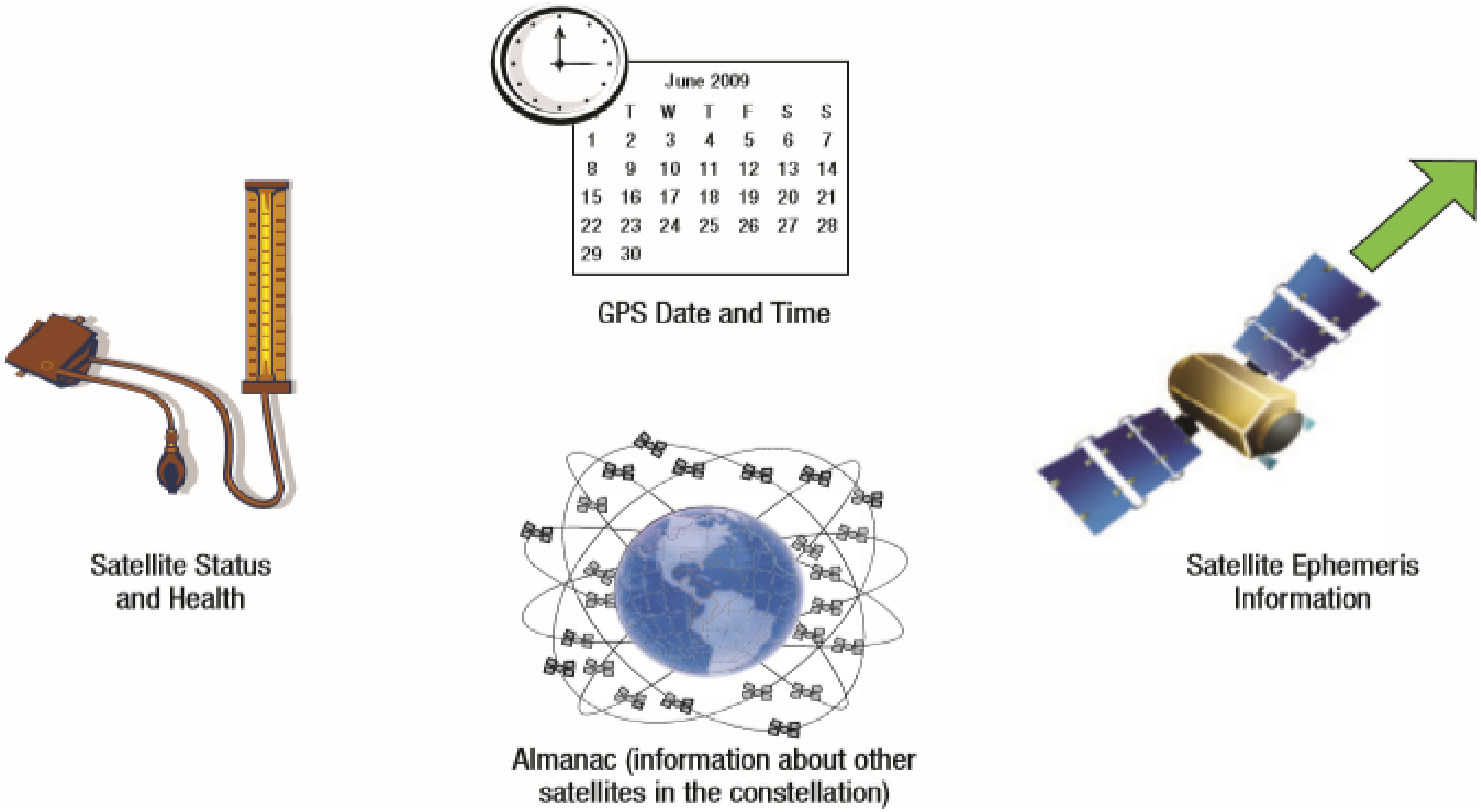
C/A Code
1.023 MHz

Navigation Message
50 Hz

Precise Code
10.23 MHz

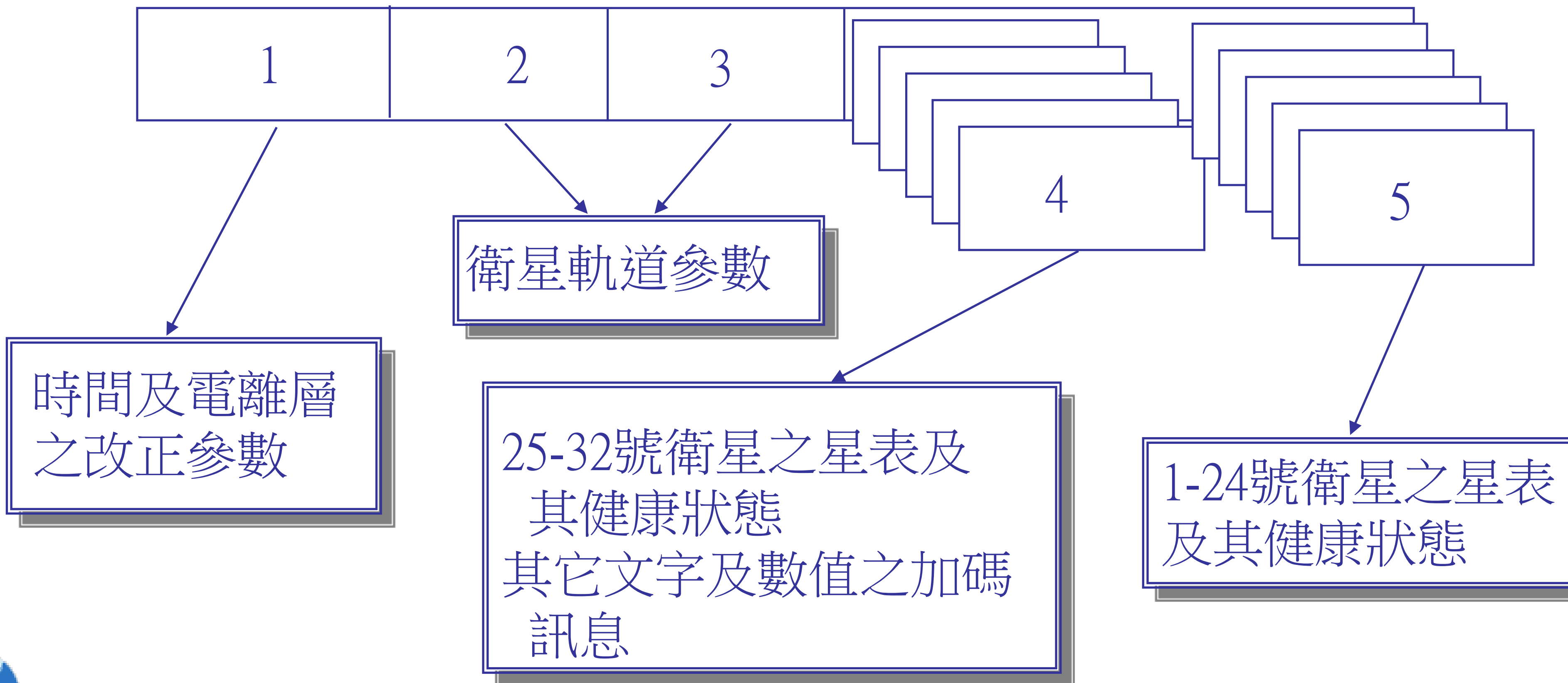
GPS導航訊息內容

- Satellite time-of-transmission
- Satellite position
- Satellite (SIS) health
- Satellite clock correction
- Single-frequency (SF) ionospheric delay model corrections
- Time transfer to Coordinated Universal Time (UTC) as kept by the U.S. Naval Observatory (USNO)
- Constellation status



GPS導航訊息配置

1 subframe = 10 words = 300 bits (= 6 sec)



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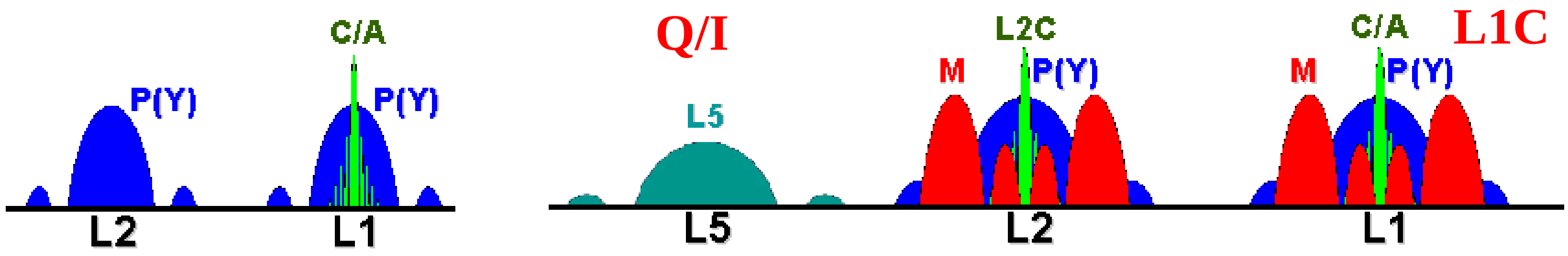
GPS更新計畫(modernization)

GPS三頻信號



現有信號　　1176.45 MHz　　更新信號

L2C / L5 + navigation message (CNAV)

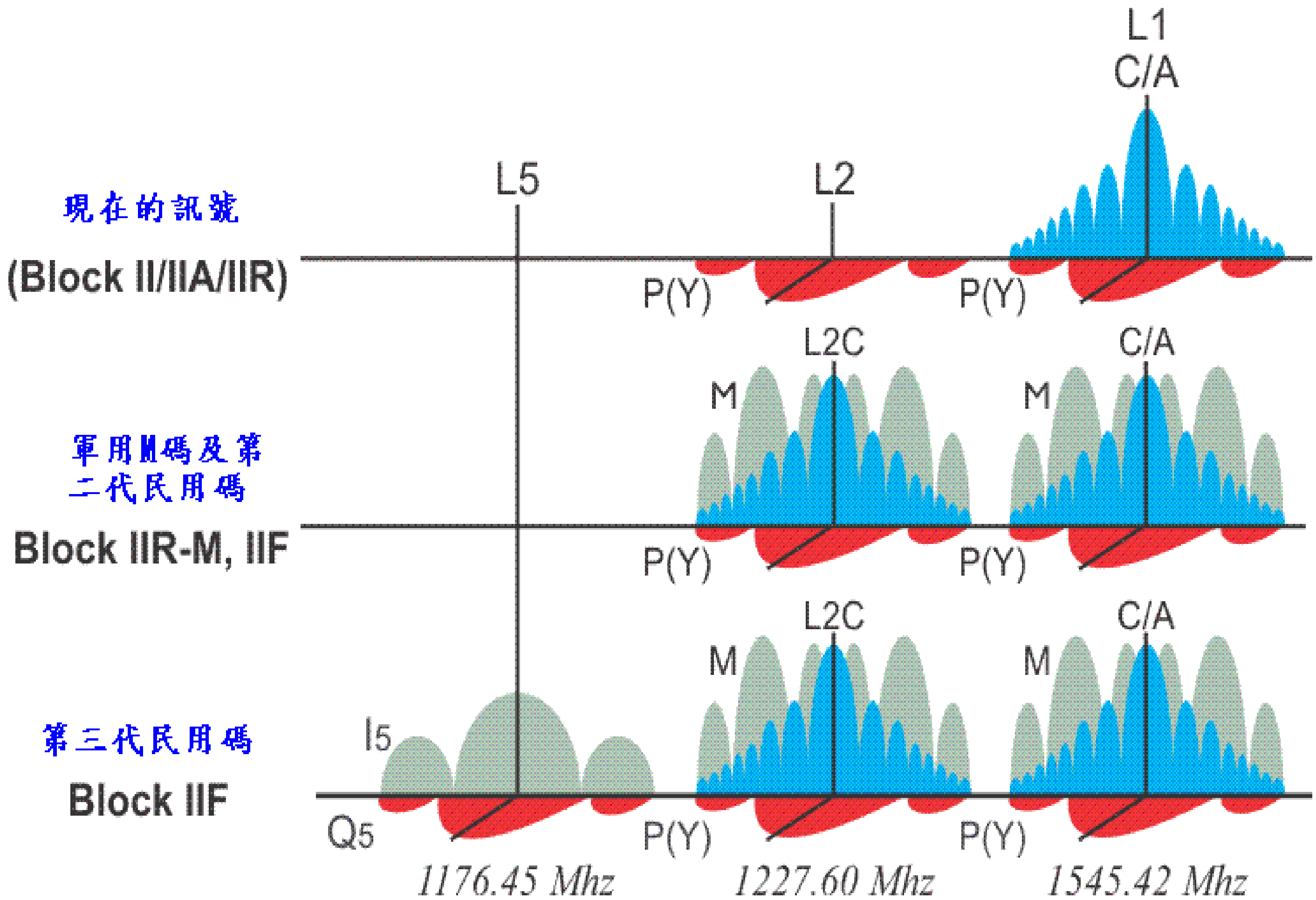
L1C + navigation message (CNAV-2)

CNAV-2 由 3 個 subframes 組成:

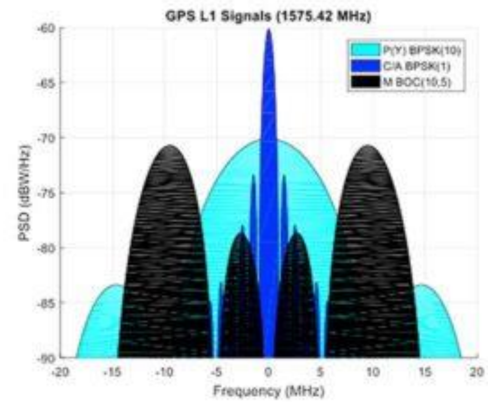
1. 當下時刻的資訊
2. 時表(含信號間改正量)及星曆資料(每2小時更新)
3. 變動性內容如右表

Page	Content
1	GPS/UTC parameters, leap seconds
2	GPS/Galileo and GPS/GLONASS time offset, Earth orientation parameters
3	Reduced almanac
4	Midi almanac
5	Differential corrections
6	ASCII text (29 characters)
7	Reserved

GPS三頻電碼



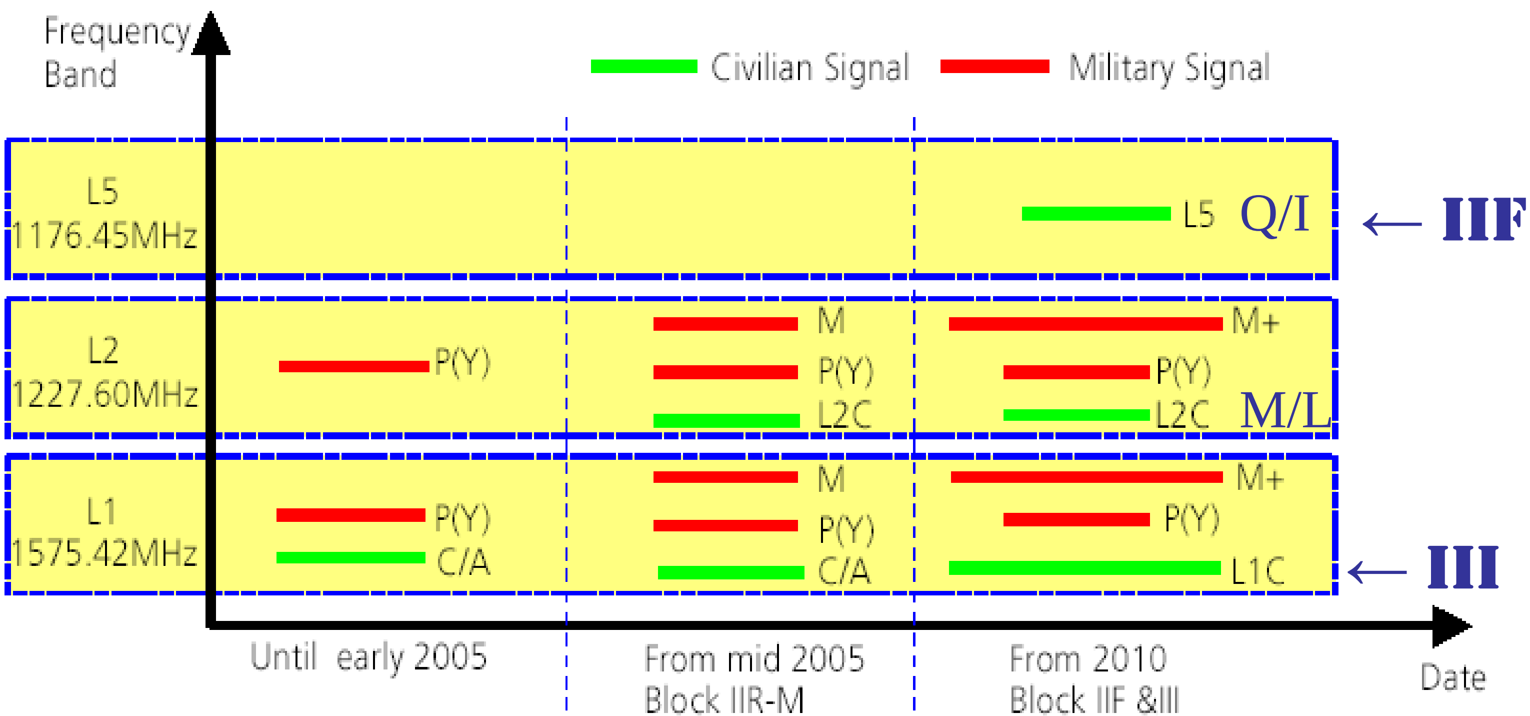
M碼抗干擾



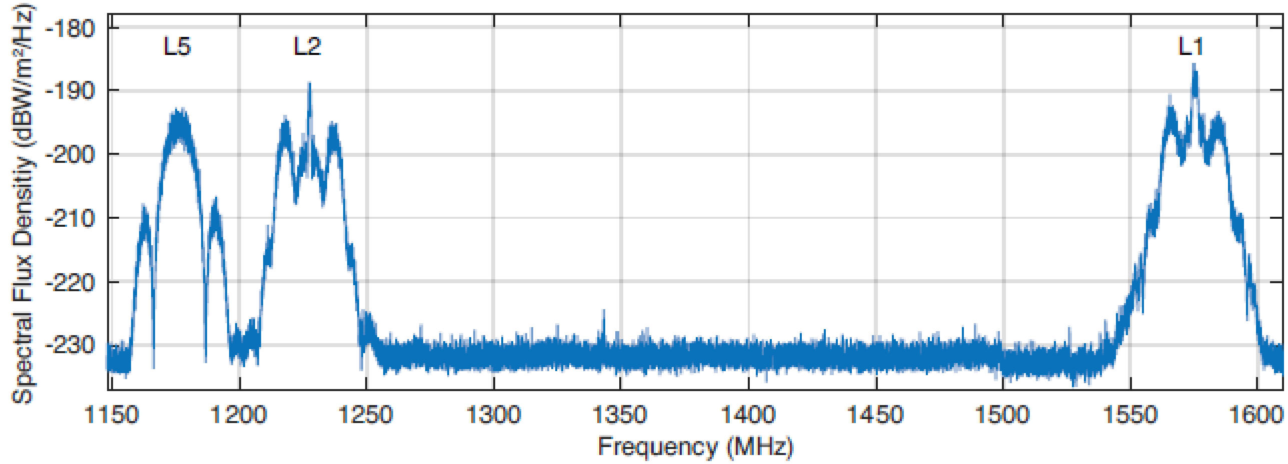
Block III
+ L1C

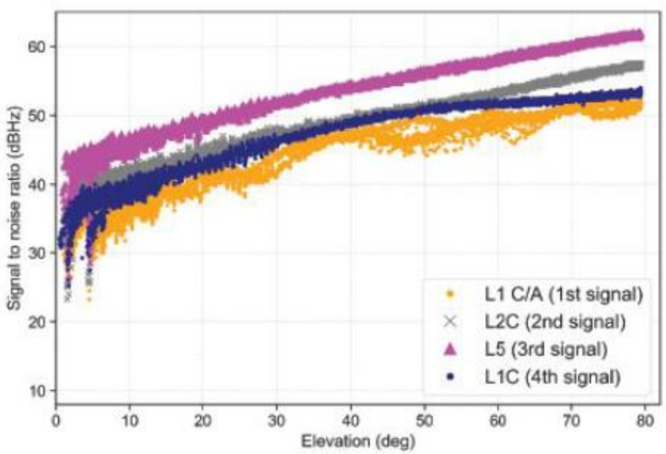
GPS更新歷程

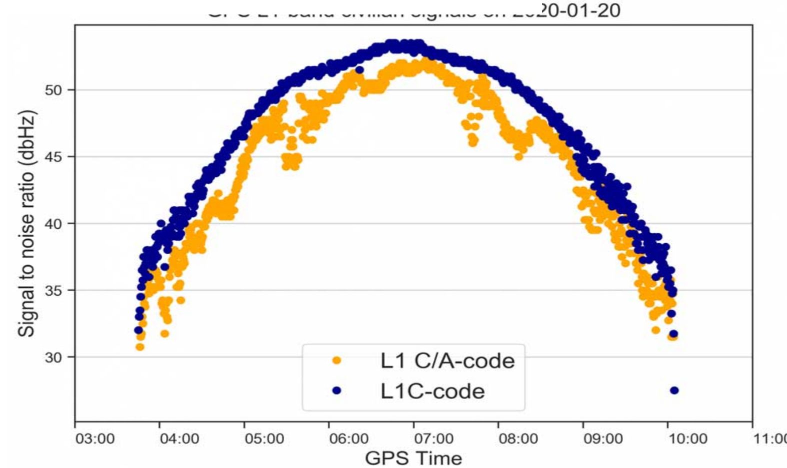
- New civilian signal at 1176.45MHz (L5 Frequency). This signal should be more robust than previous civilian signals and can be used in aviation during critical approaches.
- Increase in the signal strength of the M Signals (= M+) through the use of concentrating beam antennas.
- Improvement of the C/A Signal Structure for the civilian L1 Frequency. (To be designated L1C).



GPS III提供第四個民用碼 L1C







- ✓ 繼L1 C/A / L2C / L5之後的第4個GPS民用碼
- ✓ 信號更強/更穩健/更加抗干擾
- ✓ 使GPS/Galileo/BeiDou更加相容

CNAV (new) vs LNAV (legacy) 導航訊息

CNAV MESSAGES		LNAV SUBFRAMES	
Message Type	**Contents**	**Subframe (Page)**	**Contents**
Every	Satellite Time-of-Transmission	All	Satellite Time-of-Transmission
10	Satellite Position (half of ephemeris)	2	Satellite Position (half of ephemeris)
11	Satellite Position (rest of ephemeris)	3	Satellite Position (rest of ephemeris)
10	Satellite (SIS) Health	1	Satellite (SIS) Health
10, 3x	Satellite User Range Accuracy (URA)	1	Satellite User Range Accuracy (URA)
3x	Satellite Clock Correction	1	Satellite Clock Correction
30	Satellite Delays & Ionospheric Delay	4(18)	Constellation Ionospheric Delay
33	Constellation UTC(USNO) Offset	4(18)	Constellation UTC(USNO) Offset
		4 & 5	Constellation Status (full almanacs)
37	Constellation Status (midi almanacs)	–	–
31 or 12	Constellation Status (mini almanacs)	–	–
32	Constellation Earth Orientation	–	–
34 or 13/14	Constellation Differential Corrections	4(13)	Constellation Differential Corrections
35	Constellation GPS-GNSS Time Offset	–	–
36 or 15	Constellation Text Messages	4(17)	Constellation Text Messages
0	Default CNAV Data (alternating 1s/0s)	Any	Default LNAV Data (alternating 1s/0s)

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GPS更新(現代化)總體面觀

Space Segment
SV families provide L-Band broadcast to User Segment

GPS IIA/IIR
- Basic GPS
- Nuclear Detonation Detection System (NDS)

GPS IIR-M
- 2nd Civil Signal (L2C)
- New Military Signal
- Increased Anti-Jam Power

GPS IIF
- 3rd Civil Signal (L5)
- Longer Life
- Better Clocks

GPS III (SV01-10)
- Accuracy & Power
- Increased Anti-Jam Power
- Inherent Signal Integrity
- 4th Civil Signal (L1C)
- Longer Life
- Better Clocks

GPS IIIF (SV11-32)
- Unified S-Band Telemetry, Tracking & Commanding
- Search & Rescue (SAR) Payload
- Laser Retroreflector Array
- Redesigned NDS Payload

Control Segment
TT&C of Space Segment assets & distribution of data to user interfaces

Legacy (OCS)
- Mainframe System
- Command & Control
- Signal Monitoring

Architecture Evolution Plan (AEP)
- Distributed Architecture
- Increased Signal Monitoring Coverage
- Security
- Accuracy

OCX Block 0
- GPS III Launch & Checkout System

GPS III Contingency Ops (COps)
- GPS III Mission on AEP

M-Code Early Use (MCEU)
- Update OCS to operationalize Core M-Code

OCX Block 1/2
- Fly Constellation & GPS III
- Begin New Signal Control
- Upgraded Information Assurance

OCX Block 2+
- Control all signals
- Capability On-Ramps
- GPS IIIF Evolution

User Segment
Applies Space and Control Segment data for PNT applications

Continued support to an ever-growing number of applications
- Annual Public Interface Control Working Group (ICWG)
- Standard Positioning Service (SPS) Performance Standard Updates
- Precise Positioning Service (PPS) Enhancements
- Sustained commitment to transparency
- Visit GPS.gov for more info

Modernized Civil Signals
- L2C (Various commercial applications)
- L5 (Safety-of-life, frequency band protected)
- L1C (Multi-GNSS interoperability)

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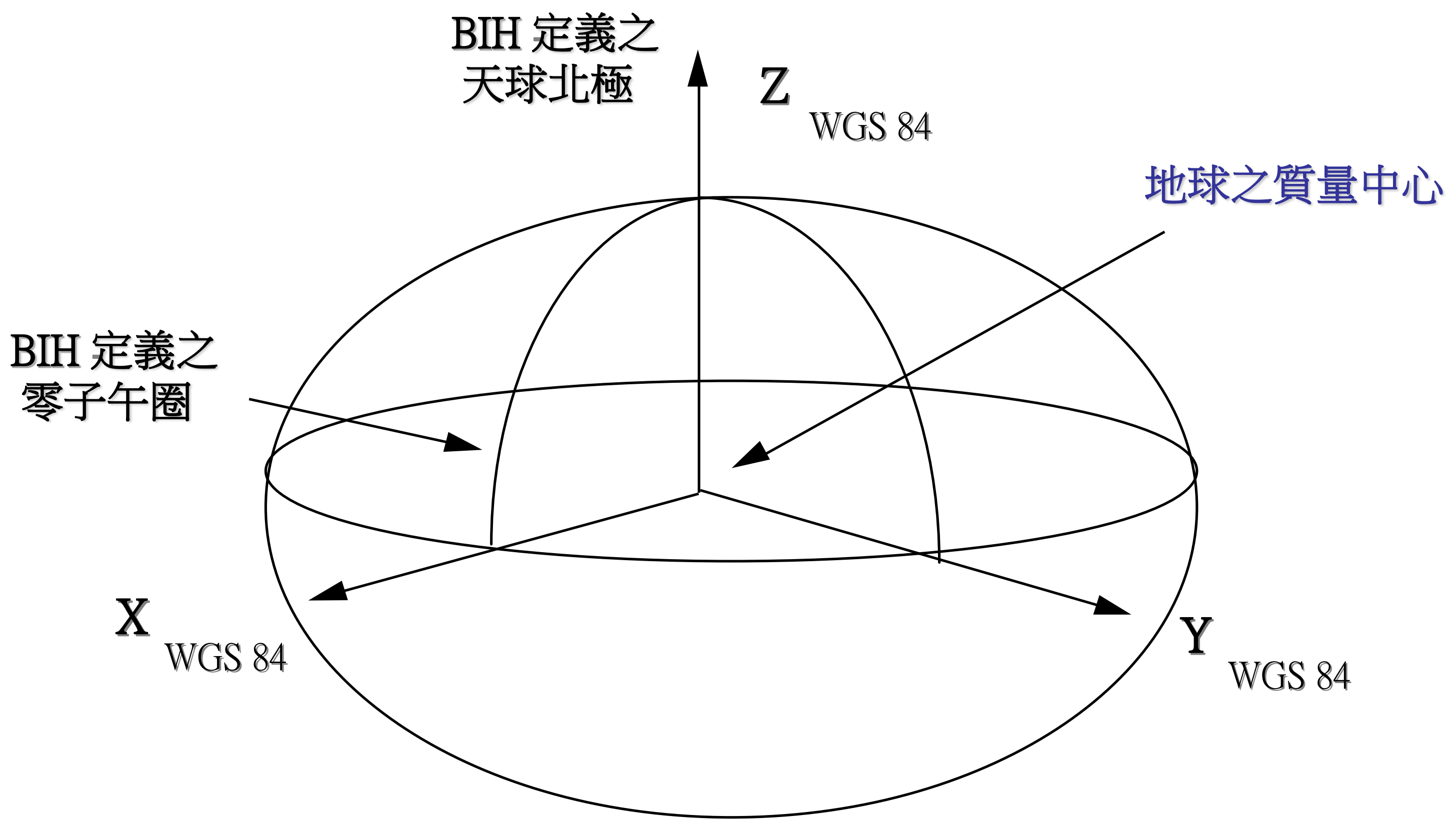
GPS的坐標基準(WGS84)

World Geodetic System 1984



Identical to ITRF and TWD97!

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WGS84更新歷程

WGS-84 (Original) – 1987

Aligned with NAD83/86 (original) but standard deviation of the transformation was +/- 2 meters.

WGS-84 (G730) – 1994

Aligned with ITRF91 (epoch date 1994.0). A significant shift took place with this adjustment.

WGS-84 (G873) – 1996

Aligned with ITRF97 (epoch date 1997.0)

WGS-84 (G1150) – 2002

Aligned with ITRF00 (epoch date 2001.0)

WGS-84 (G1674) – 2012

Aligned with ITRF08 (epoch date 2005.0)

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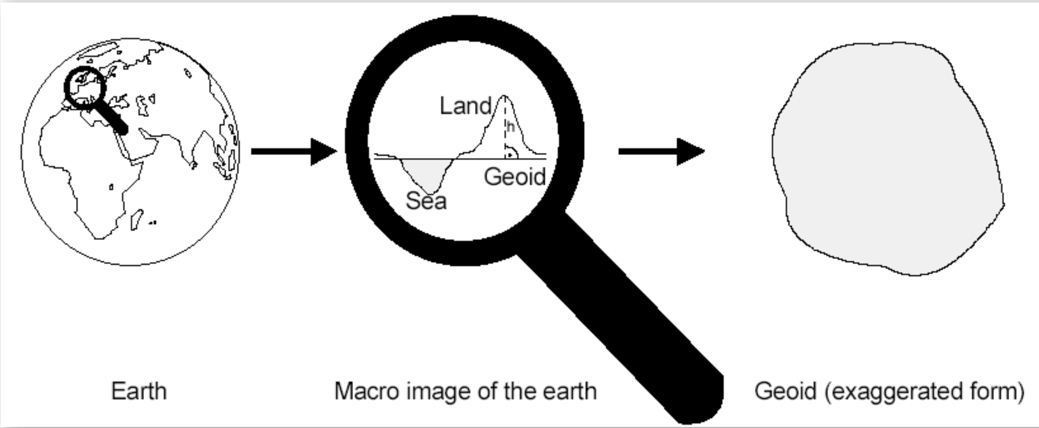
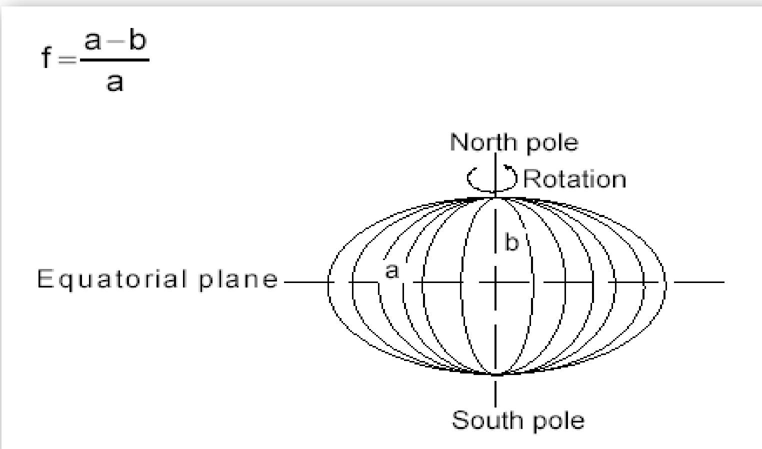
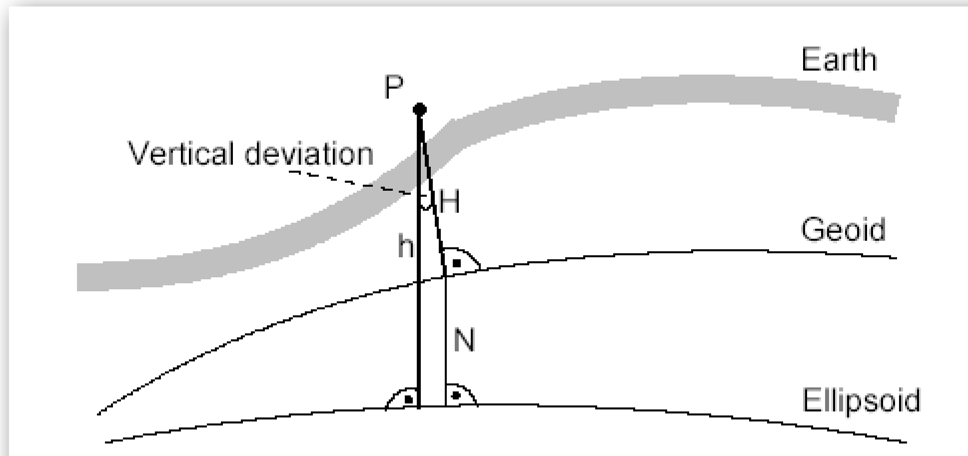
地球形狀與大小的表示



物理性-大地水準面





幾何性-橢球面

H(正高)=h(GPS高)-N(大地起伏)

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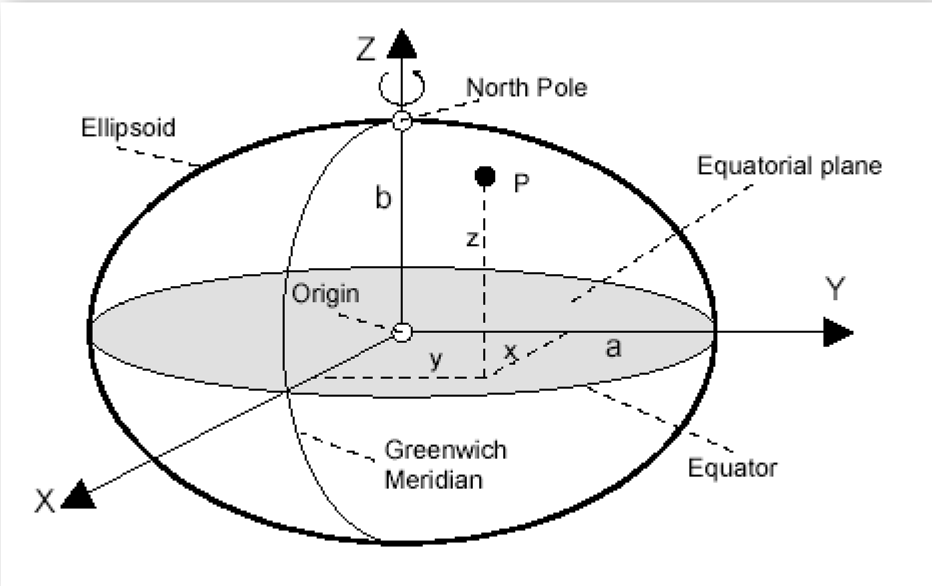
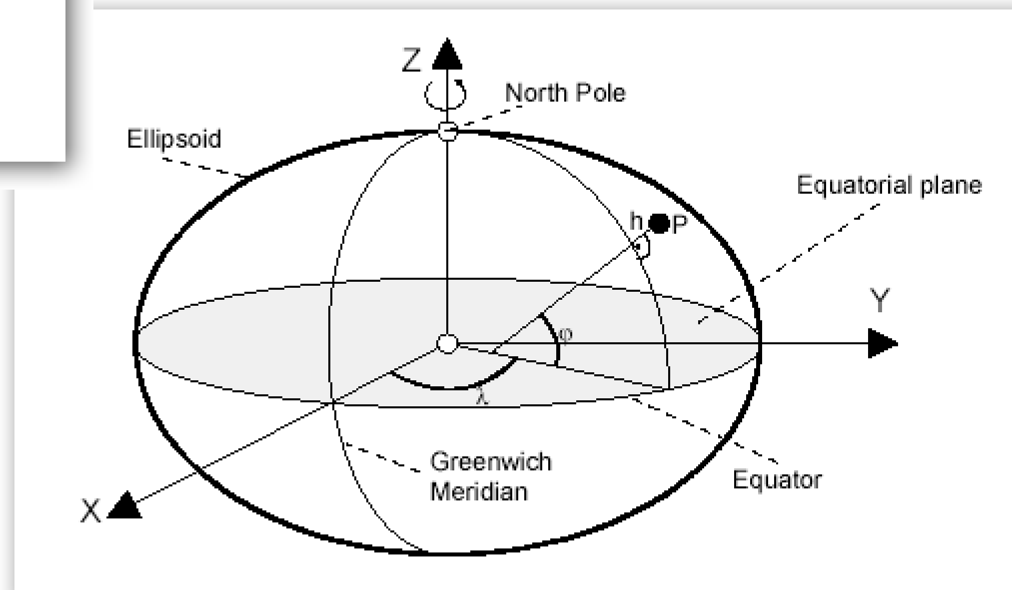
慣用的全球性坐標值

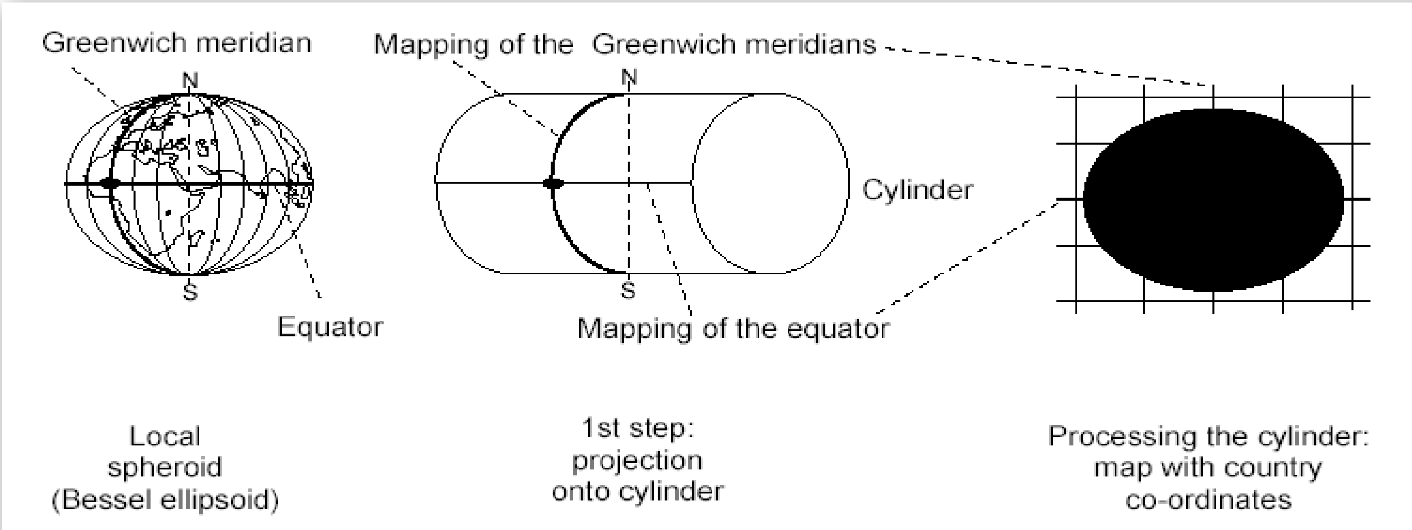


三維直角/卡式坐標 (X,Y,Z)

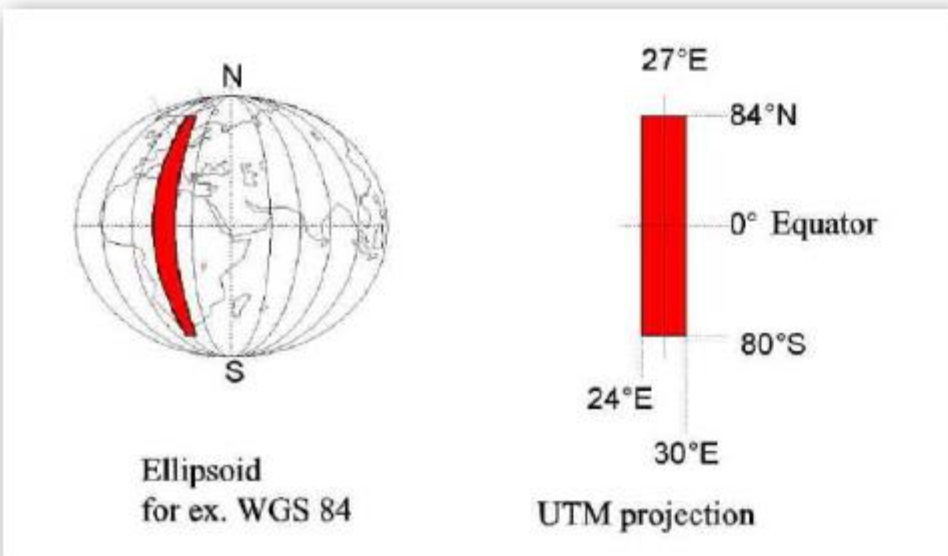


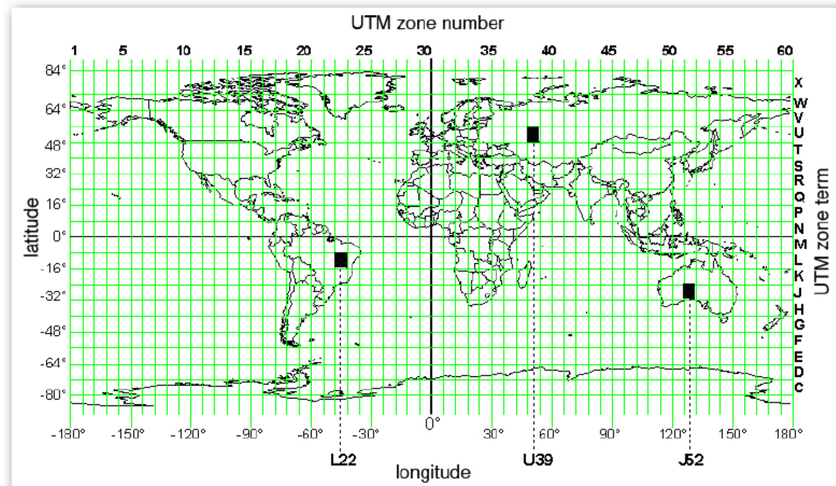
橢球坐標(經緯高度)

慣用的地區性坐標

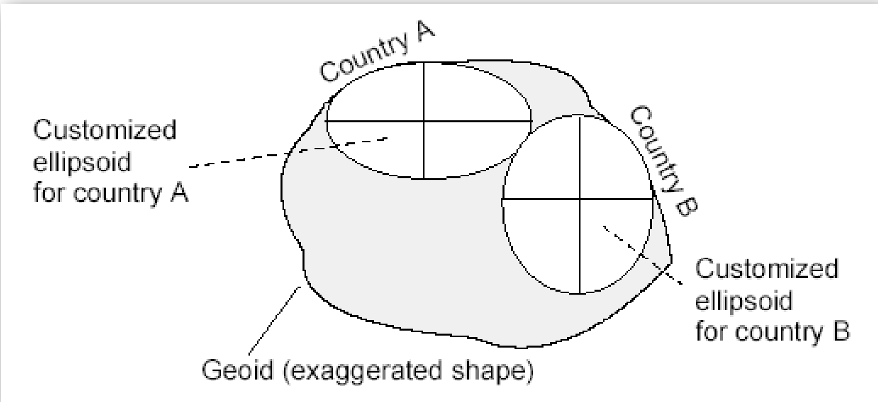


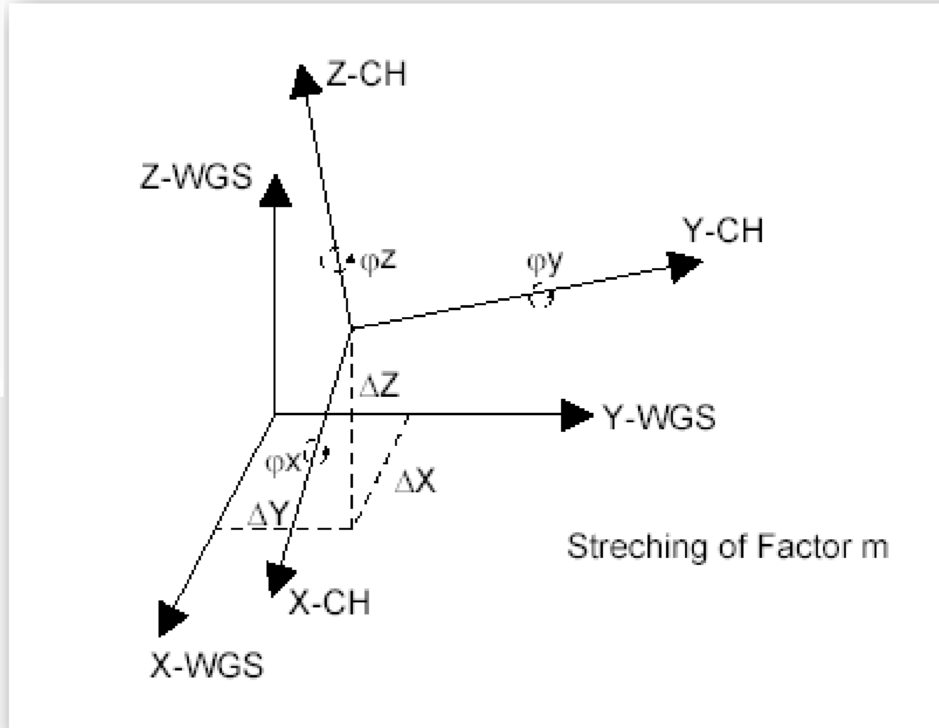
平面投影坐標
(x, y/N, E)





坐標基準的轉換





三個平移量
三個旋轉角
一個尺度比

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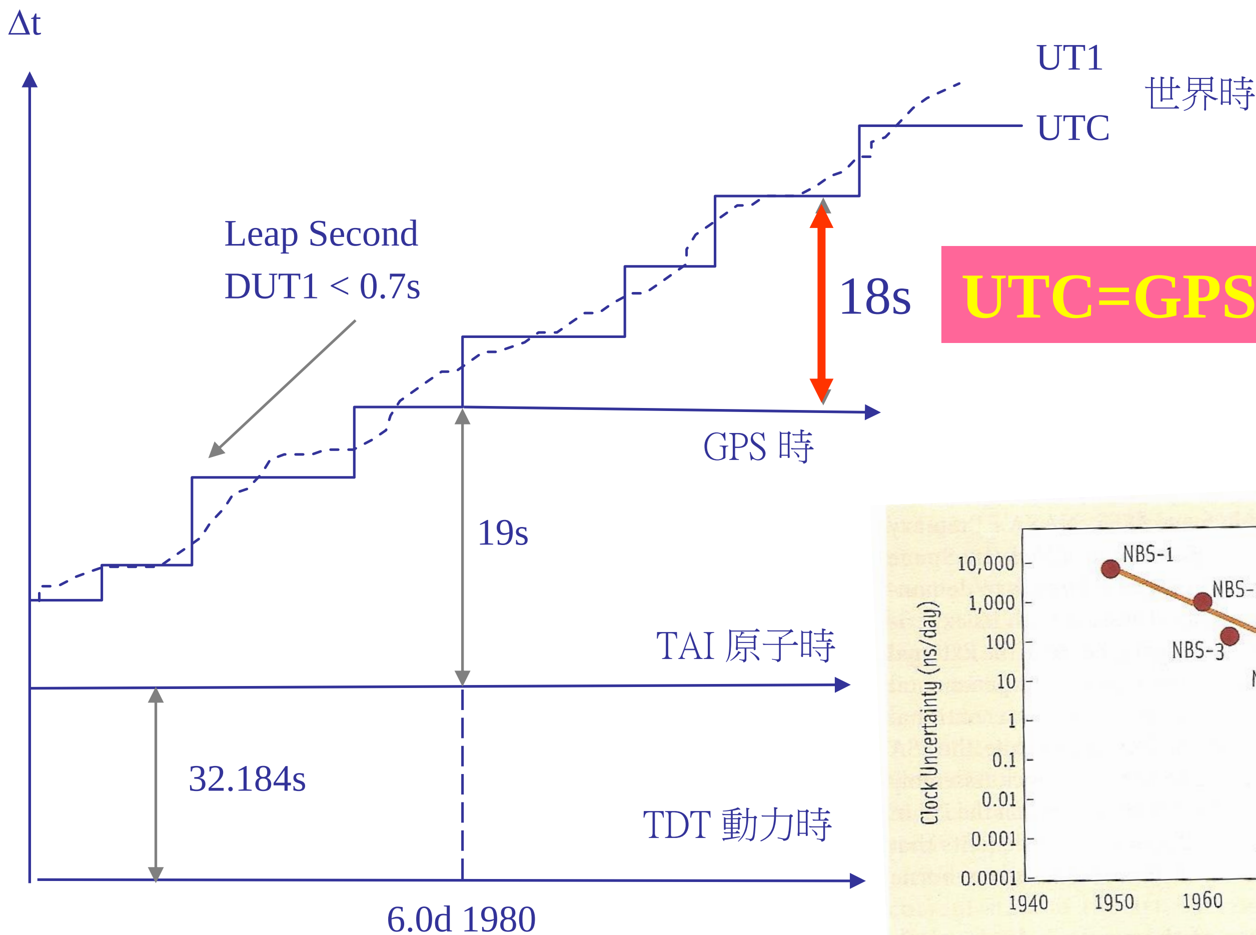
GPS時間系統



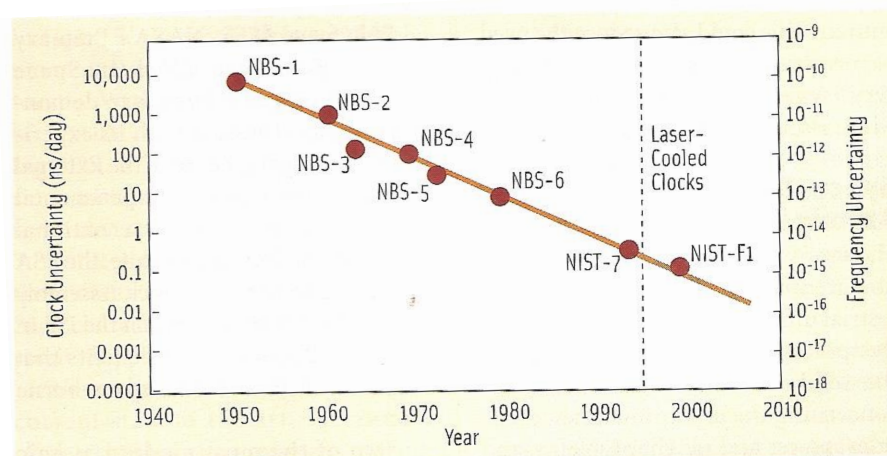
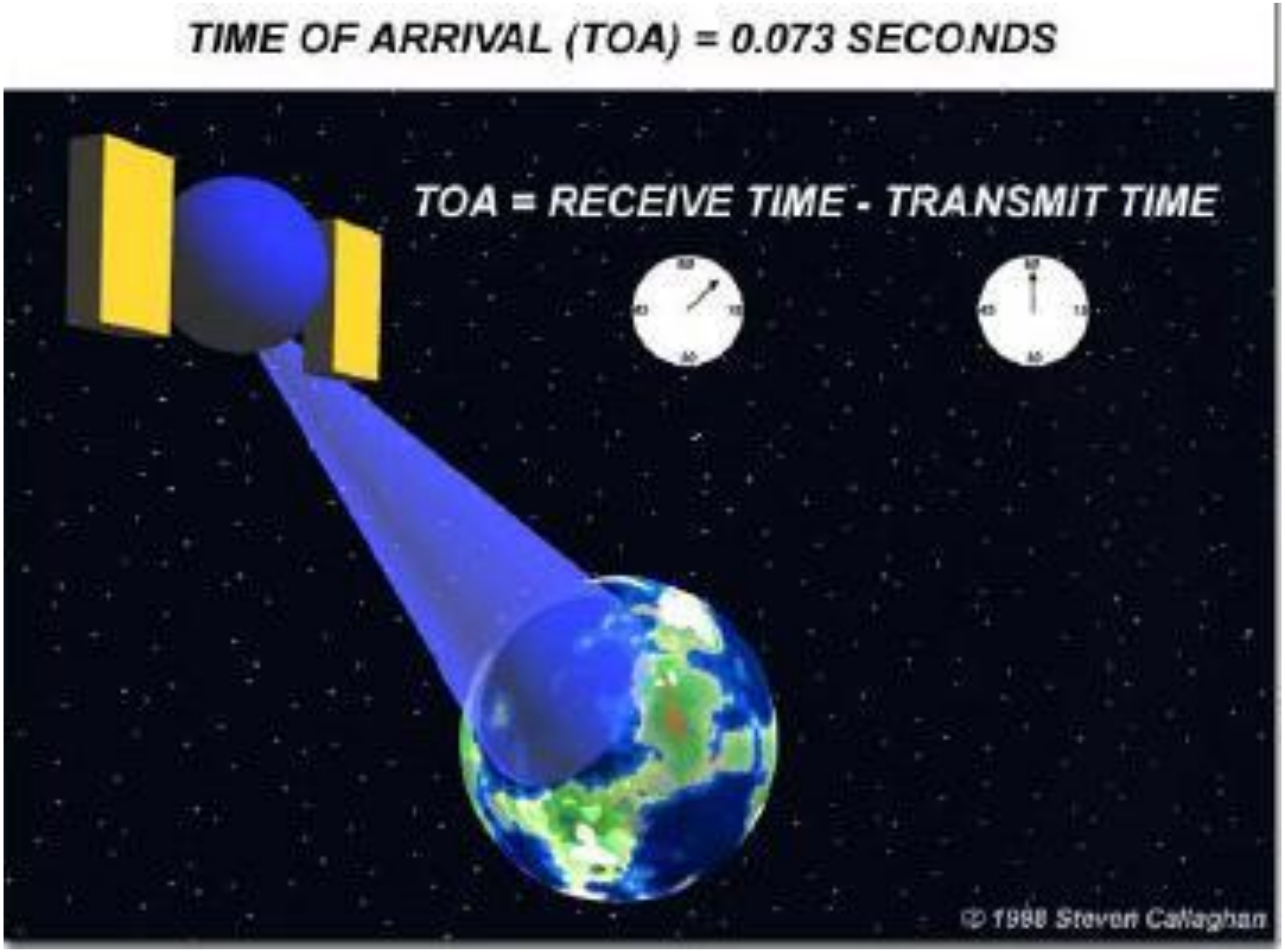
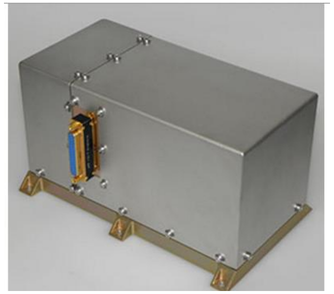


FIGURE 1 Accuracy of terrestrial caesium atomic clocks at the National Institute of Standards and Technology. The NIST-7 is an optically pumped, thermal atomic-beam, microwave caesium spectrometer and the NIST-F1 is a caesium fountain atomic clock

GPS時間的運用


TIME OF ARRIVAL (TOA) = 0.073 SECONDS
TOA = RECEIVE TIME - TRANSMIT TIME
© 1998 Steven Callaghan

GPS時間的量測



衛星時表

- **4 clocks (cesium/rubidium/hydrogen maser)**
- **$100,000 - $500,000** 美金

接收機時表

- 類似於石英表
- 衛星與接收機之間通常存在時表誤差(Δt)
- 須接收4顆衛星方可解算 X, Y, Z, Δt

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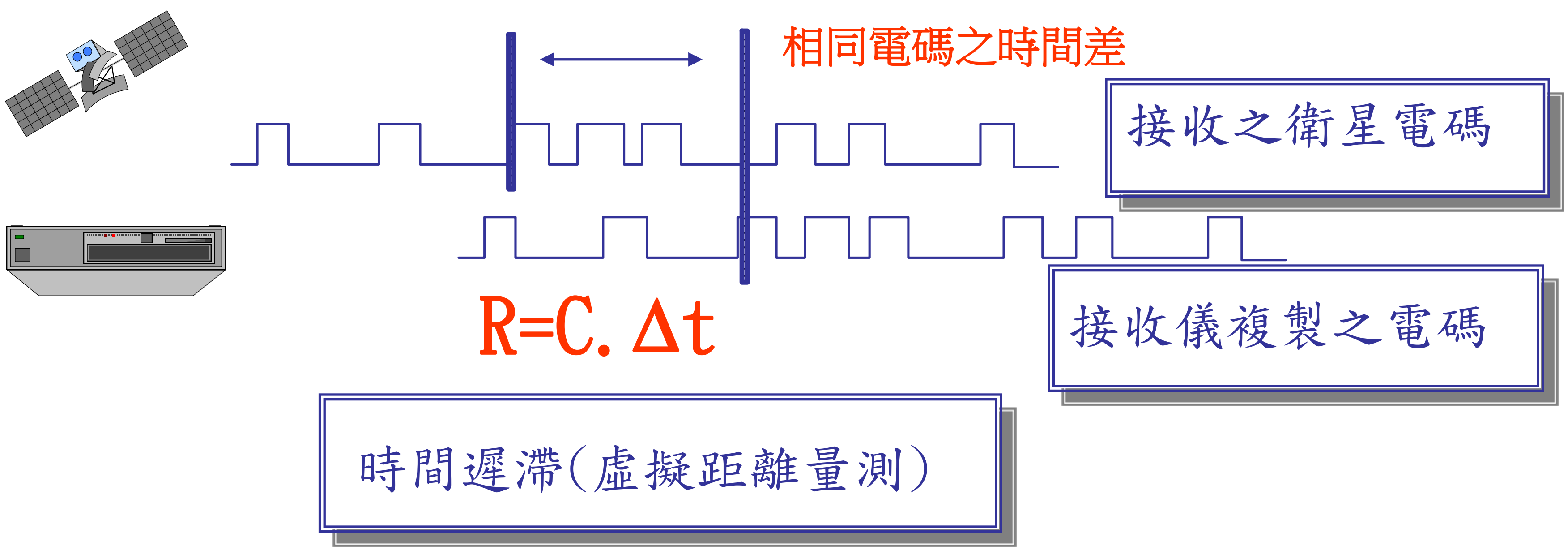
GPS基本觀測量

- 虛擬距離（pseudo-range）



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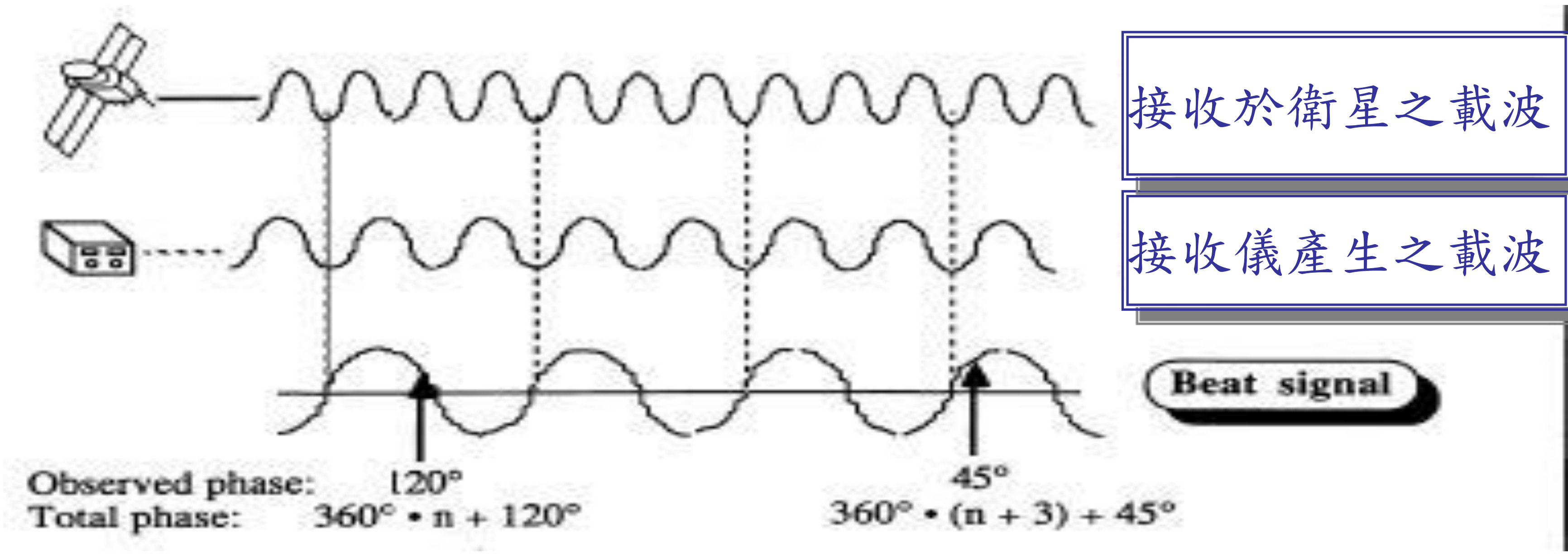
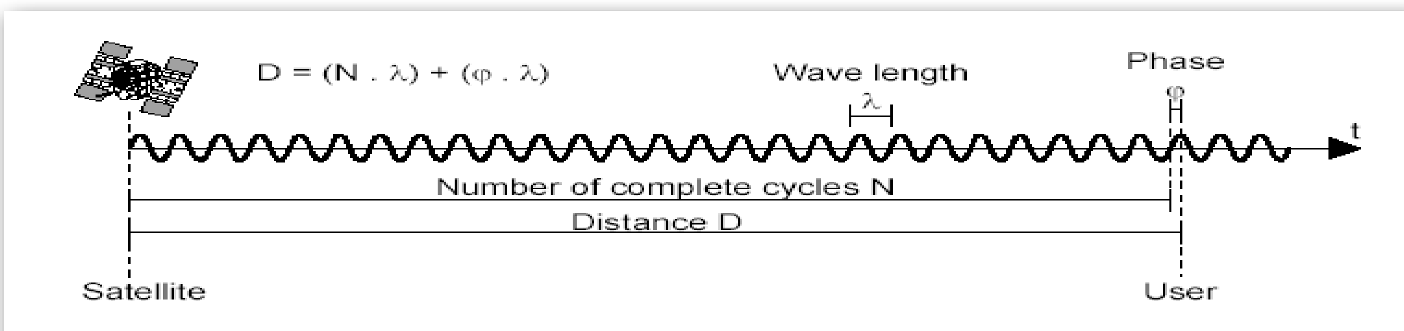
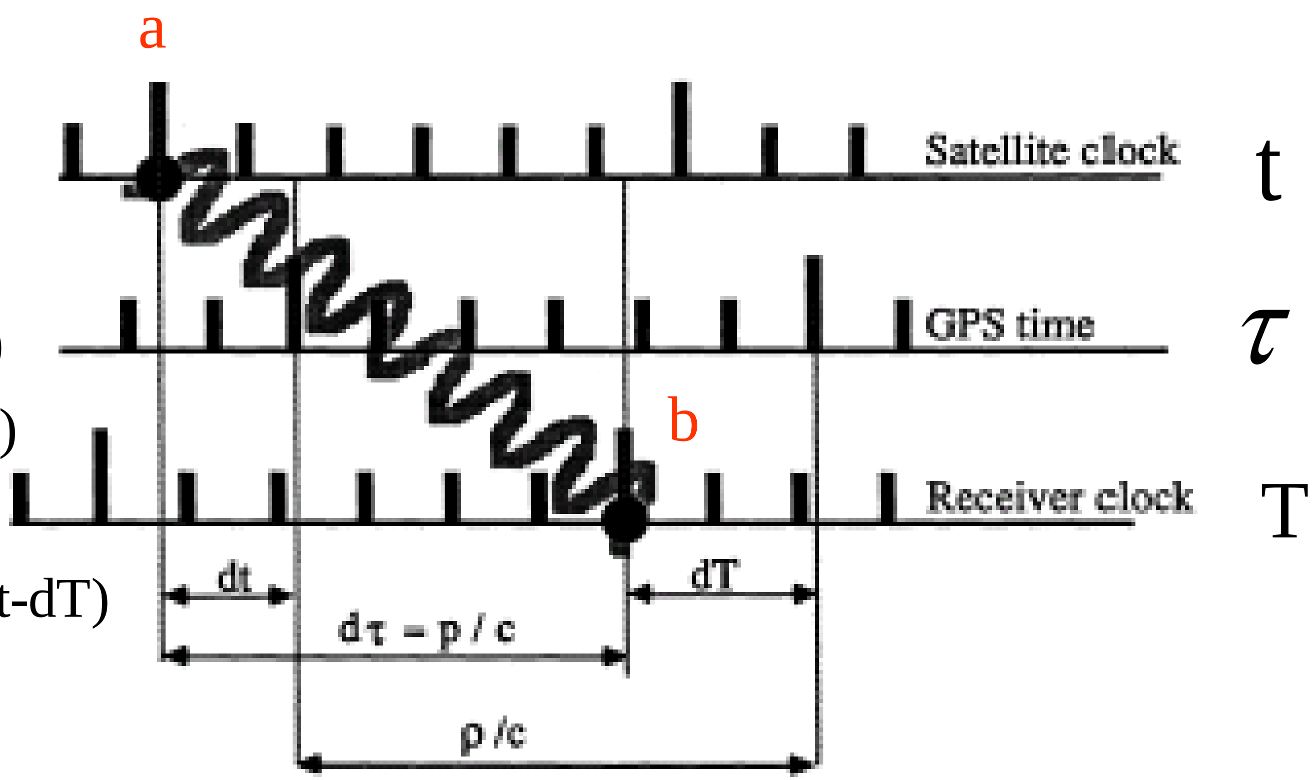
GPS基本觀測量

- 載波相位（carrier phase）





虛擬距離觀測方程式



$d\tau = T_b - t_a$

$= (\tau_b - dT) - (\tau_a - dt)$

$= (\tau_b - \tau_a) + (dt - dT)$

$P = c\, d\tau$

$= c\,(\tau_b - \tau_a) + c\,(dt - dT)$

$= \rho + c\,(dt - dT)$

虛擬距離　真實距離　衛星及接收器時錶差

電離層及對流層延遲

$$p = \rho + c\cdot(dt - dT) + d_{ion} + d_{trop}$$

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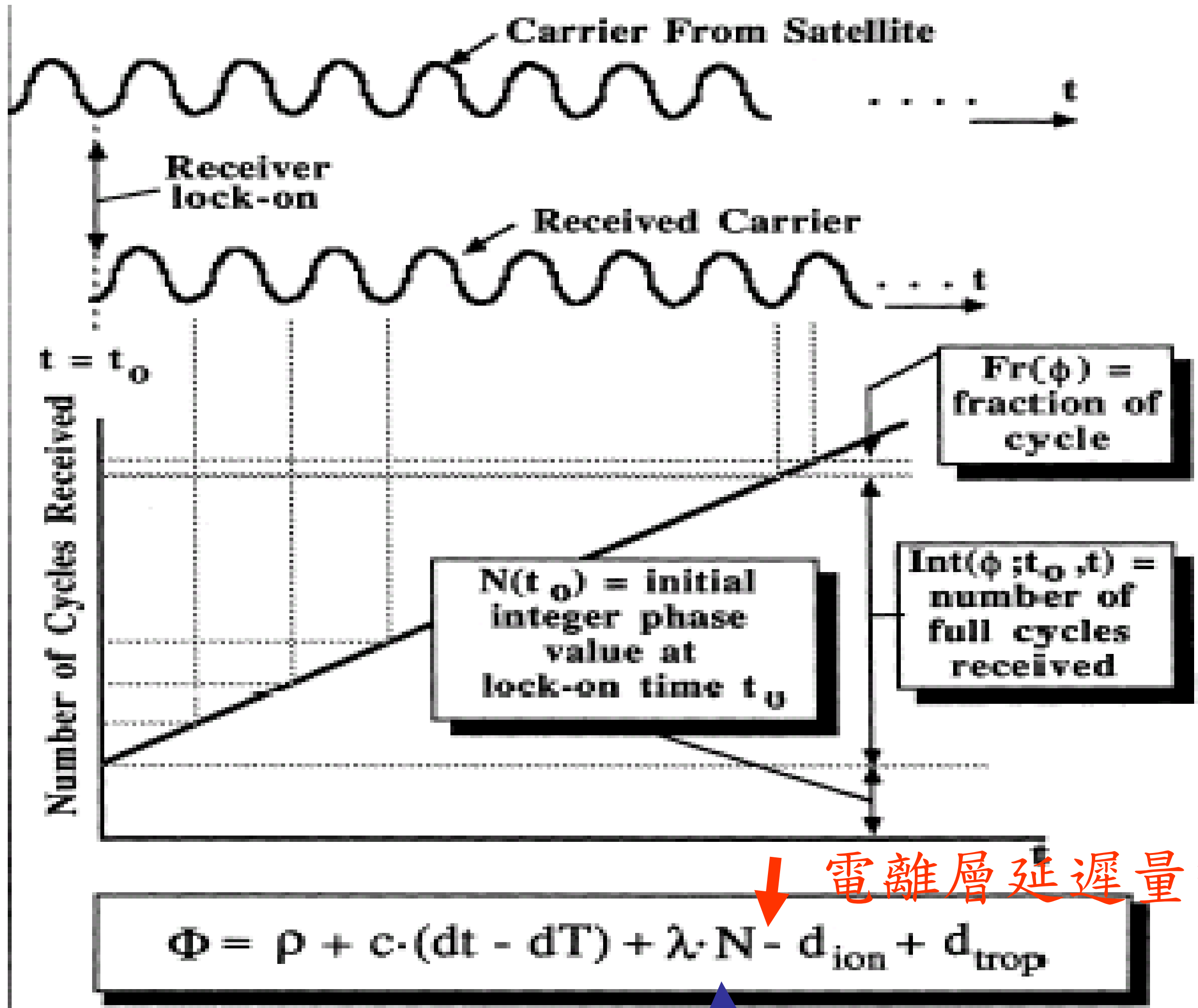
載波相位觀測方程式

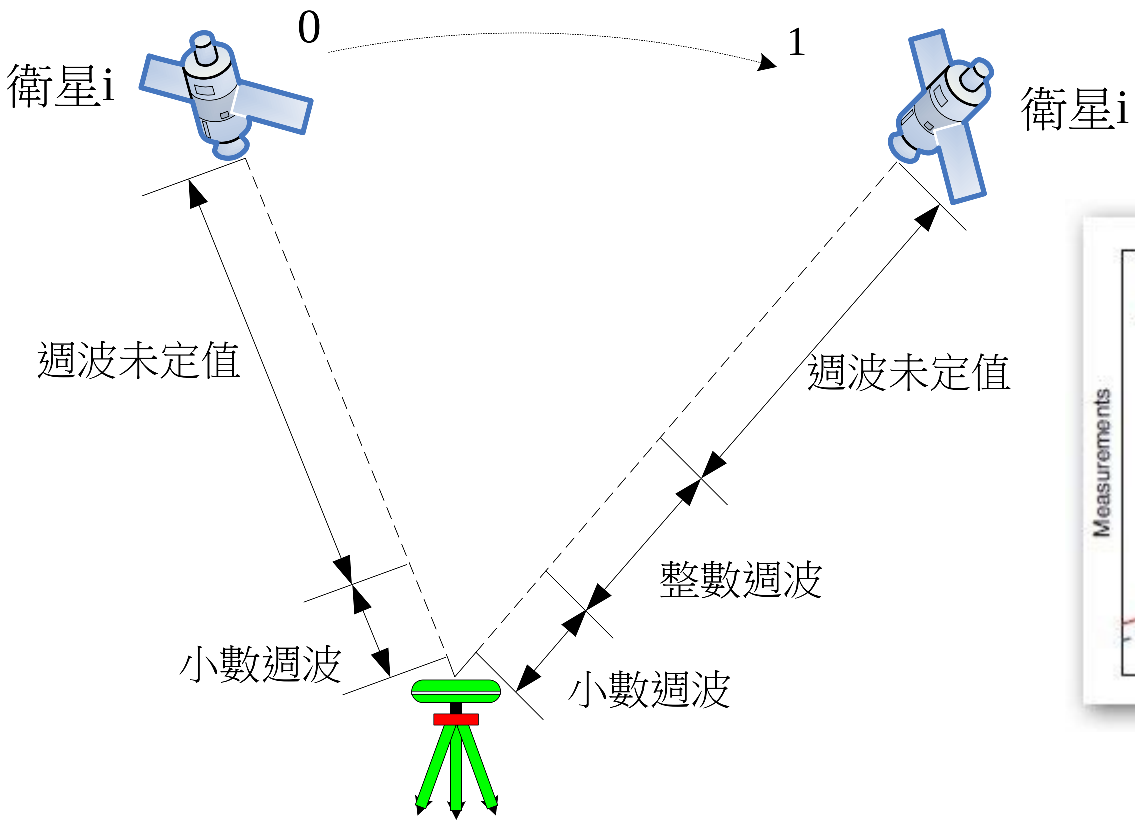


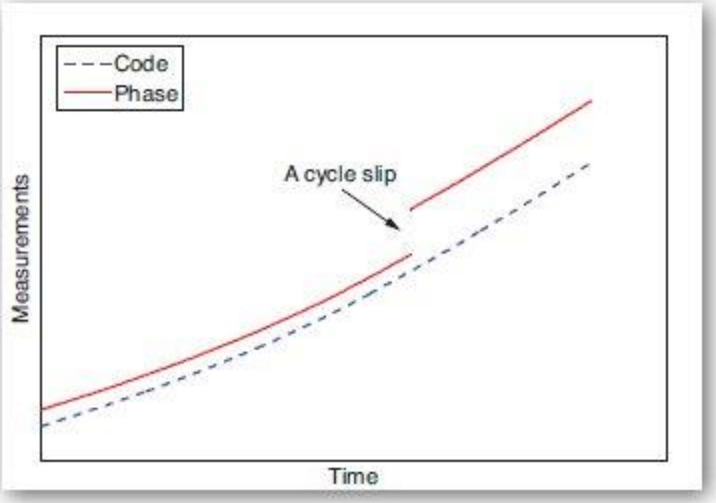
$$\Phi = \rho + c\cdot(dt - dT) + \lambda\cdot N - d_{ion} + d_{trop}$$

電離層延遲量變號

相位起始未定值(ambiguity)

相位起始整數週波未定值





Remain constant if no cycle slip occurred/Solved for RTK

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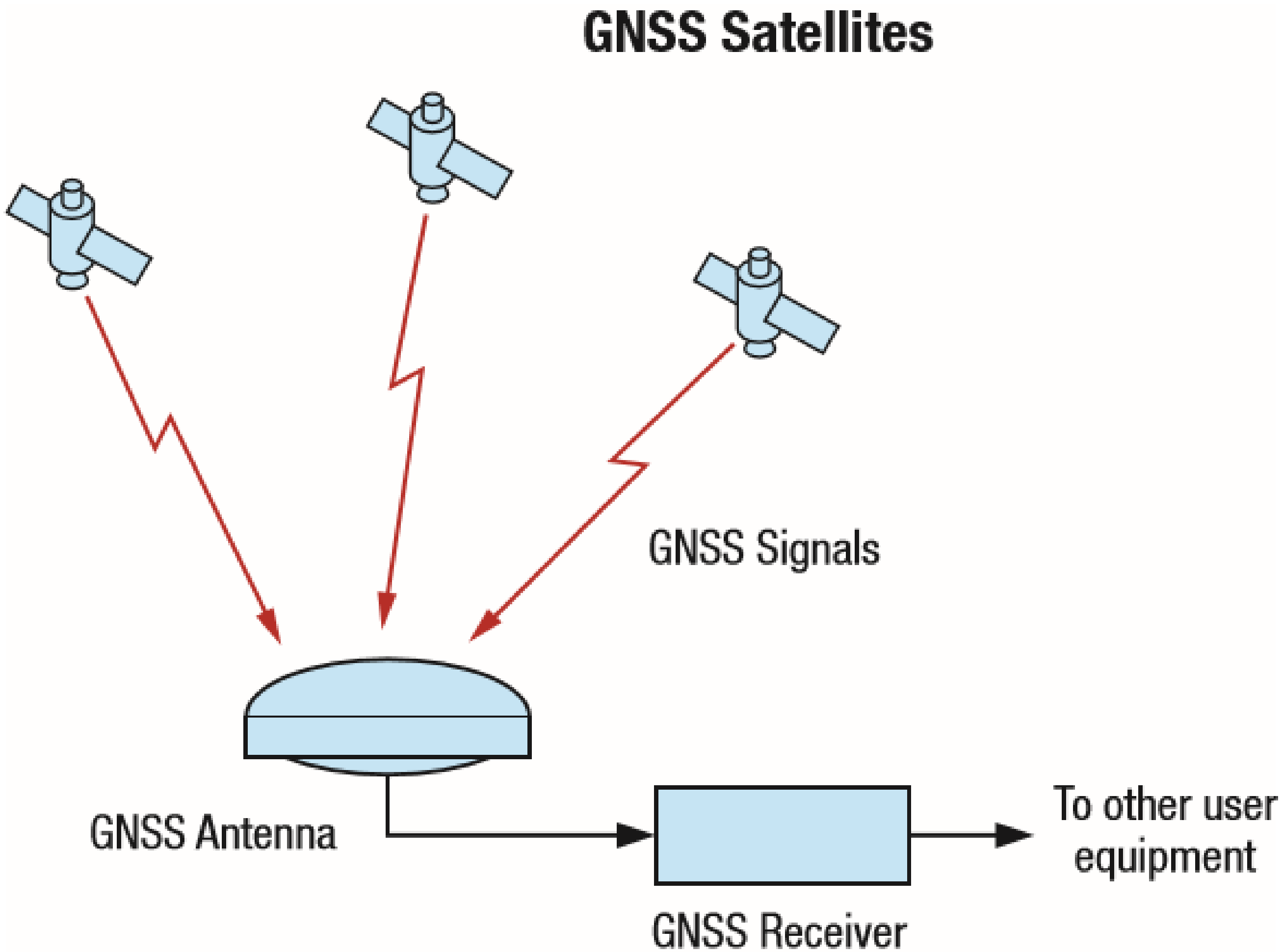
GPS觀測量解析度

- 觀測量解析度約為其波長之 1%
- 虛擬距離
  - C/A 電碼之波長為 300 m ----> 解析度 3 m
  - P 電碼之波長為 30 m ----> 解析度 30 cm
- 載波相位
  - L1及L2之波長約為 20 cm ----> 解析度 2 mm

衛星定位使用裝備


GNSS Satellites
GNSS Signals
GNSS Antenna
GNSS Receiver
To other user equipment

GPS接收器

天線單元

電纜線

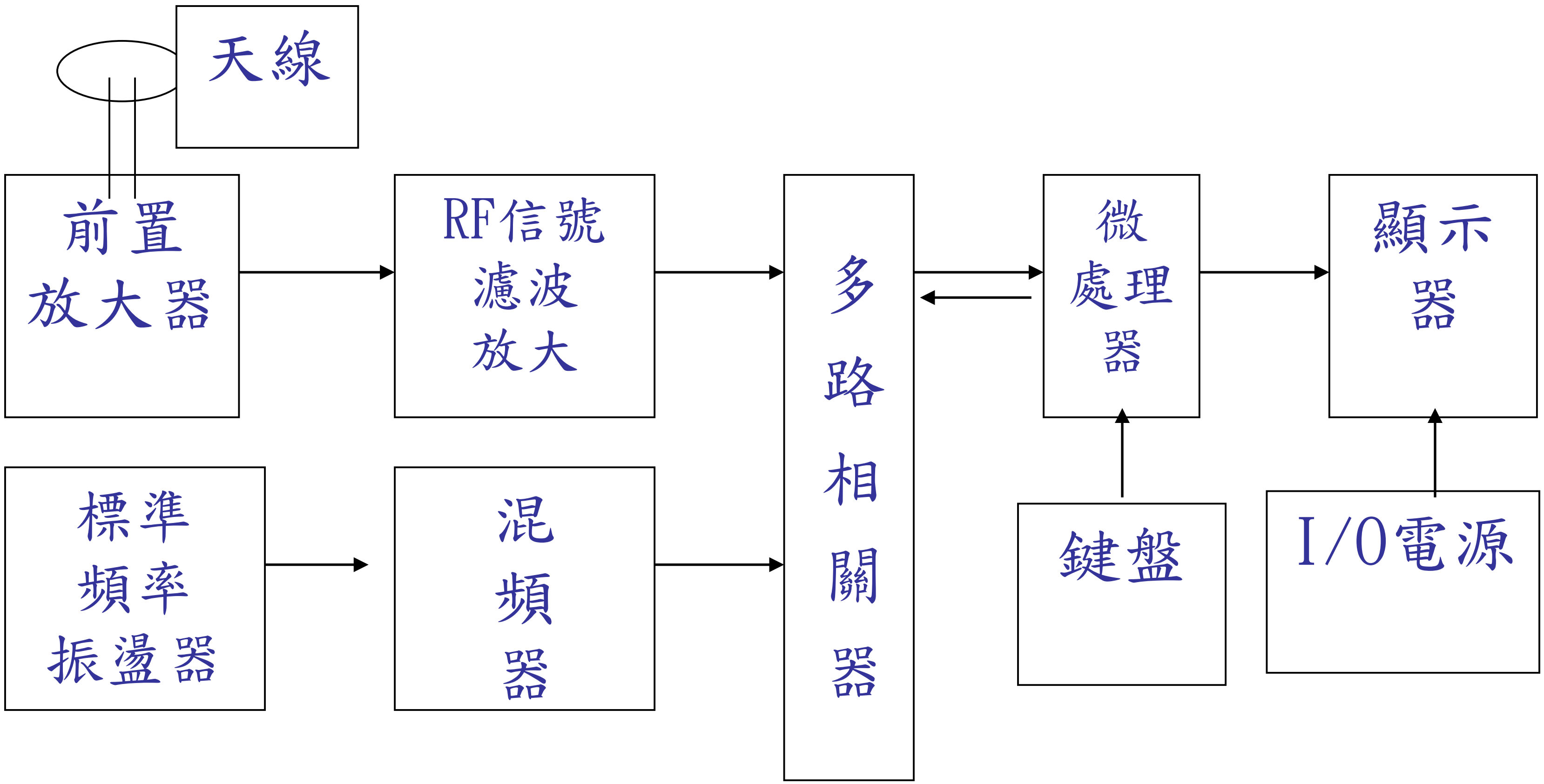
電源線

電源

接收器單元

信號處理器(多頻道L1,L2)
時錶(參考頻率)
微處理機(資料先期處理)
磁碟(儲存資料)
電源
顯示器及鍵盤
輸出孔

GPS信號處理程序



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GPS接收機類型

- 導航型(L1 C/A code range)
  - 導航器
  - 軌跡紀錄器
- 大地型(L1/L2 phase + C/A + P)
  - 野外型
  - 追蹤站型

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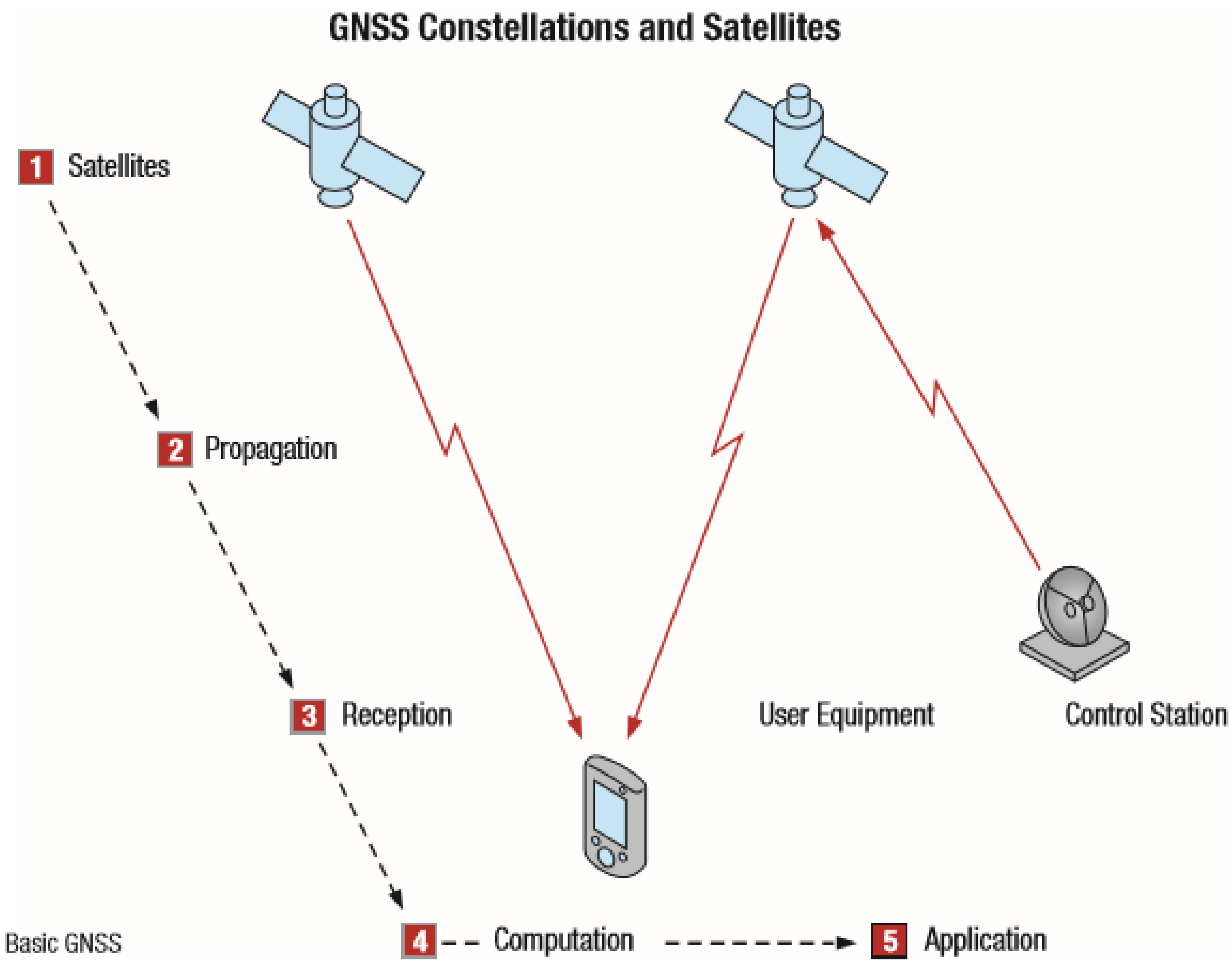
衛星定位基本程序



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GPS定位基本要素

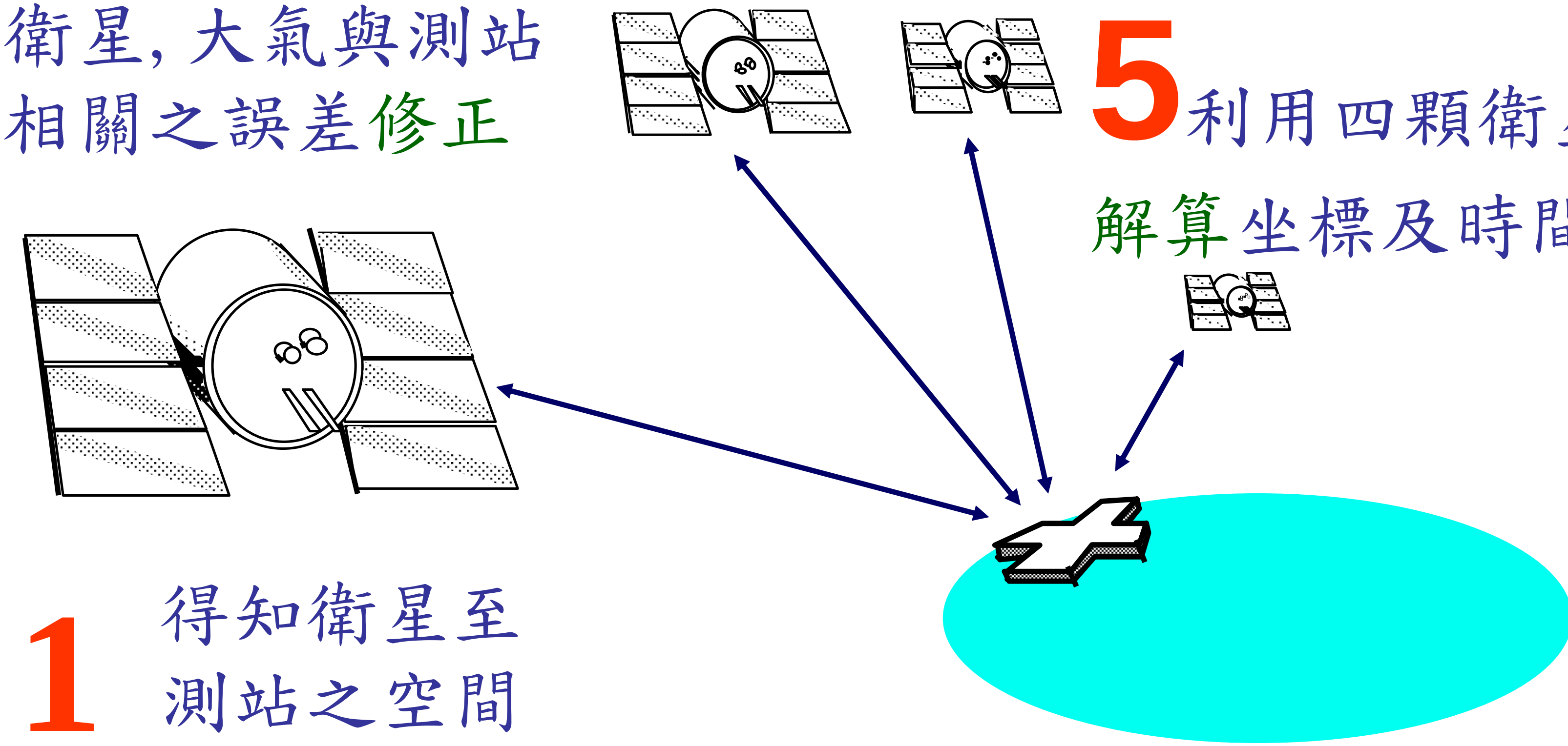
1 得知衛星至測站之空間距離

2 衛星,大氣與測站相關之誤差修正

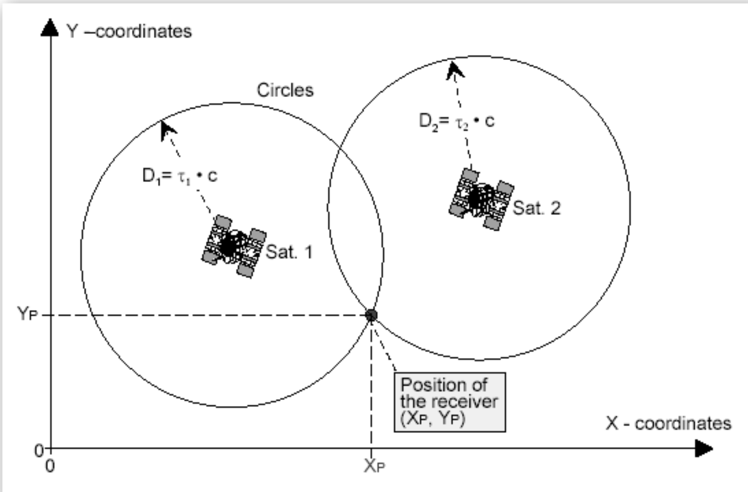
3 知道衛星軌道位置

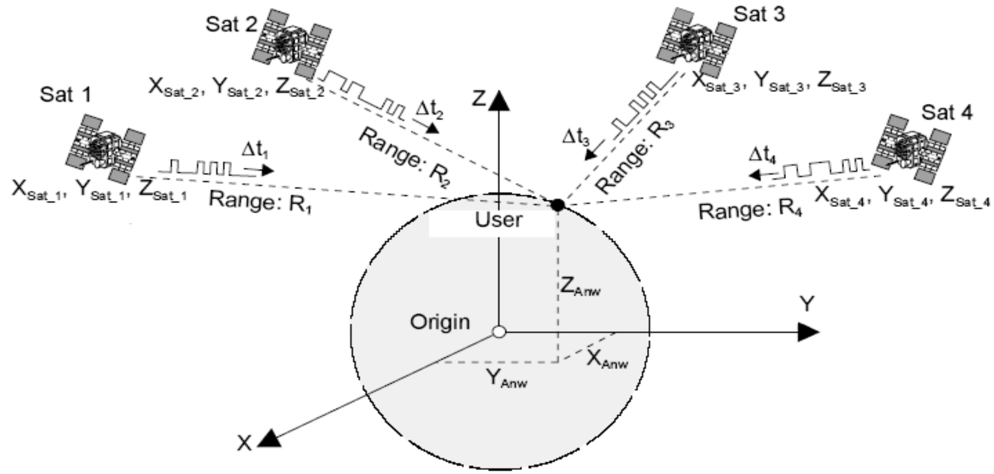
4 依據後方交會原理

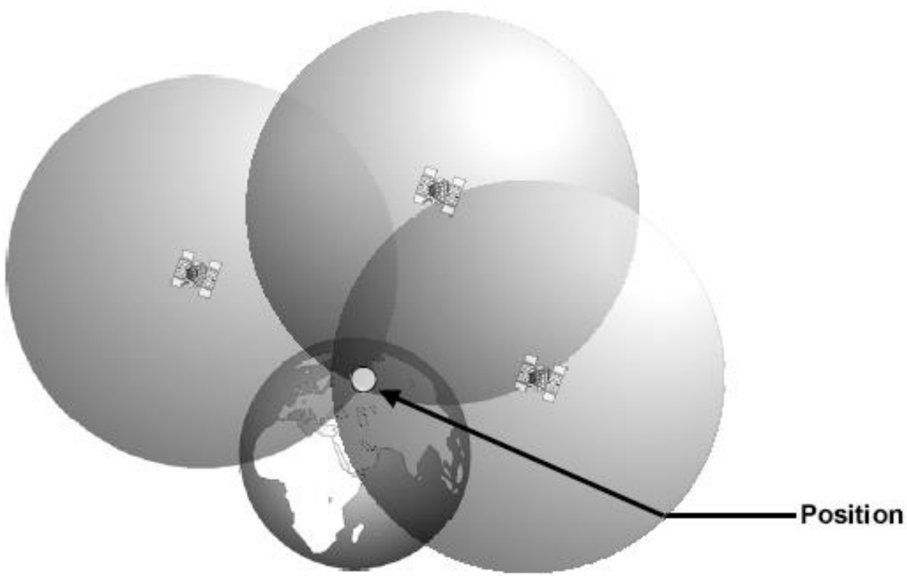
5 利用四顆衛星解算坐標及時間

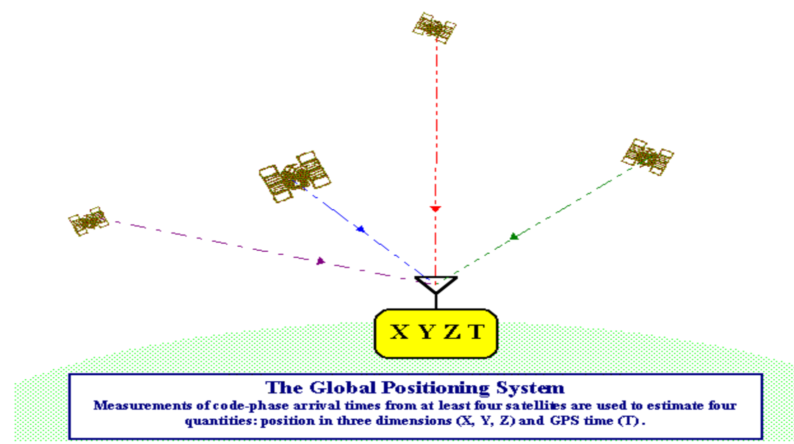


交會定位原理

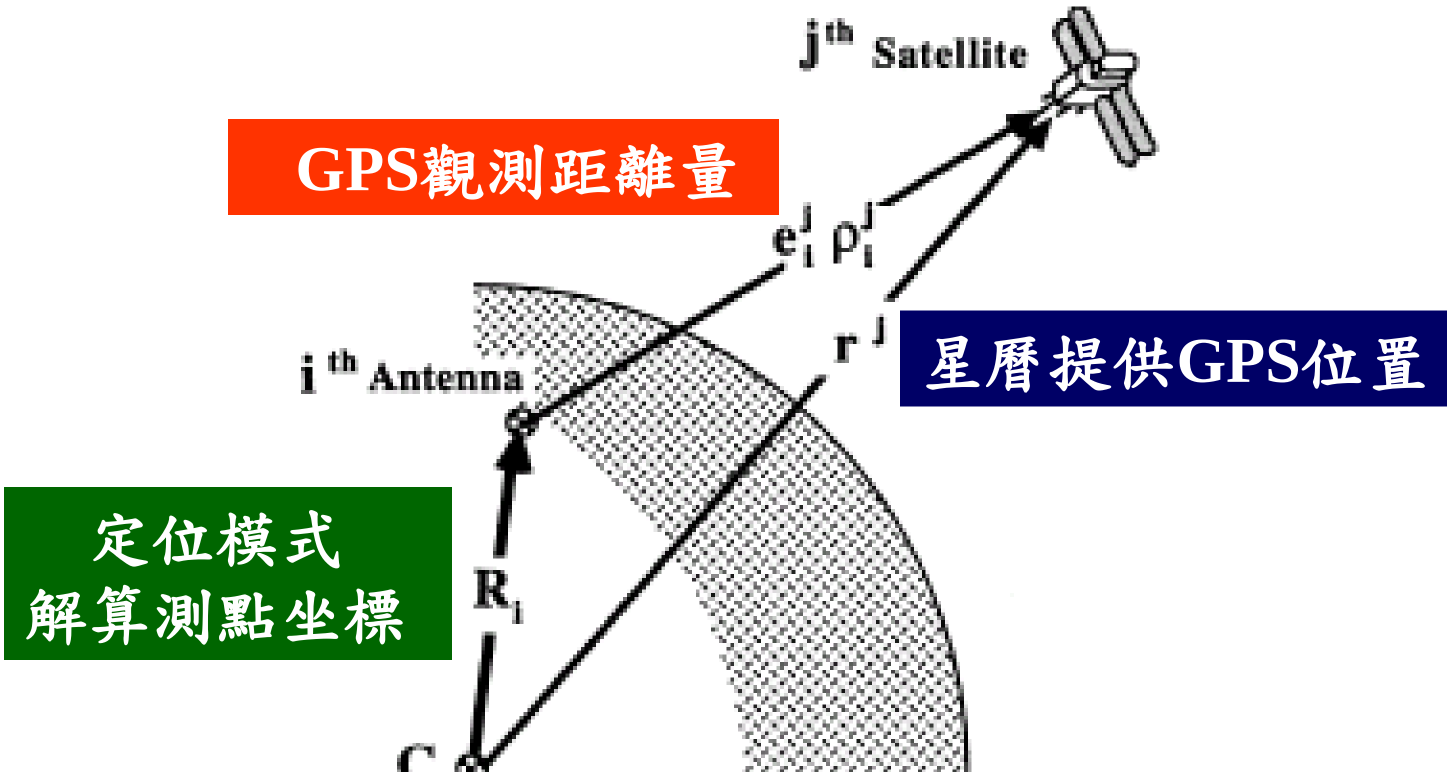

Y –coordinates
Circles
D1= τ1 • c
D2= τ2 • c
Sat. 1
Sat. 2
YP
Position of
the receiver
(XP, YP)
X - coordinates
0
0
XP


Sat 1
Sat 2
Sat 3
Sat 4
XSat_1, YSat_1, ZSat_1
XSat_2, YSat_2, ZSat_2
XSat_3, YSat_3, ZSat_3
XSat_4, YSat_4, ZSat_4
Δt1
Δt2
Δt3
Δt4
Range: R1
Range: R2
Range: R3
Range: R4
Z
Y
X
User
Origin
ZAnw
XAnw
YAnw


Position


X Y Z T
The Global Positioning System
Measurements of code-phase arrival times from at least four satellites are used to estimate four quantities: position in three dimensions (X, Y, Z) and GPS time (T).

距離觀測量為資料源



$$R_i = r^j - e_i^j \rho_i^j$$

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NMEA導航定位資料格式

National Marine Electronics Association

$GPRMC,130303.0,A,4717.115,N,00833.912,E,000.03,043.4,200601,01.3,W*7D<CR><LF>
$GPZDA,130304.2,20,06,2001,,*56<CR><LF>
$GPGGA,130304.0,4717.115,N,00833.912,E,1,08,0.94,00499,M,047,M,,*59<CR><LF>
$GPGLL,4717.115,N,00833.912,E,130304.0,A*33<CR><LF>
$GPVTG,205.5,T,206.8,M,000.04,N,000.08,K*4C<CR><LF>
$GPGSA,A,3,13,20,11,29,01,25,07,04,,,,,1.63,0.94,1.33*04<CR><LF>
$GPGSV,2,1,8,13,15,208,36,20,80,358,39,11,52,139,43,29,13,044,36*42<CR><LF>
$GPGSV,2,2,8,01,52,187,43,25,25,074,39,07,37,286,40,04,09,306,33*44<CR><LF>
$GPRMC,130304.0,A,4717.115,N,00833.912,E,000.04,205.5,200601,01.3,W*7C<CR><LF>
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$GPGSV,2,1,8,13,15,208,36,20,80,358,39,11,52,139,43,29,13,044,36*42<CR><LF>
$GPGSV,2,2,8,01,52,187,43,25,25,074,39,07,37,286,40,04,09,306,33*44<CR><LF>

GPGGA導航定位格式說明

Field	Description
$	Start of the data set
GP	Information originating from a GPS appliance
GGA	Data set identifier
130305.0	UTC positional time: 13h 03min 05.0sec
4717.115	Latitude: 47° 17.115 min
N	Northerly latitude (N=north, S= south)
00833.912	Latitude: 8° 33.912min
E	Easterly longitude (E= east, W=west)
1	GPS quality details (0= no GPS, 1= GPS, 2=DGPS)
08	Number of satellites used in the calculation
0.94	Horizontal Dilution of Precision (HDOP)
00499	Antenna height data (geoid height)
M	Unit of height (M= meter)
047	Height differential between an ellipsoid and geoid
M	Unit of differential height (M= meter)
,,	Age of the DGPS data (in this case no DGPS is used)
0000	Identification of the DGPS reference station
*	Separator for the checksum
58	Checksum for verifying the entire data set
<CR><LF>	End of the data set

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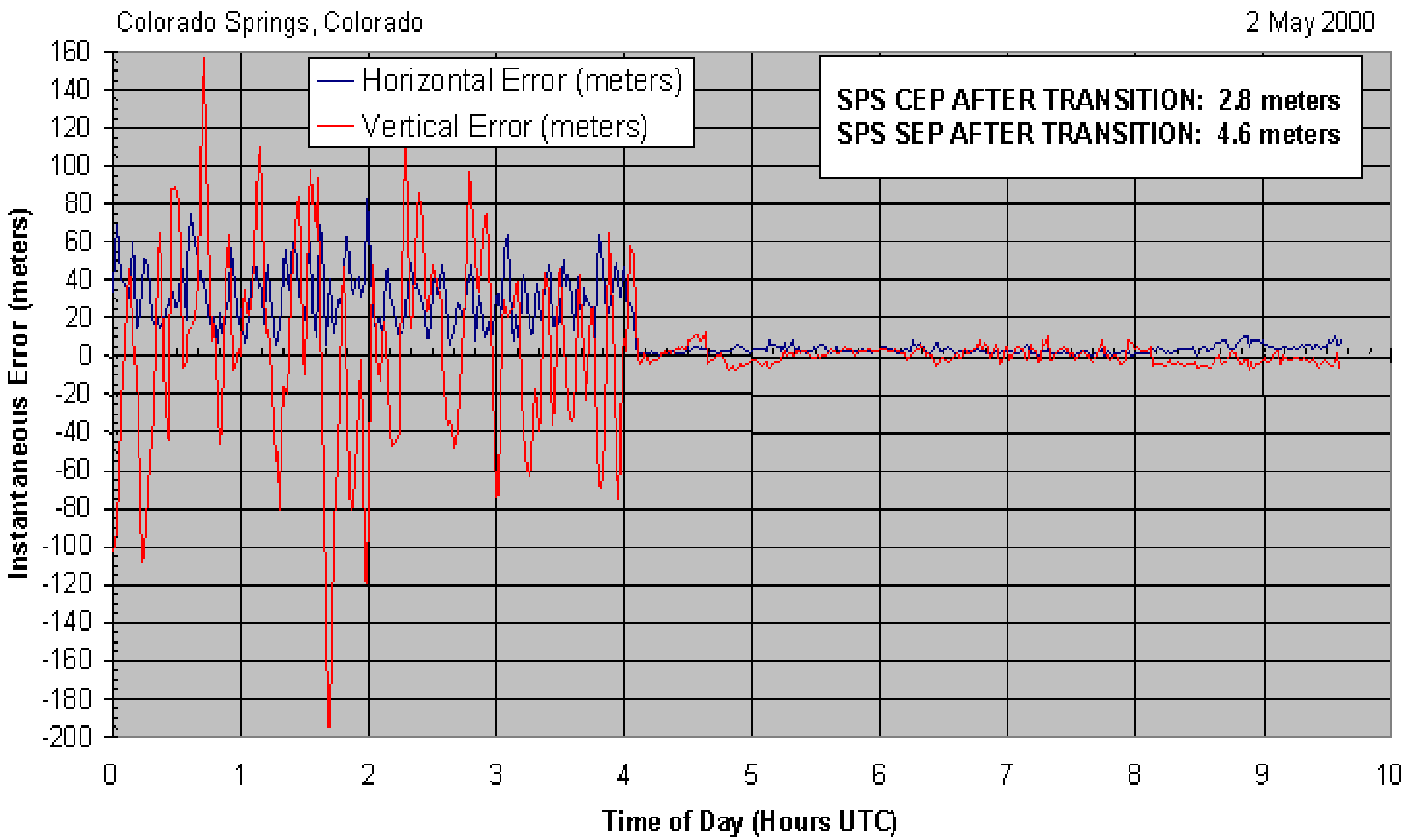
擇用效應(SA)

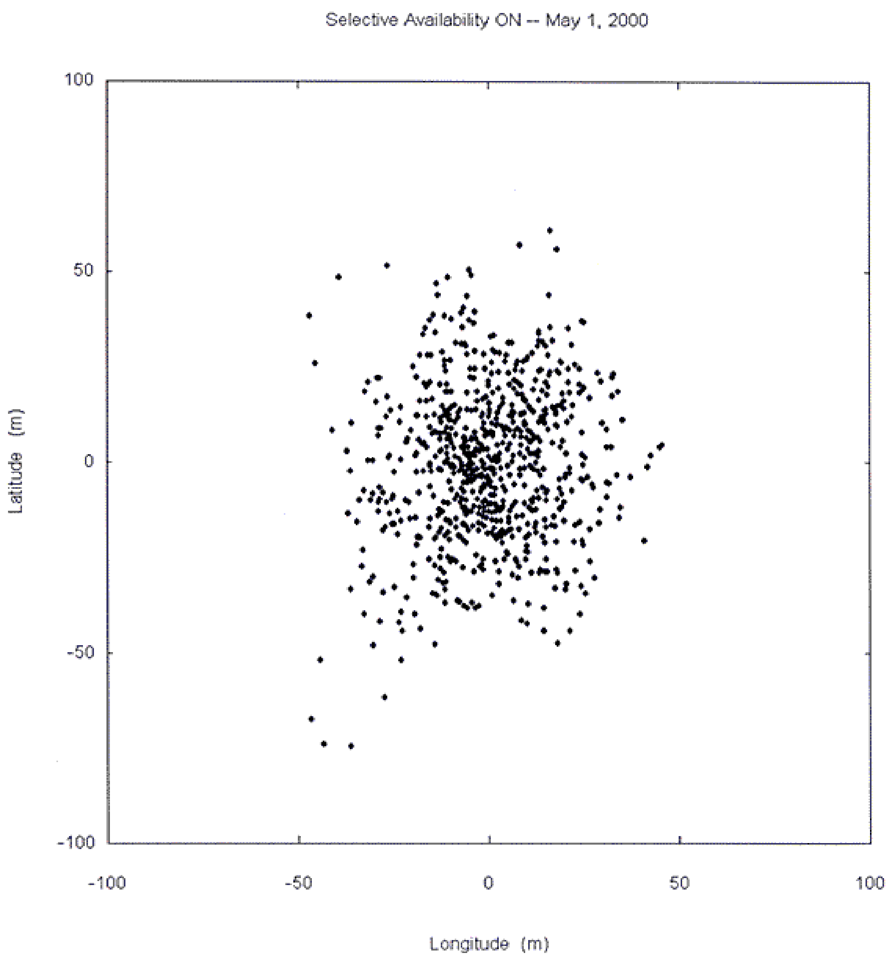
Selective Availability

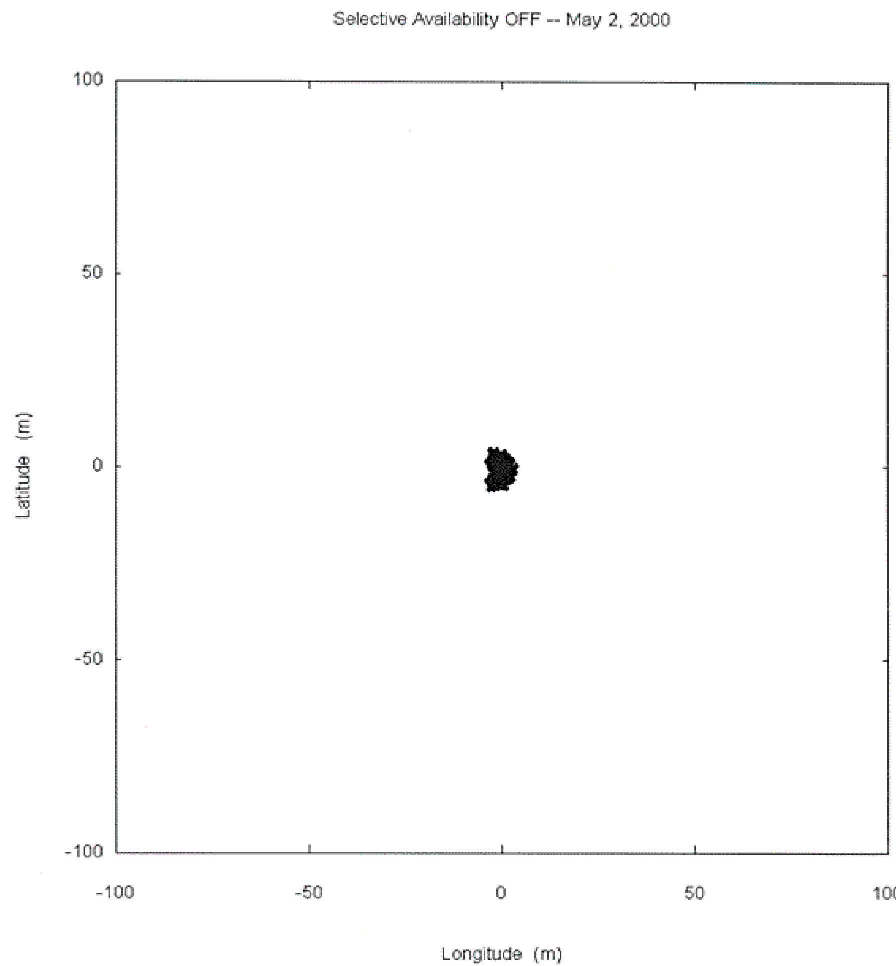
- 對非授權使用者限制其GPS導航定位精度
- 抖動衛星時錶，降低星曆軌道精度
- 該政策下提供約100 m之定位精度
- 克林頓總統1996年宣佈於10年內逐步取消此效應
- 2000年5月2日解除此項精度管制措施，但保留戰時局部開啟之權利
- 2007年9月18日宣布BLOCK III衛星不再具此效應

SA Transition -- 2 May 2000



SA關閉前後之水平定位精度





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反愚效應(A-S)

Anti-Spoofing

- 避免GPS接收儀被假信號所愚弄(spoofed)
- 在L1及L2頻道之P電碼上另行添加W碼以組合成P(Y)電碼
- 授權使用者方可利用解碼裝置接收P電碼
- 非授權者因無法接收L2頻道之電碼信號以致無法獲得L2之虛擬距離觀測量
- 大地測量型GPS接收儀之L2載波相位觀測會受到影響
- 現代機型具克服此效應之技術
- 伴隨新一代衛星佈設完成,2020/12/31舊雙頻機(codeless)將失效應改採可直接接收L2C/L5之機型

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精度稀釋因子(DOP)

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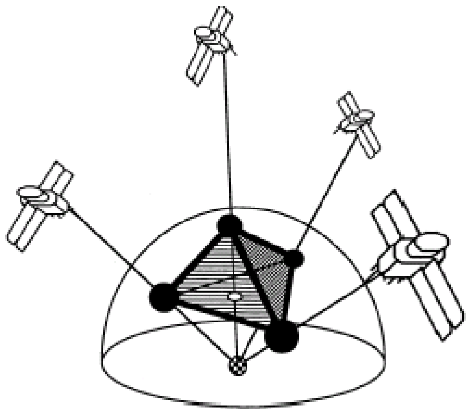
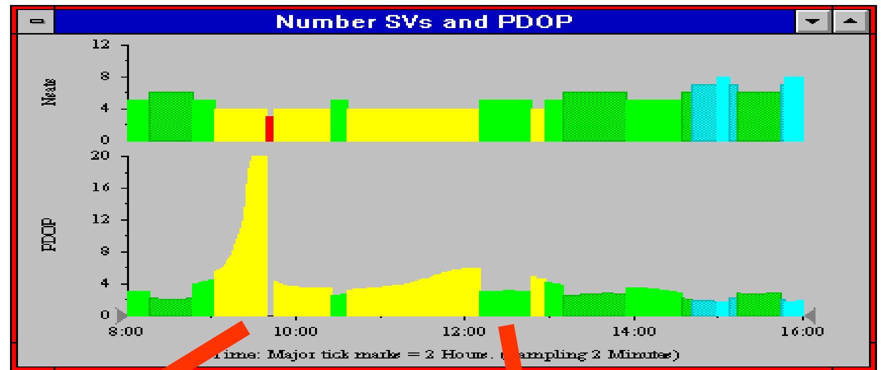
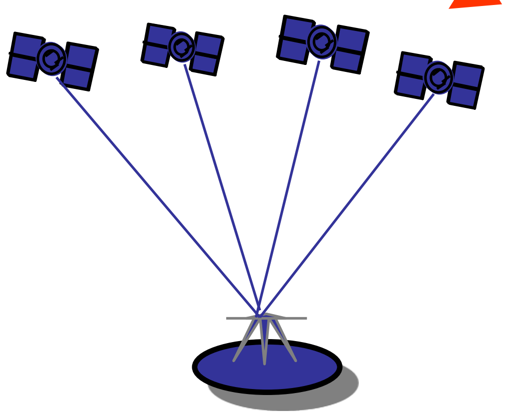
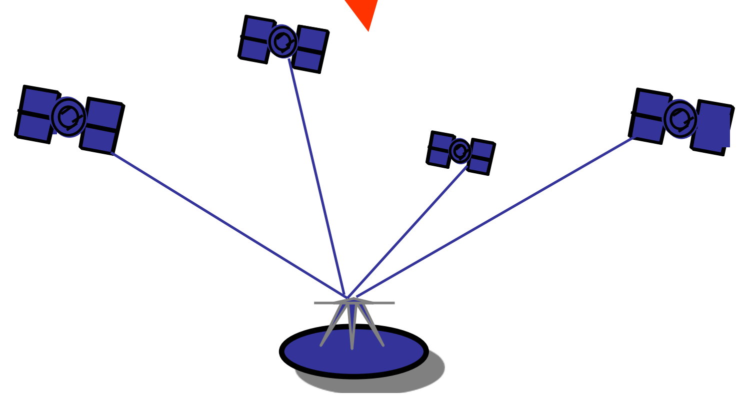
Dilution of Precision









幾何條件差 = DOP值大 = 定位精度差

$$\sigma = DOP \cdot \sigma_0$$

Positioning accuracy — Geometry (Dilution of Precision) — Measurement accuracy

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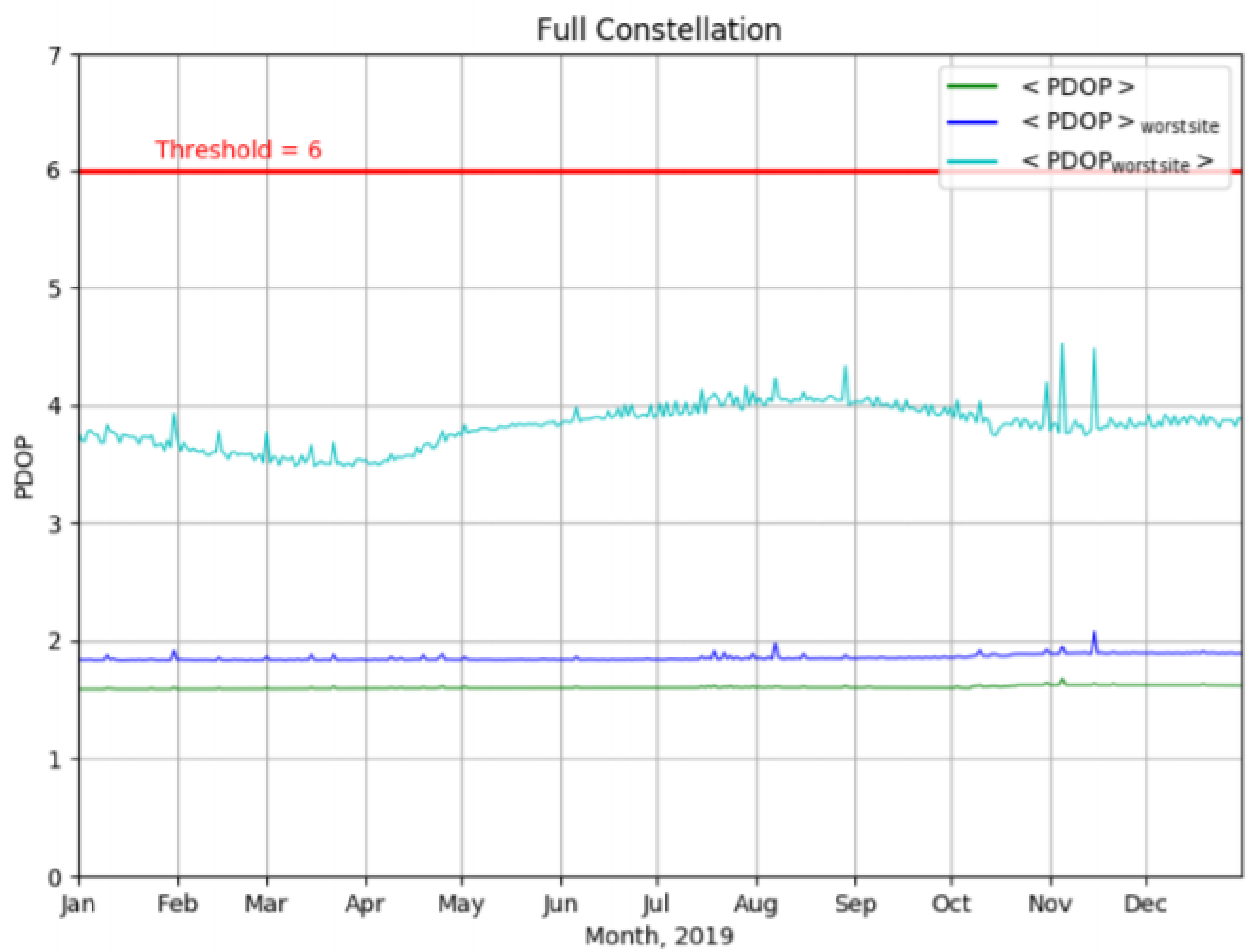
DOP的分類

- **P**DOP = **Position** Dilution Of Precision *(Most Commonly Used)*
- **V**DOP = **Vertical** Dilution Of Precision
- **H**DOP = **Horizontal** Dilution Of Precision
- **T**DOP = **Time** Dilution Of Precision
- **G**DOP = **Geometric** Dilution Of Precision

QUALITY	DOP
Very Good	*1-3*
Good	*4-5*
Fair	*6*
Suspect	*>6*

Mission Planning Is Critical to Obtain Good DOP

DOP值監測



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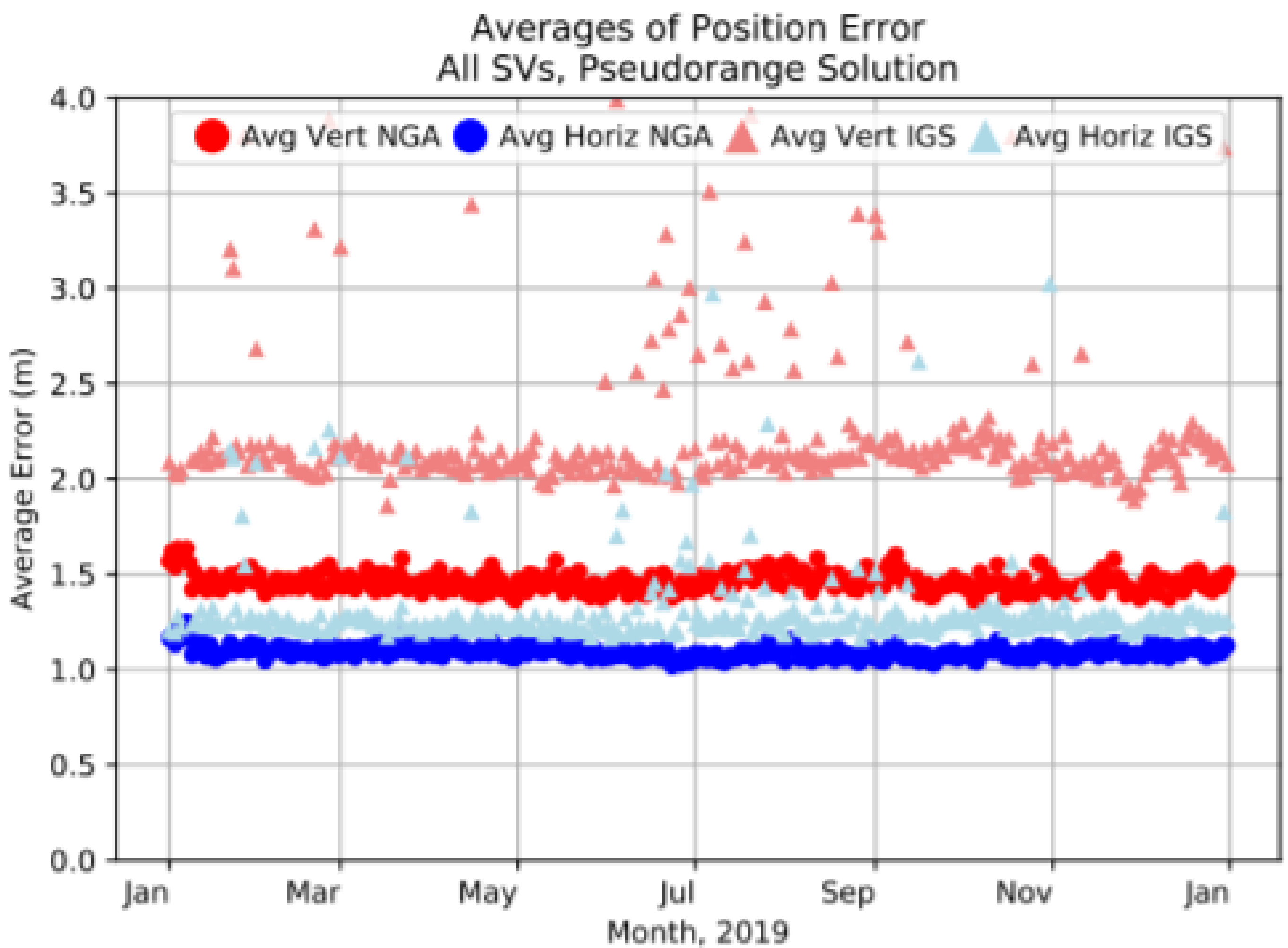
導航定位精度監測



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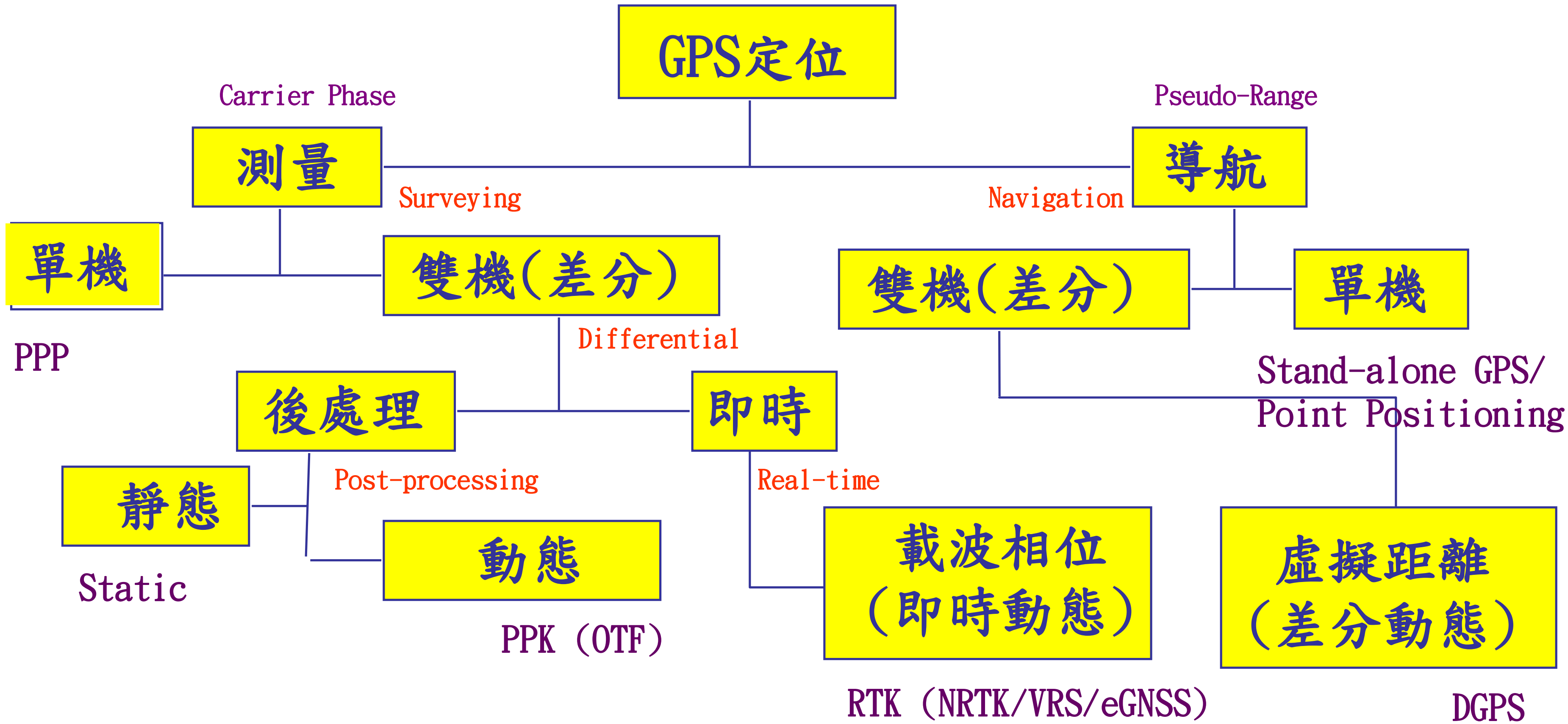
GPS定位方法分類



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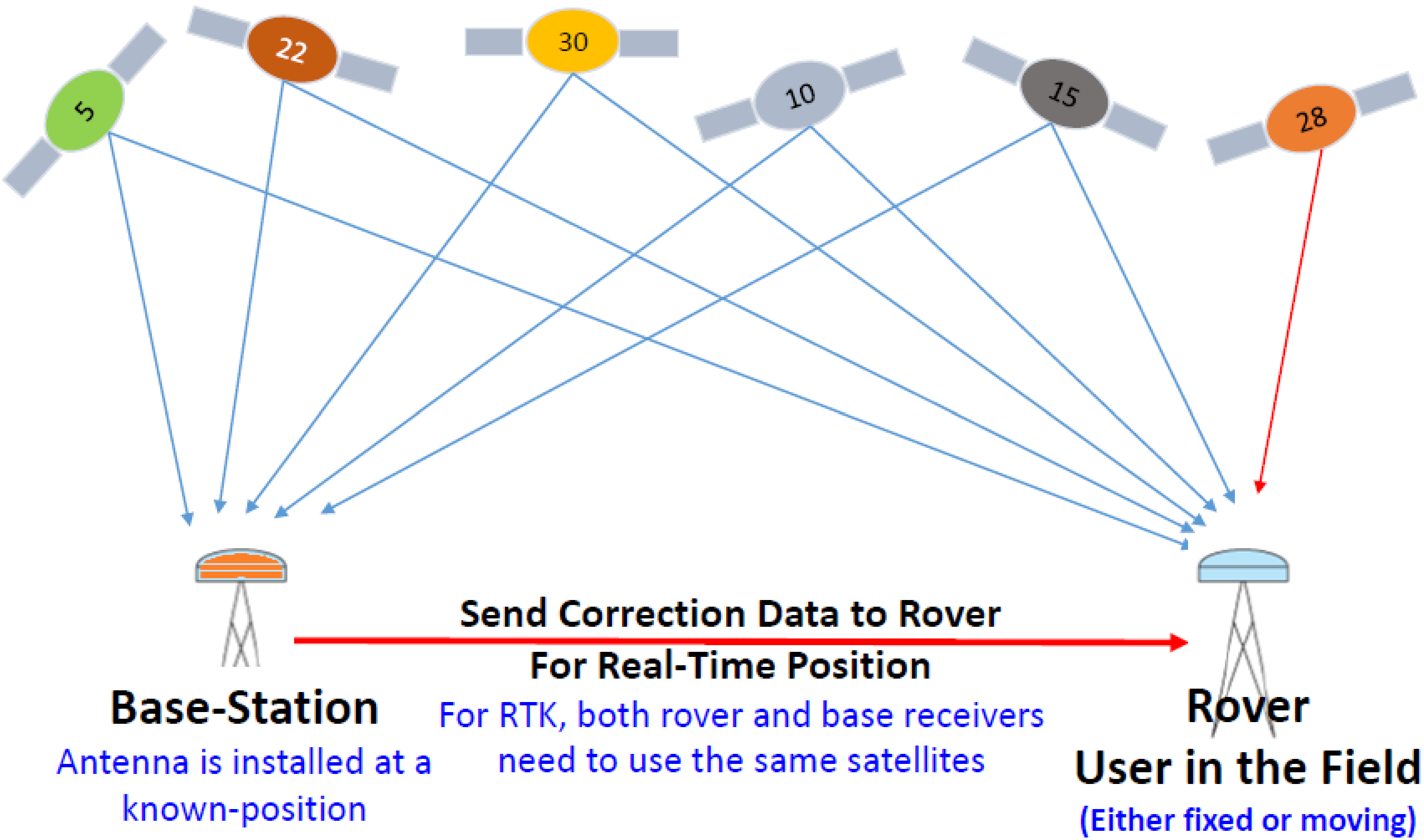
差分定位


5
22
30
10
15
28
Send Correction Data to Rover
For Real-Time Position
Base-Station
Antenna is installed at a known-position
For RTK, both rover and base receivers need to use the same satellites
Rover
User in the Field
(Either fixed or moving)

GPS定位特性分析

項目	觀測量		觀測型態		機款		資料		時間		星曆		精度等級	用途
技術種類	虛擬距離	載波相位	單機	雙（多）機	單頻	雙頻	單（少）筆	多筆	即時	後處理	廣播	精密		
PP	✓		✓		✓		✓		✓		✓		3～5m	導航
DGPS	✓			✓	✓		✓		✓		✓		1m	調查
PPP		✓	✓			✓		✓		✓		✓	10～20cm	航測
NRTK		✓		✓		✓	✓		✓		✓		3～6cm	地籍
PPK		✓		✓		✓	✓			✓		✓	2～5cm	船測
Static		✓		✓		✓		✓		✓		✓	1～3cm	控制

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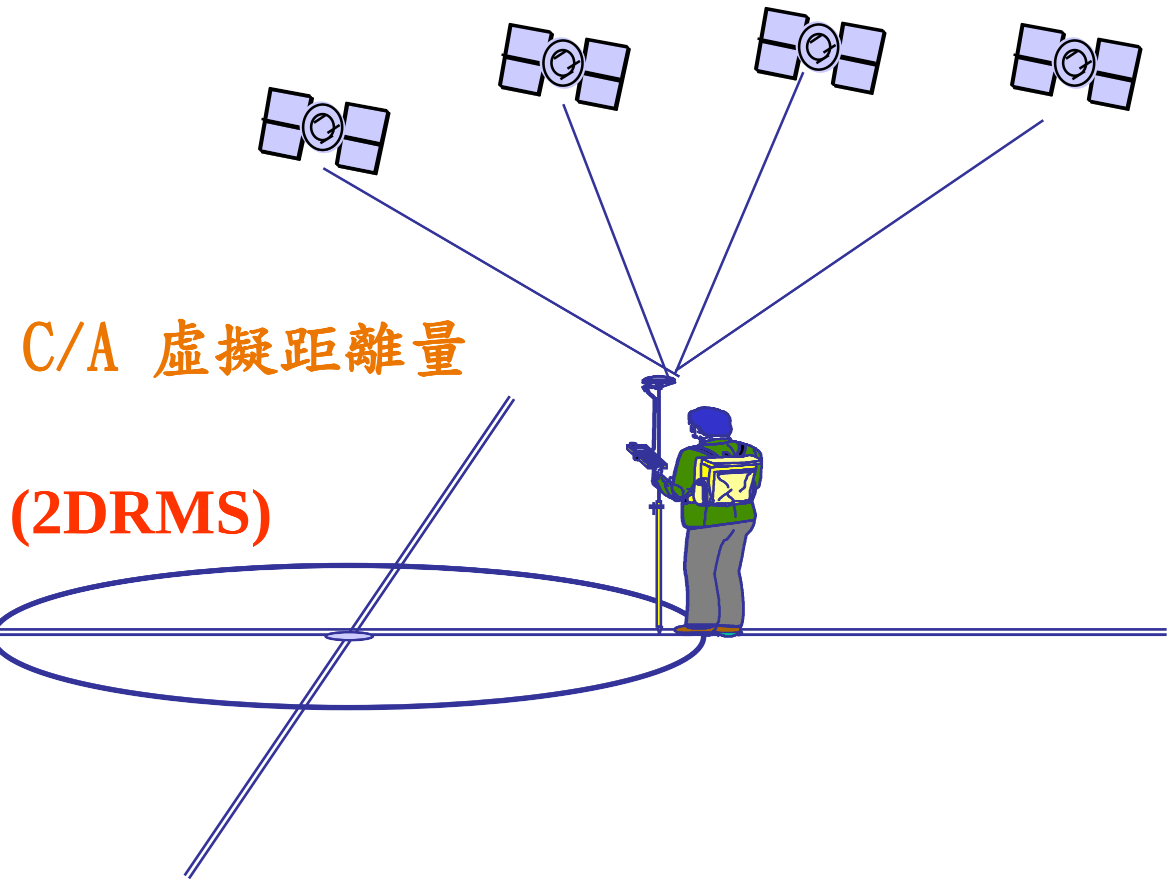
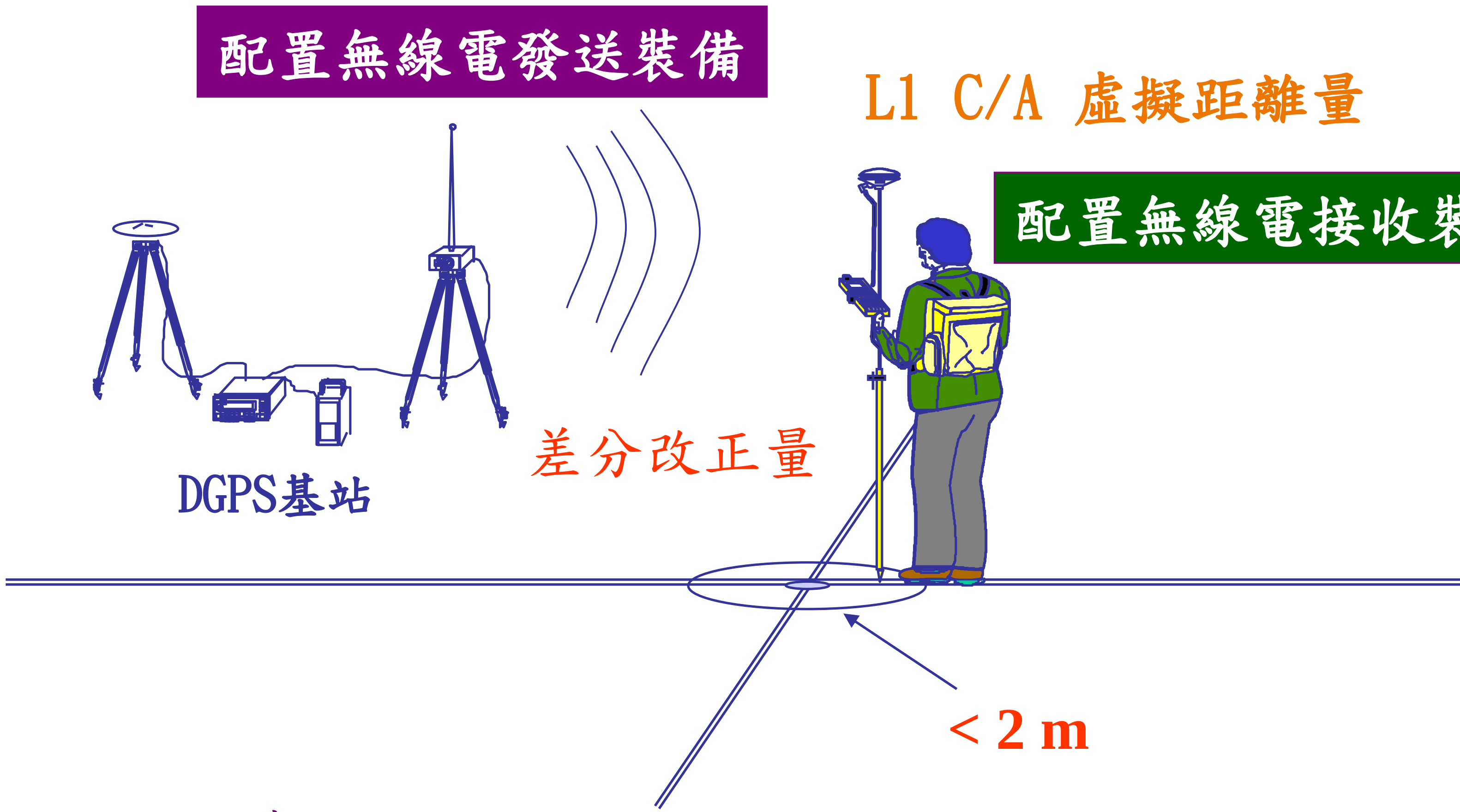
單點定位



用途： 導航

DGPS差分定位



用途： 調查

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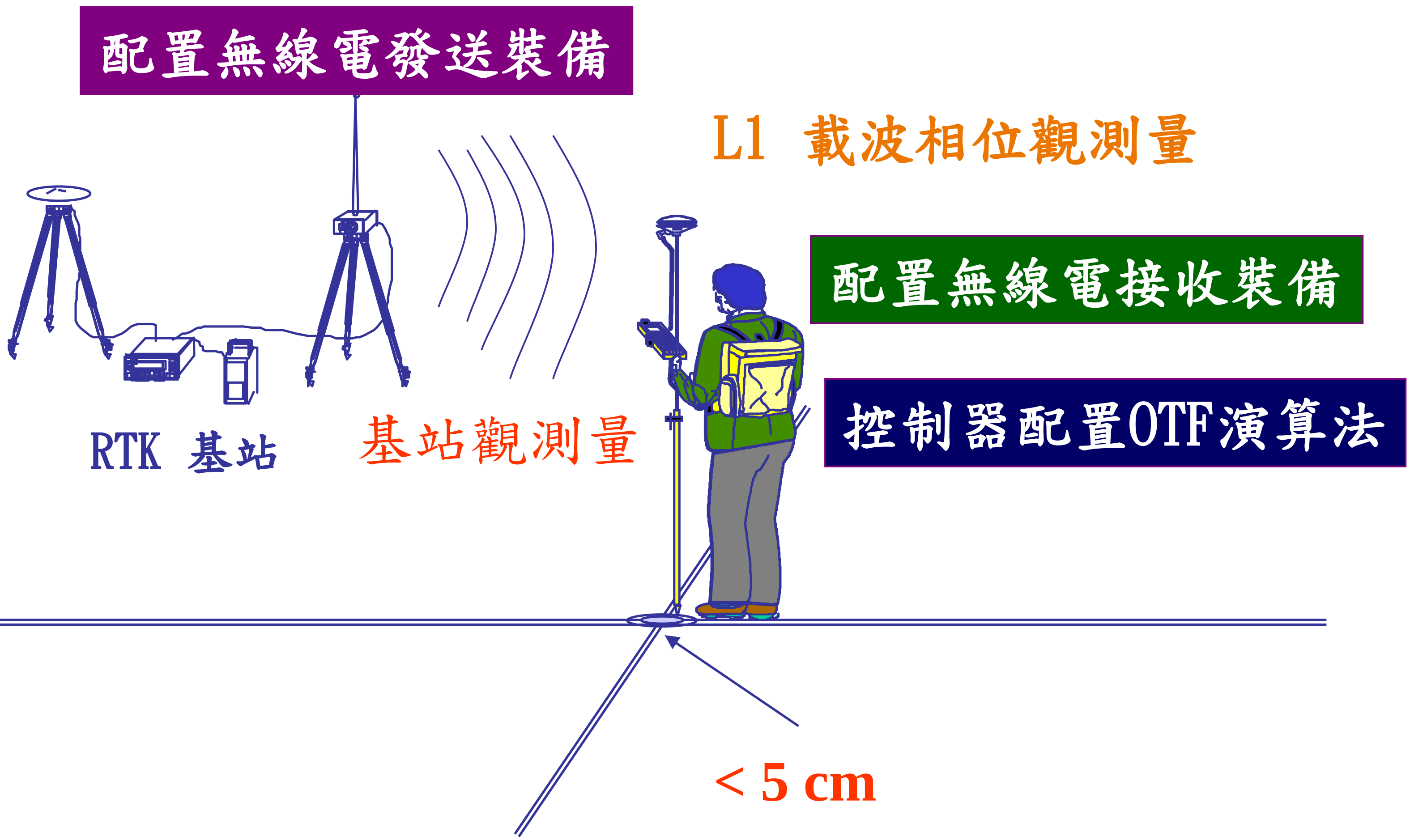
RTK即時動態定位



用途：放樣/導線/戶地/複丈

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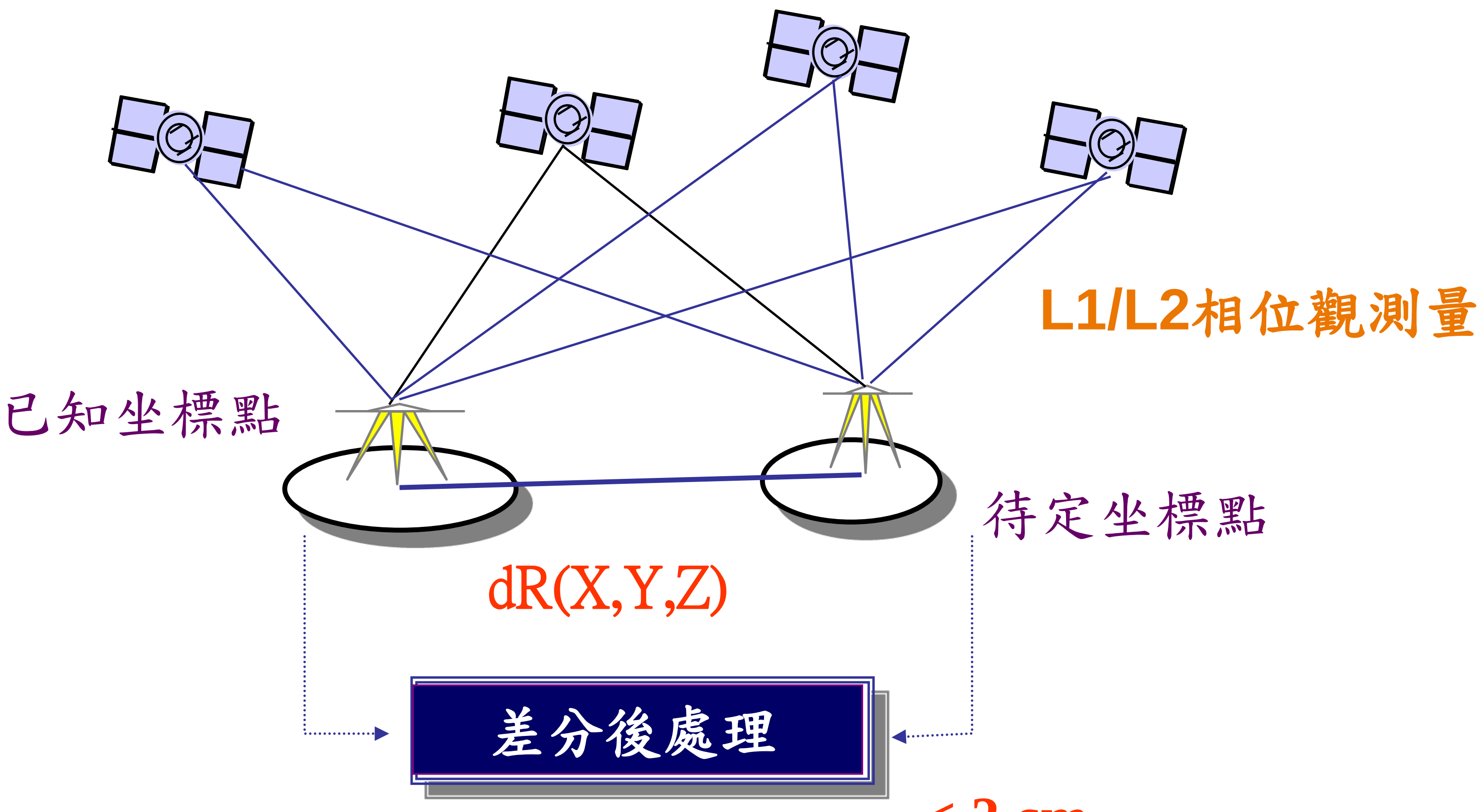
靜態相對定位



用途：控制/監測

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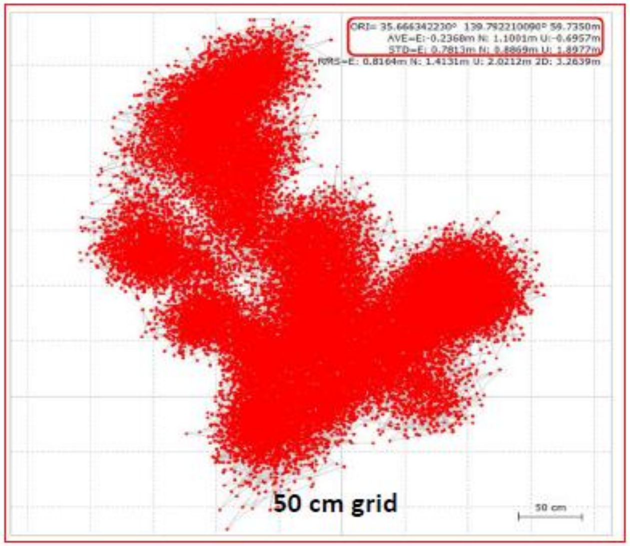
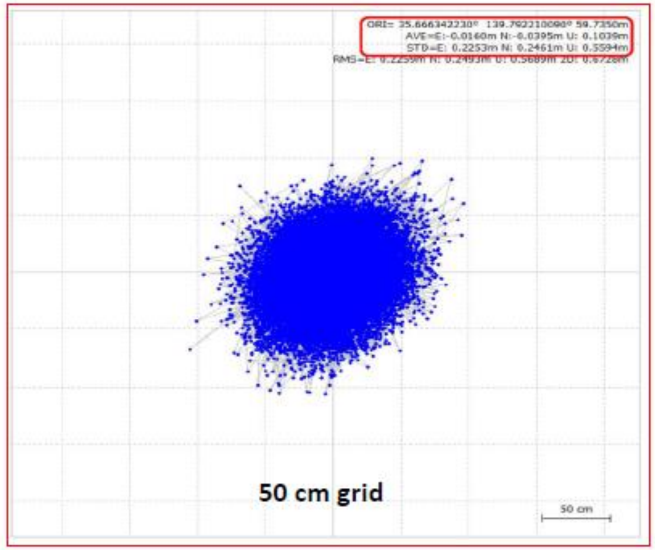
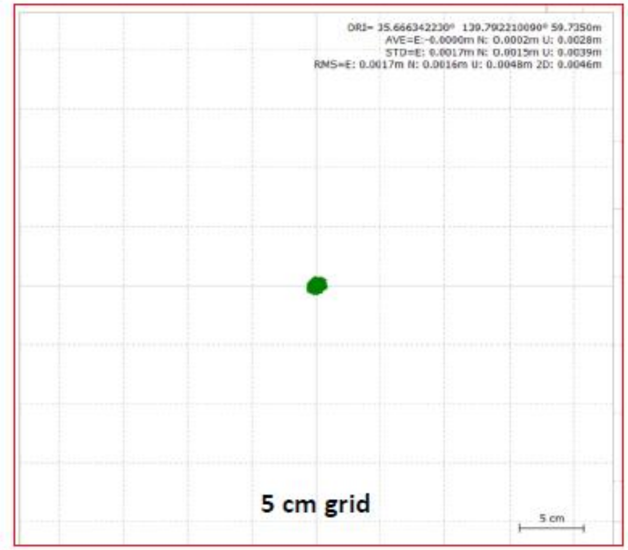
GPS定位成果差異



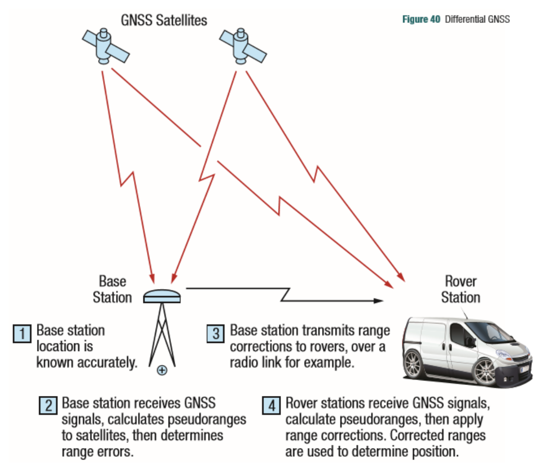
SPP (Single Point Position)

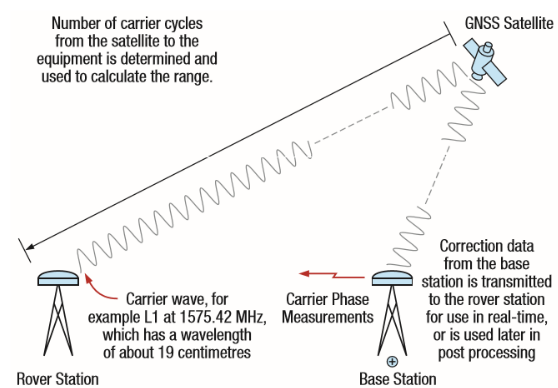


DGPS (Differential GPS)

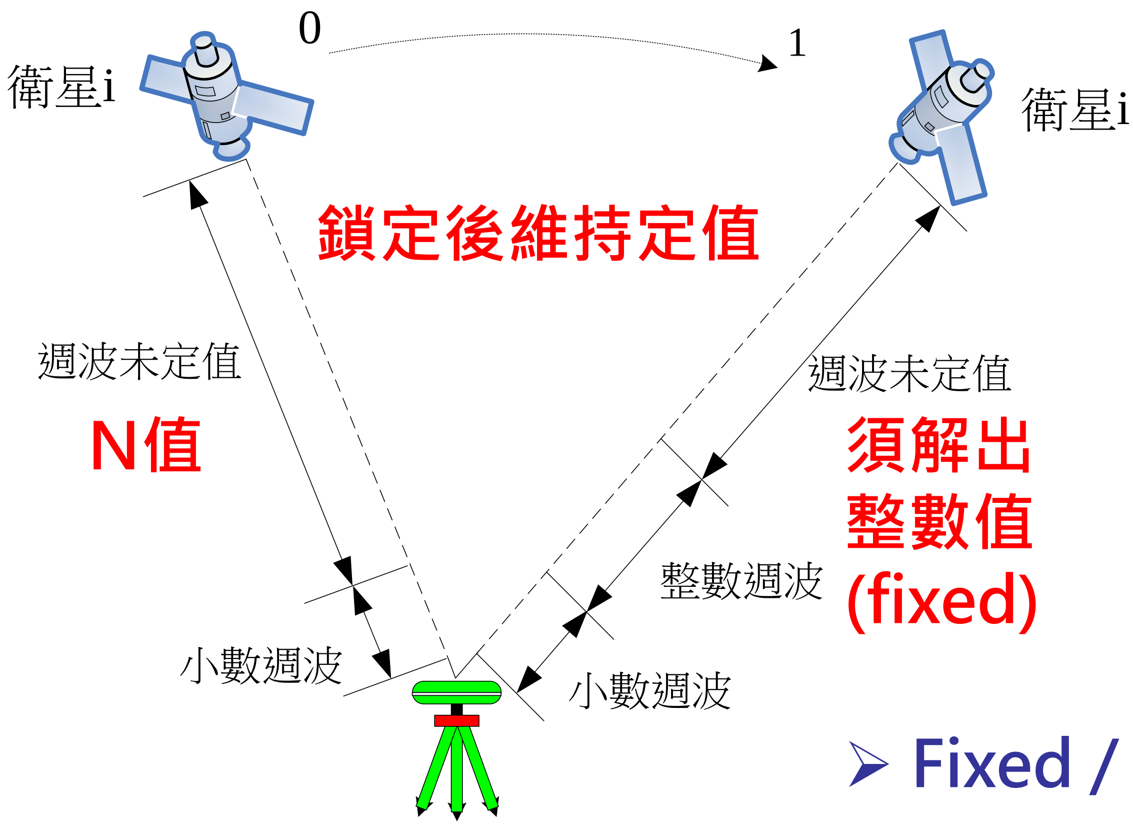


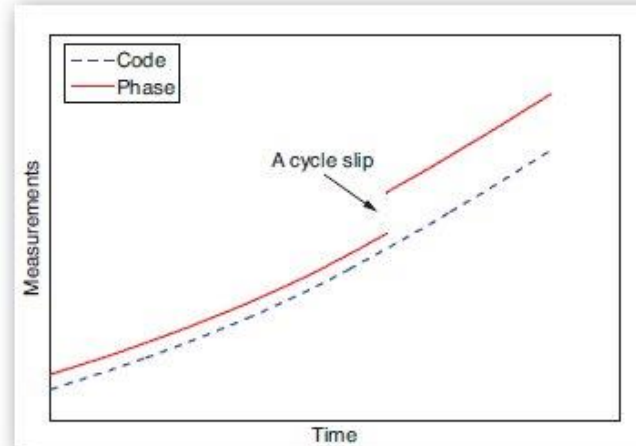
RTK (Real Time Kinematic)





固定解(fixed)與浮動解(float)





失鎖後要重解N值

- Fixed / Float 解之差異性顯著

分量	N (cm)	E (cm)	h (cm)
抽測25筆平均差異 (2km基線/有遮蔽)	38	31	34

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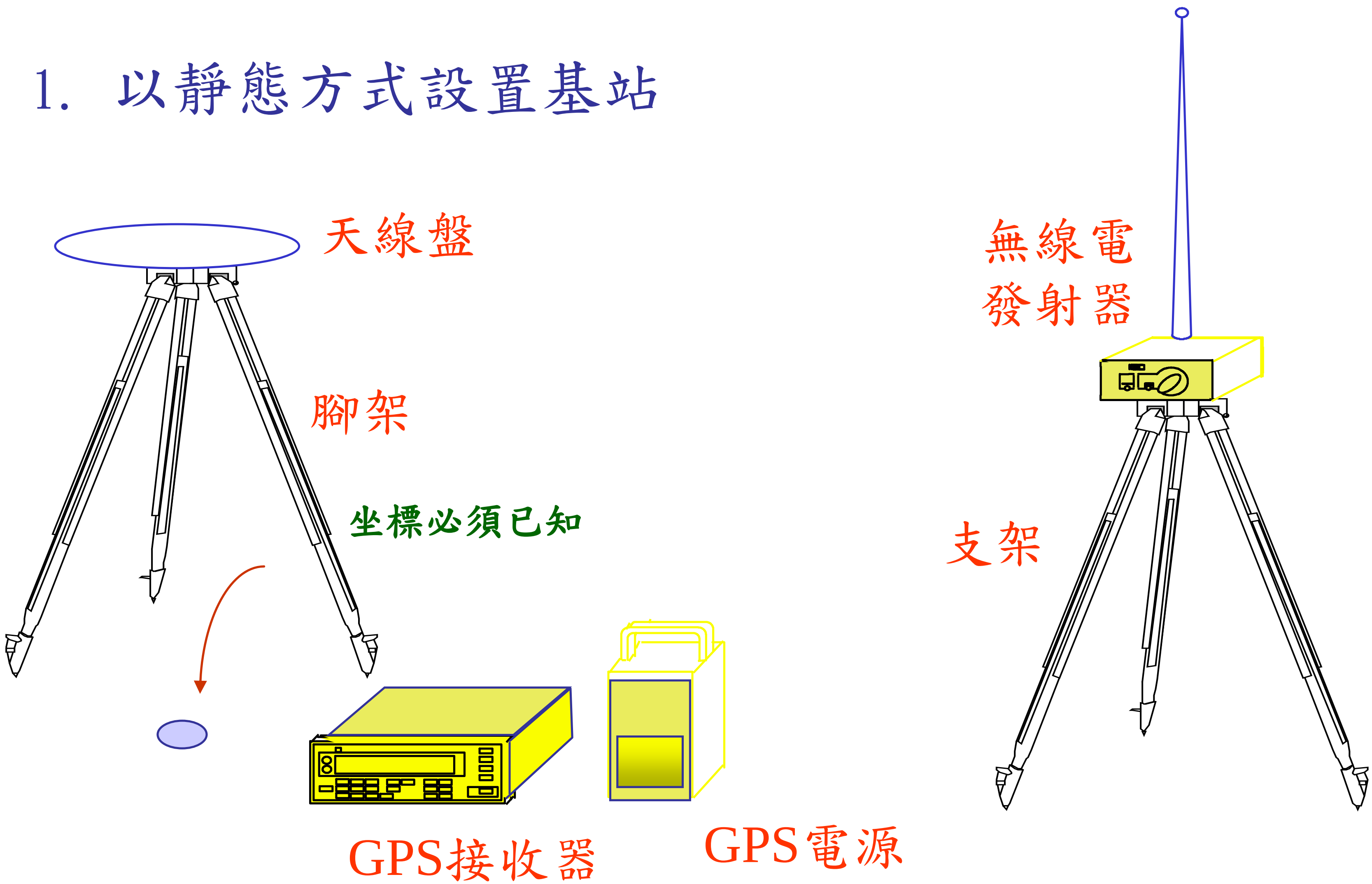
RTK作業程序(1)

1. 以靜態方式設置基站



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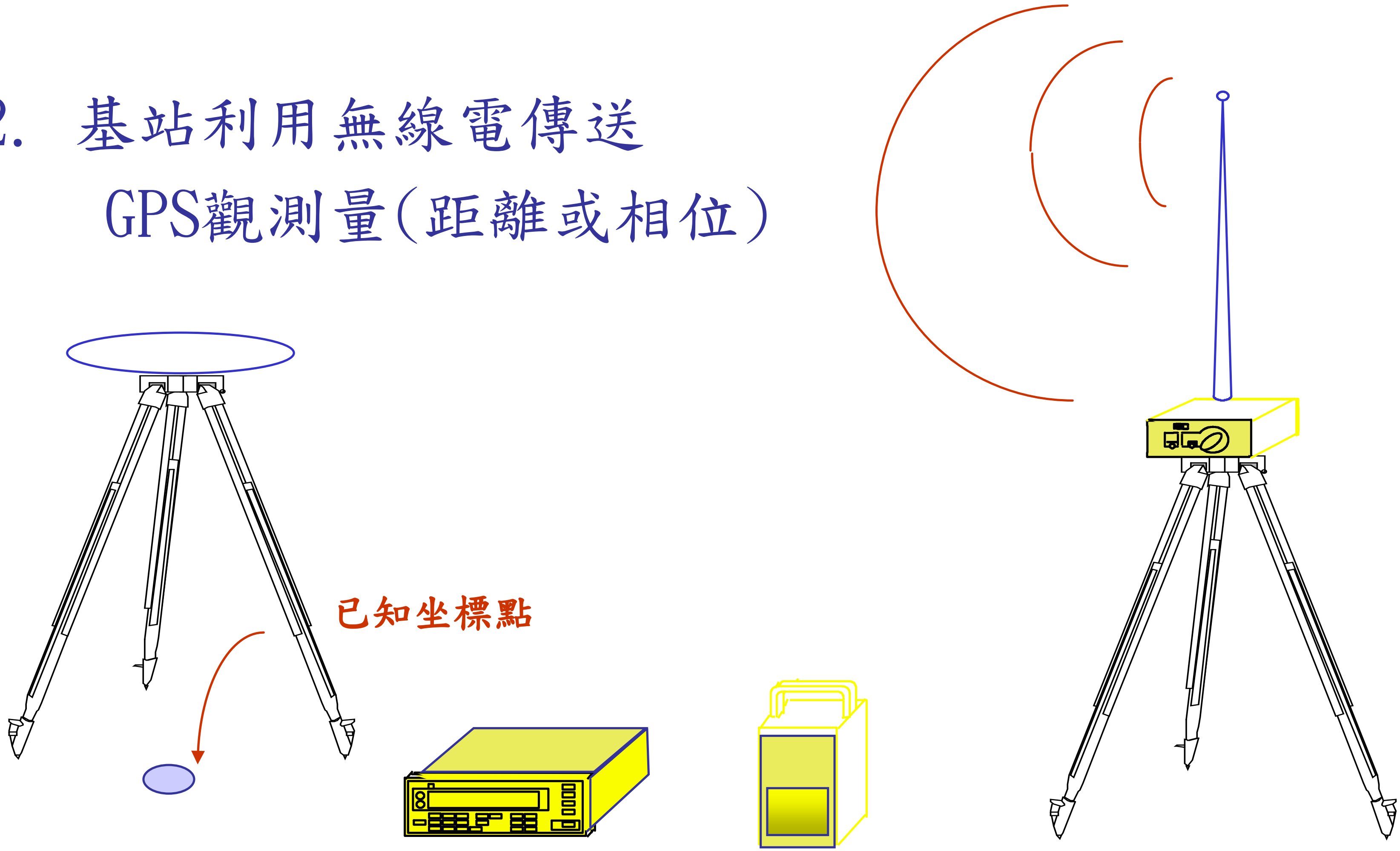
RTK作業程序(2)

2. 基站利用無線電傳送
   GPS觀測量(距離或相位)



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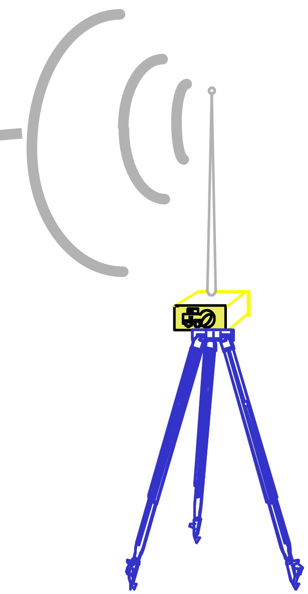
RTK作業程序(3)

3. 待測點(移動站)整合本身及基站資料求解相位未定值(公分級精度之需求)

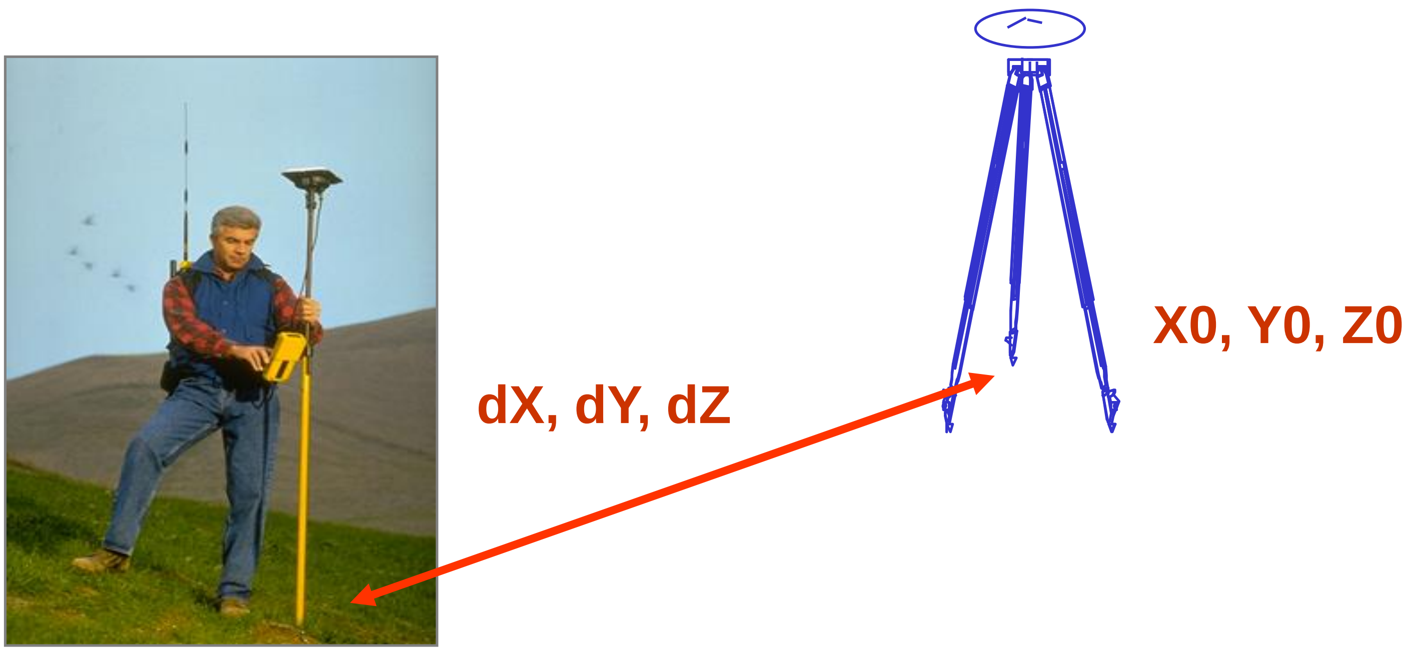
基站之GPS觀測量



GPS接收器
天線盤
支桿
控制器(內建OTF軟體)
無線電接收器

RTK作業程序(4)

4. 建立基站與移動站之間已完成共同誤差量修正之基線坐標分量值



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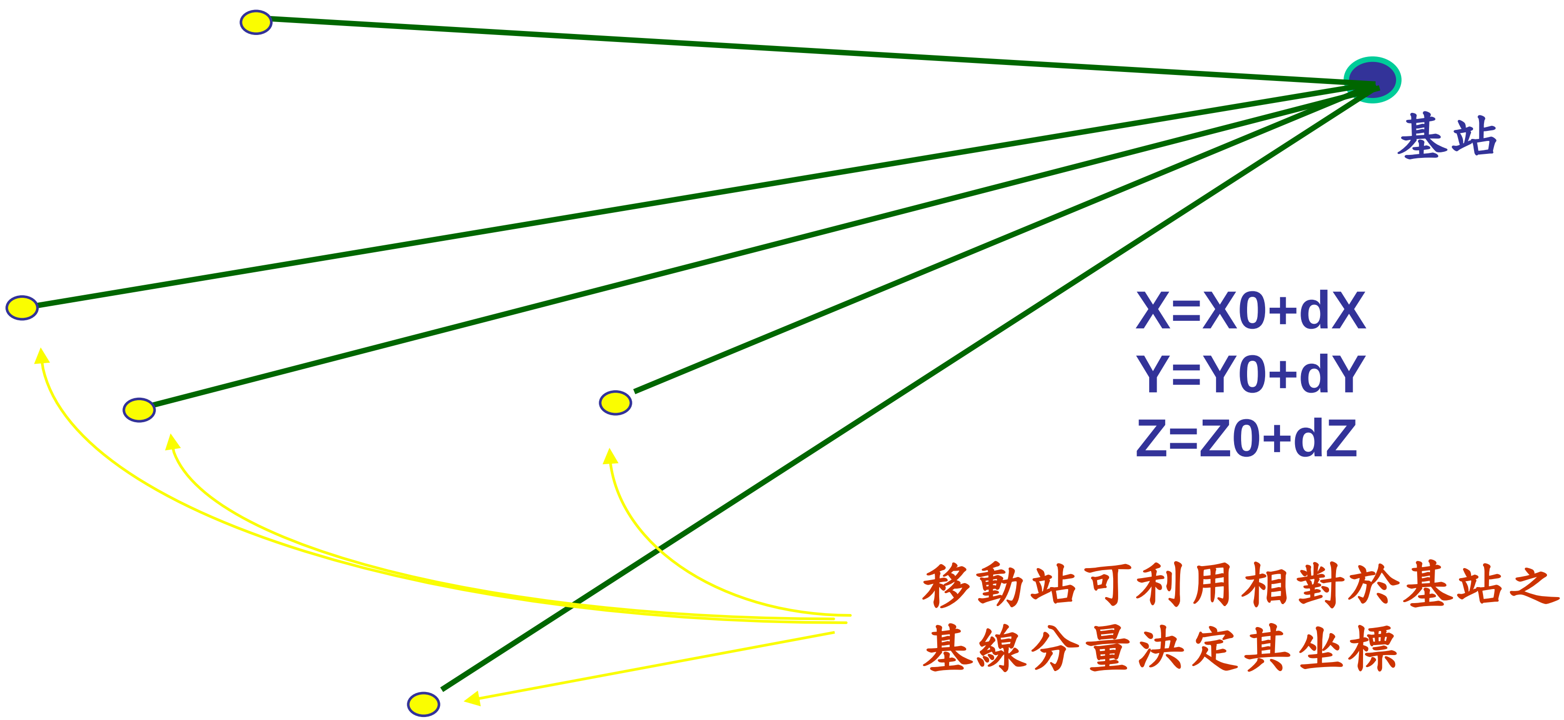
RTK作業程序(5)

5. 決定移動站相對於基站之精確位置



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RTK作業程序(6)

6. 坐標即時顯示
   或資料記錄後處理

網形RTK(NRTK/VRS)

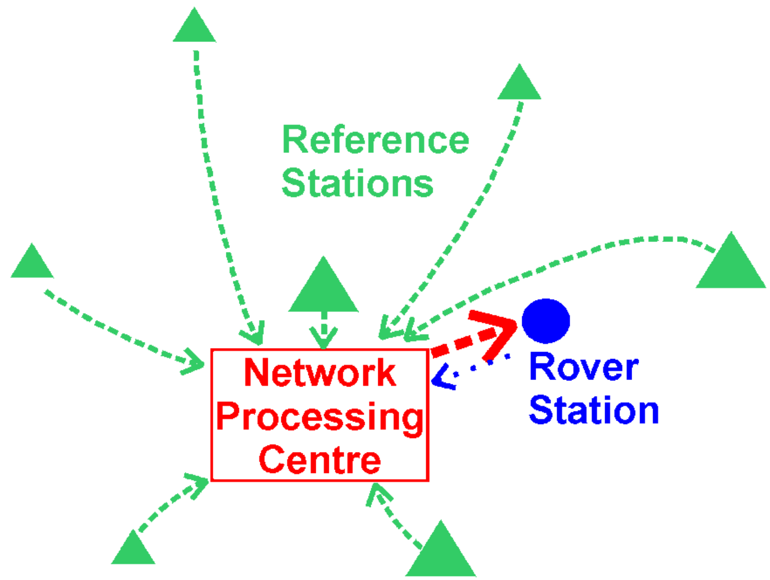
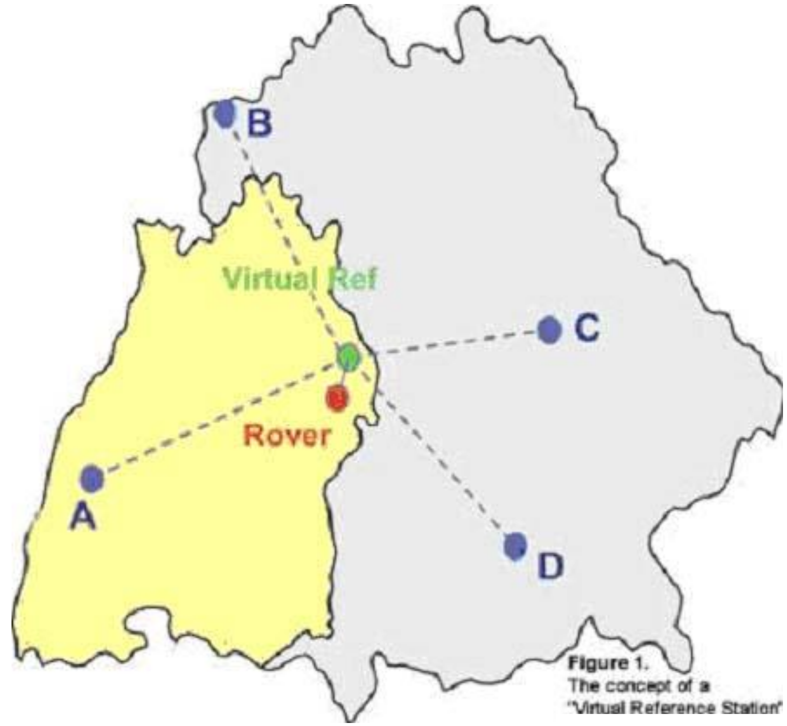


Fig. 2: Network Processing Centre and Data Flow



NRTK: Network Real Time Kinematic

VRS: Virtual Reference Station

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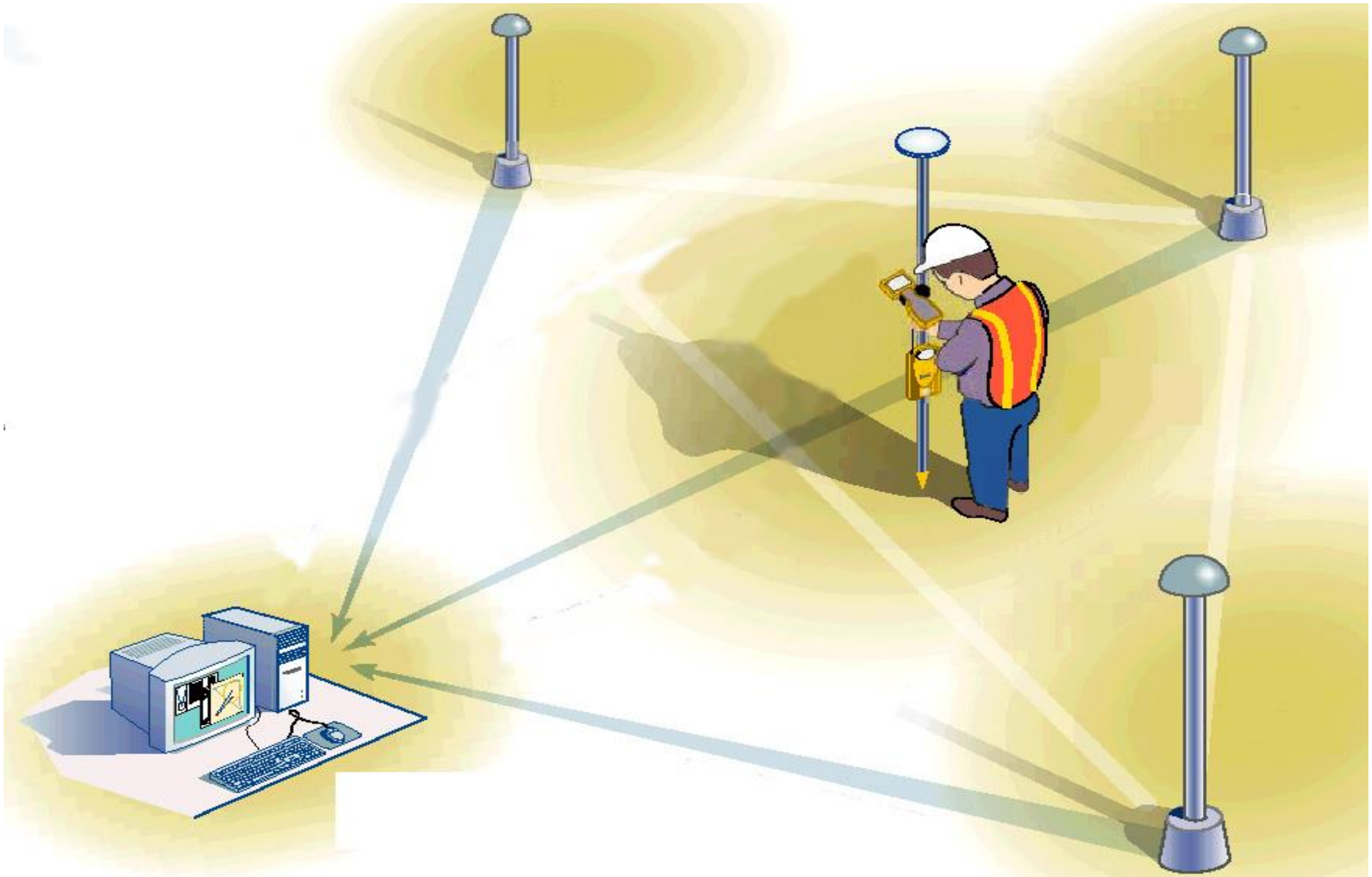
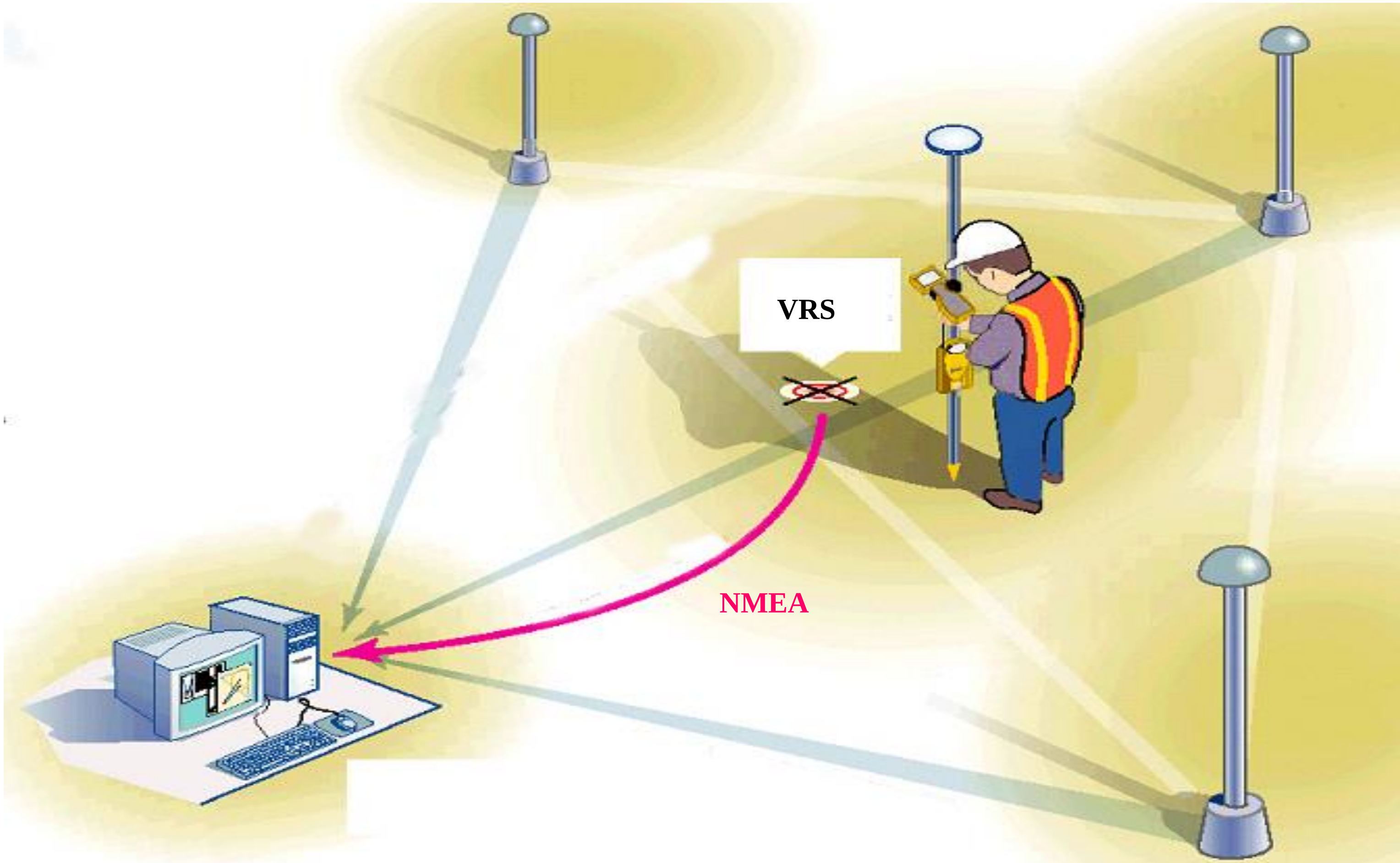
VRS運作程序(I)



基準網架構

VRS運作程序(II)



移動站傳送 NMEA格式之位置訊息至VRS網路伺服器

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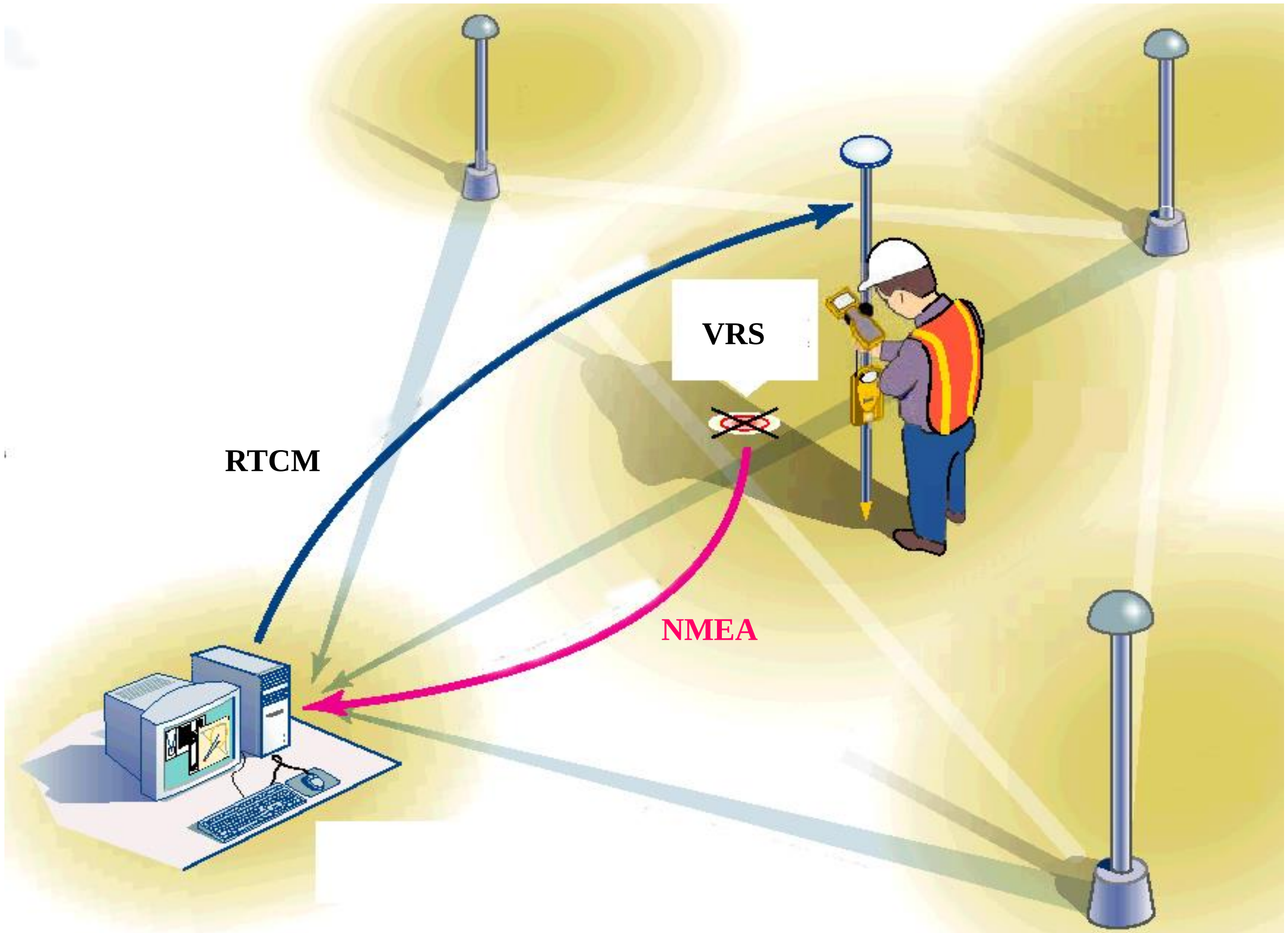
VRS運作程序(III)



網路伺服器傳送RTCM格式之改正字串(虛擬觀測量)
供VRS定位

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VRS作業分工(1)

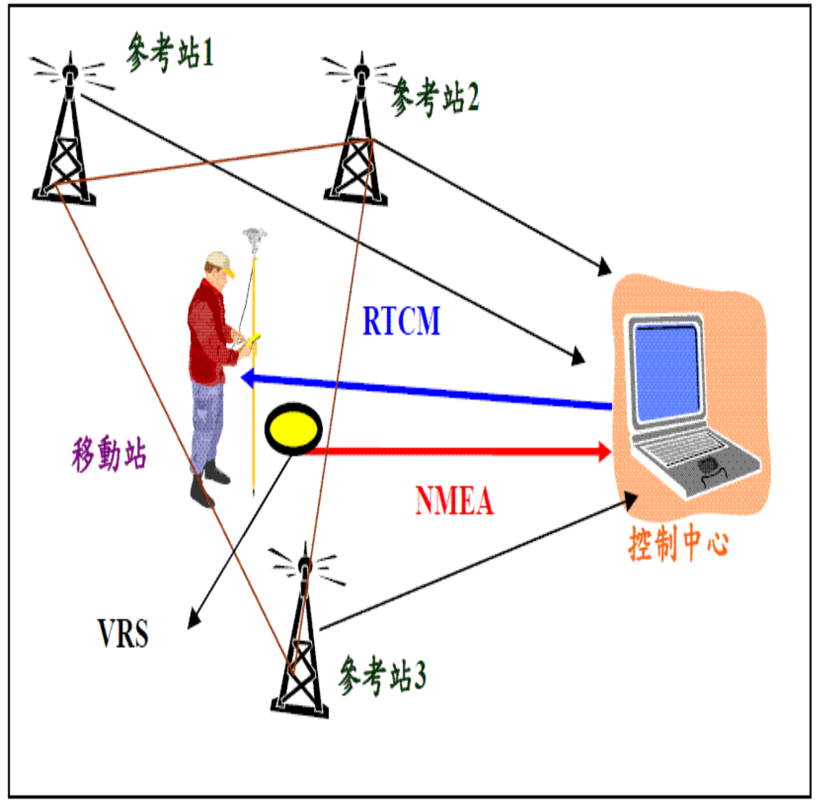
- 基準站部分：

(1)考量服務區大小，採均匀分布方式，布設適當數量之基準站

(2)觀測量可透過網路即時回傳至資料處理中心

(3)基準站透過網形觀測及平差計算建立其精密參考坐標

(4)透過長期的觀測資料建構服務區內之誤差修正資料庫



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VRS作業分工(2)

- 移動站部分：

(1)實施單點定位，將測站之近似坐標透過網路通訊方式傳送給資料處理中心

(2)資料處理中心取出測站附近至少三個基準站之即時觀測資料，並透過誤差模型資料之內插計算，建構一個虛擬參考站之觀測量

(3)處理中心將此虛擬觀測量回傳給移動站，並依此進行超短基線之即時動態定位

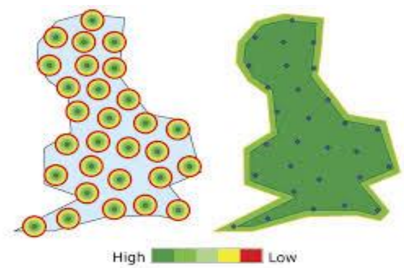
移動站儀器設備需求

- 具備RTK定位解算功能之衛星定位接收儀
- 具無線上網功能之手機或其他行動通訊設備
- 具NTRIP通訊協定通訊介面軟體

正常狀況下，30秒內可獲得2公分級精度之定位成果

NRTK的特性優勢

- 成本上：
  - –使用者無須自行架設主站，僅需負擔少額系統服務費
- 作業上：
  - –不受單基站運作範圍限制，可擴大作業範圍
  - –觀測或差分資料傳輸品質較穩定
  - –相位起始未定值收斂速度較快(TTFF所費時間較短)



- 精度上：
  - –由區域性(網形)參考站所提供之定位資訊可降低單基點的誤差影響
  - –各個基站具有專門單位維護，參考坐標精度穩定，移動站定位成果相對較優

NRTK作業特性評估

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優勢

- 單人單機即可作業
- 現場直接獲得點位坐標
- 精度符合大部分業務定位需求(2公分)
- 適合山區、交通不便、點位不易引測之地區使用

劣勢

- 須比靜態測量更佳的透空度要求
- 須有良好的無線數據傳輸環境
- 無法直接獲得角度、距離等相對觀測量
- 需轉換至法定坐標系統
- 使用須付費

內政部e-GNSS系統基準站分布圖

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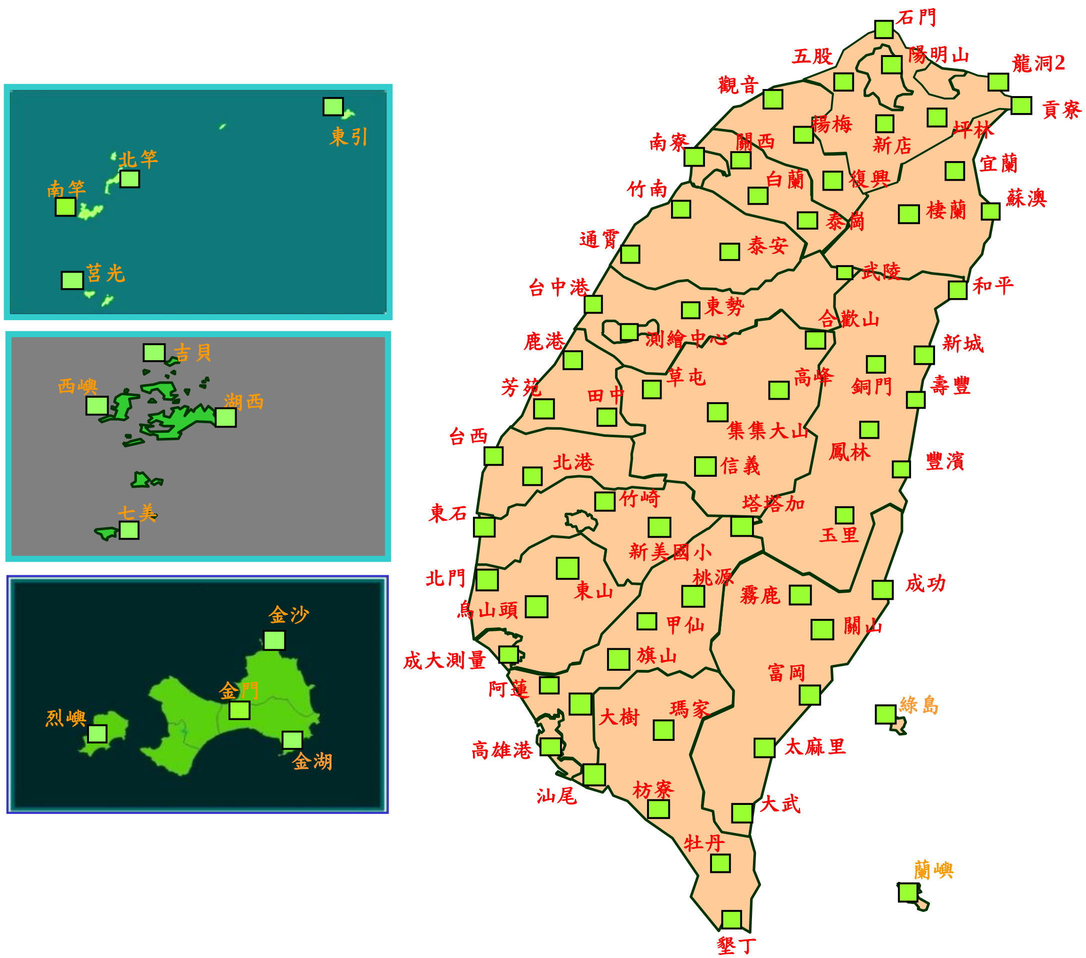


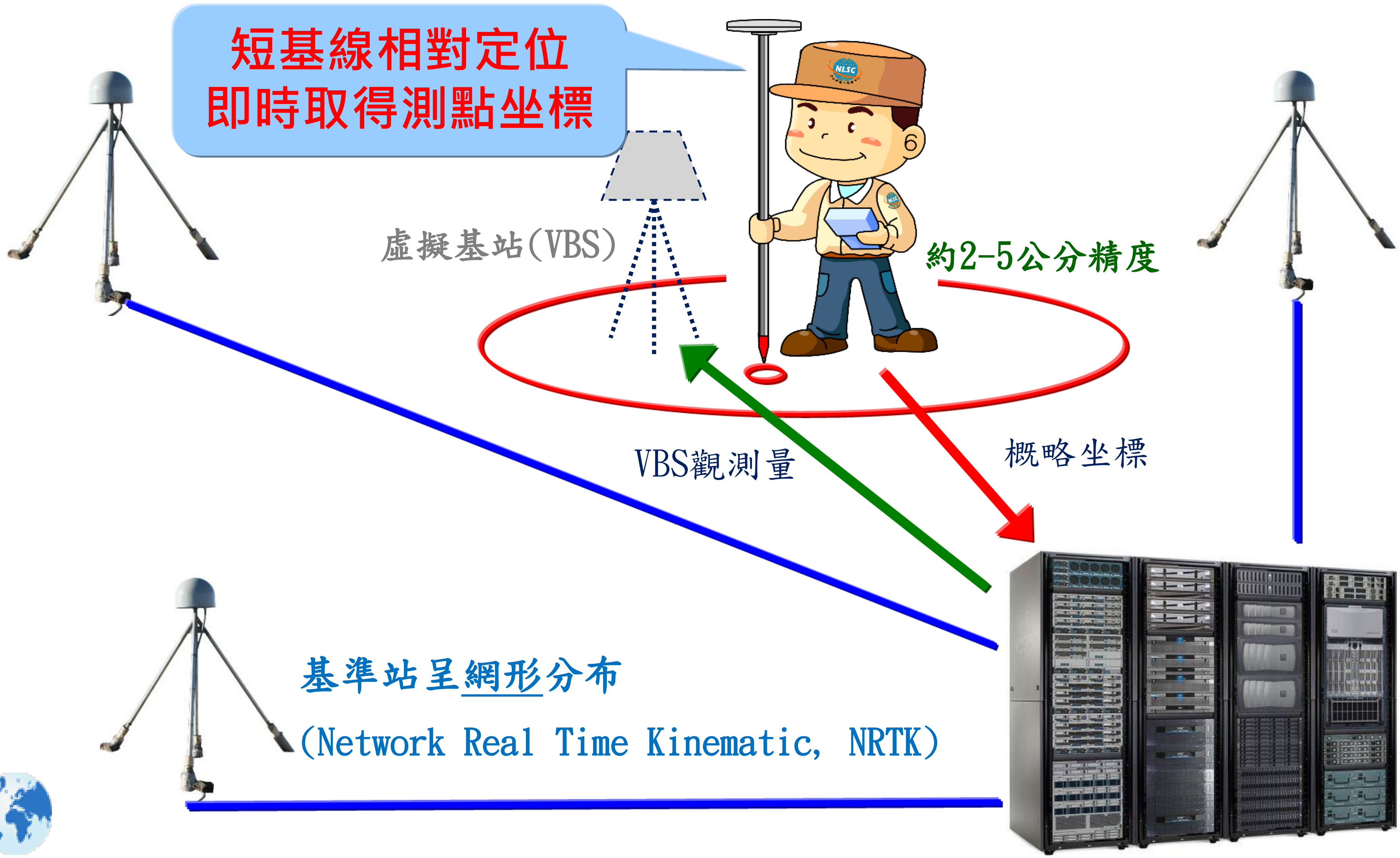
埔里(虎仔山)衛星追蹤站

e-GNSS基準站配備

❖ 主站78站/備用站72站

❖ 確保基準站間距離維持30~50公里

e-GNSS 運作程序



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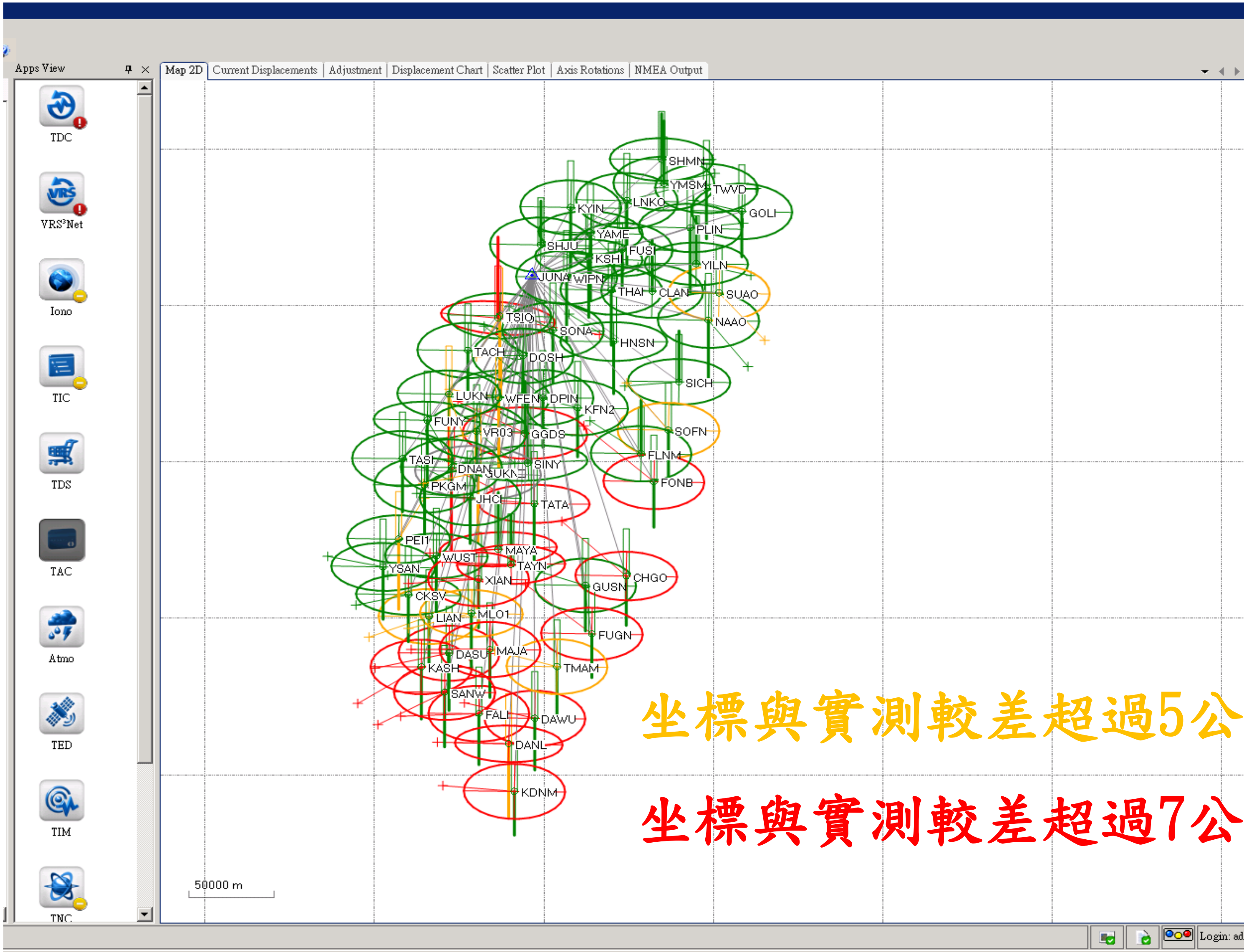
基準站坐標位移監控



坐標與實測較差超過5公分的站

坐標與實測較差超過7公分的站

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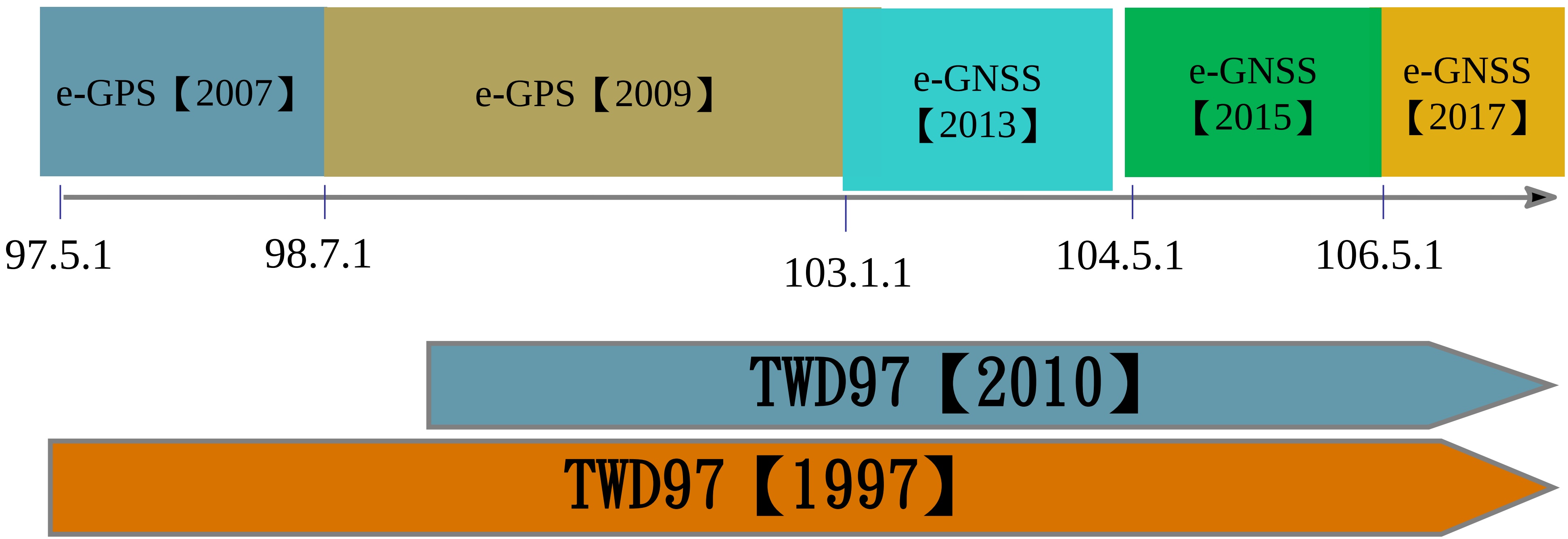
e-GNSS坐標系統變動歷程

❖ 臺灣地區



金門、澎湖及馬祖地區始終維持TWD97【1997】

- 有坐標轉換的需求
- 7(大地)/4(地籍)/3(工程)參數模型各有適用時機

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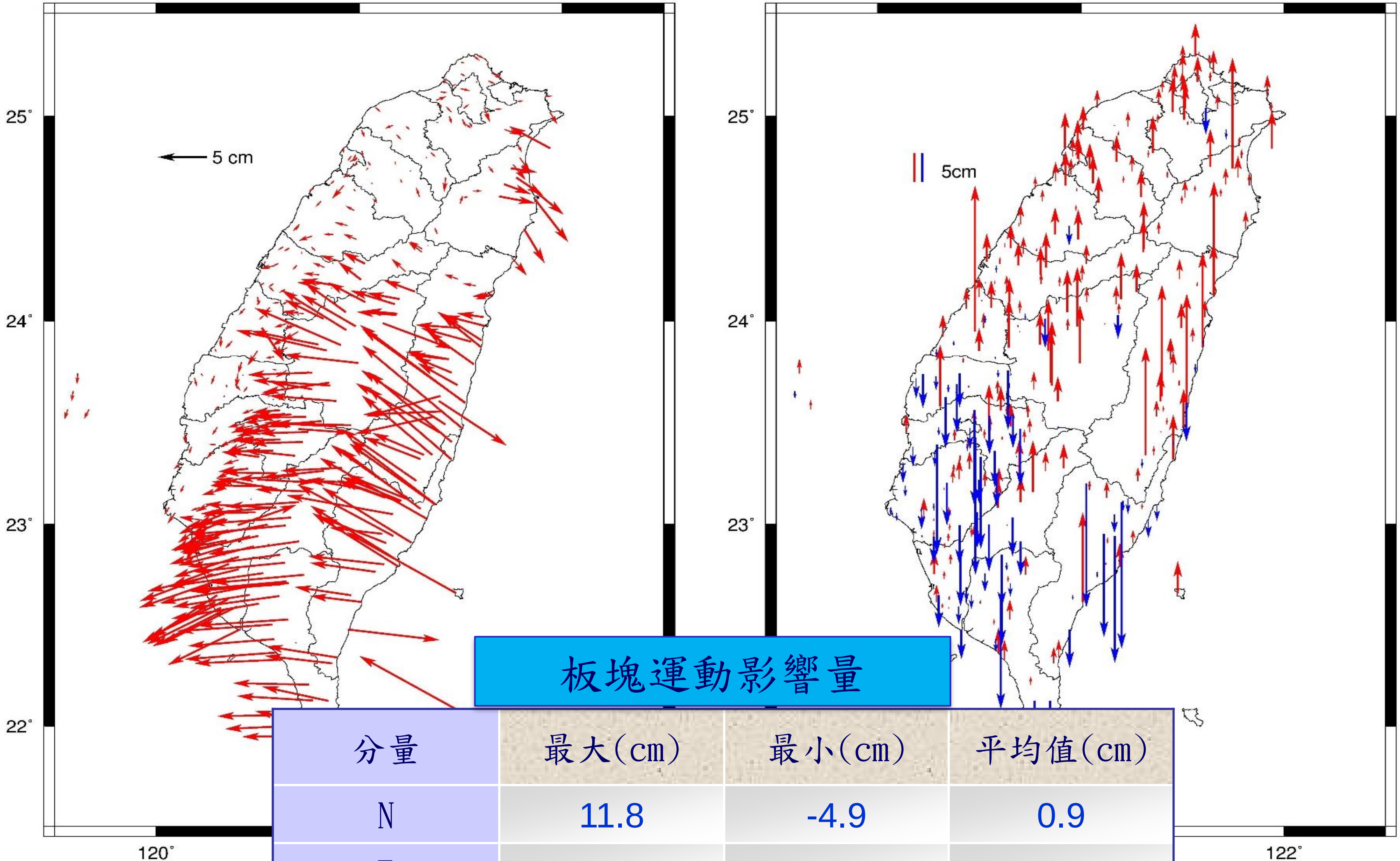
eGNSS[2017]與eGNSS[2013]之坐標差異



板塊運動影響量

分量	最大(cm)	最小(cm)	平均值(cm)
N	11.8	-4.9	0.9
E	4.9	-13.4	-3.5
h	23.2	-23.3	0.6

三維坐標轉換服務

TWD67（N,E）

TWD97【1997】（N,E）

TWD97【2010】（N,E）

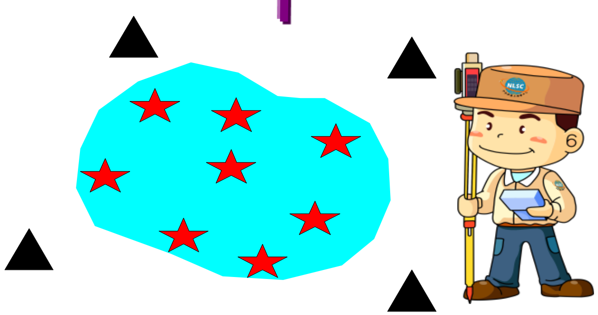
TWVD2001【2010】（H）

利用已知控制點
為共同轉換點

坐標轉換+
最小二乘配置

◆適用於小區域

◆須自行聯測控制點



三維即時
坐標轉換服務

7參數轉換+坐標
殘差網格修正

◆線上即時得到坐標

◆不需自行聯測控制點

◆非所有廠牌型號儀器皆能支援

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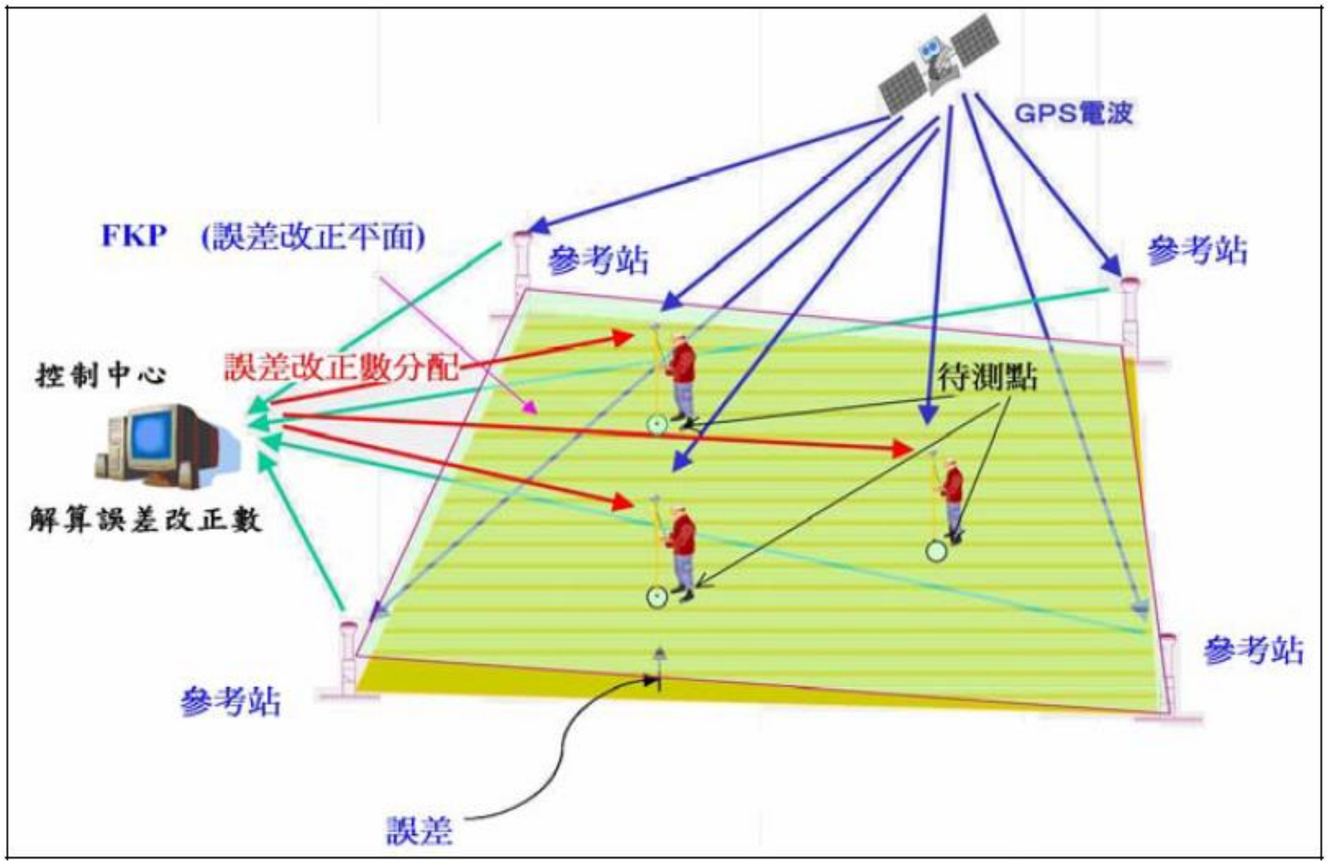
國內另一項NRTK技術(FKP)



FKP: Flächen Korrektur Parameter

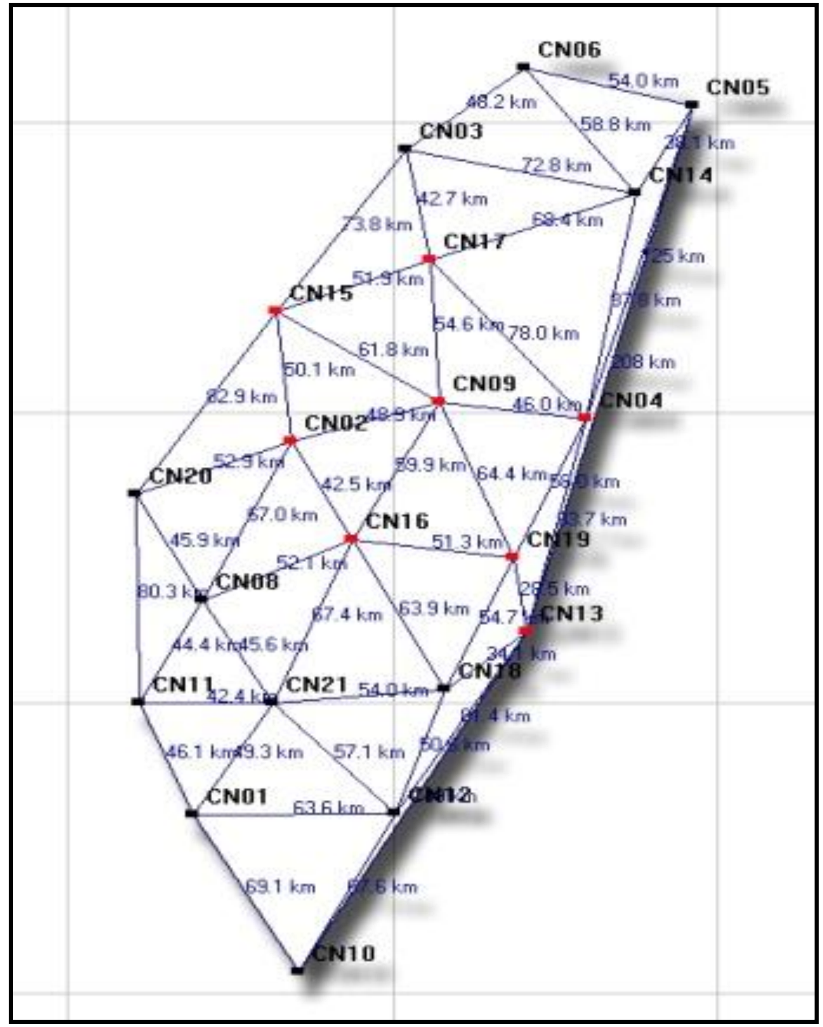
(Area Correction Parameter)

FKP作業方式

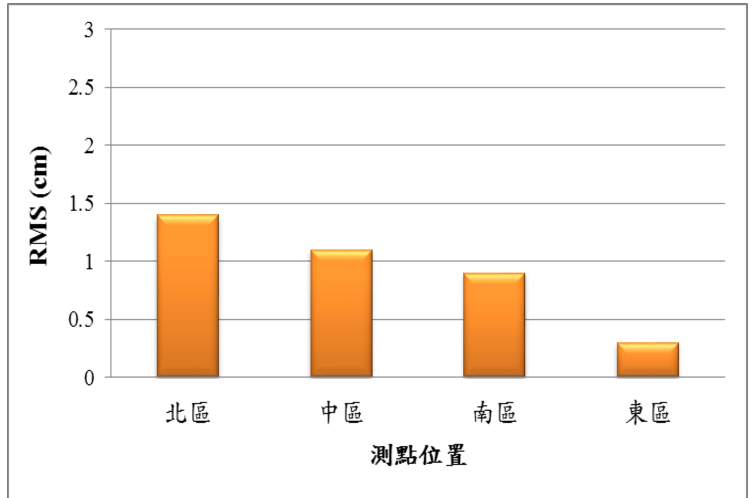
- 德國Geo++公司之GNSMART（GNSS State Monitoring And Representation Technique）軟體提供服務
- 該技術是在整個網形內生成一組FKP區域改正參數，並透過RTCM格式傳輸給移動站進行定位求解
- FKP定位之控制中心是運用多基準站資料建構移動站該地的區域性誤差改正參數，並傳送給移動站的使用者修正其觀測量，並於接收器內進行定位解算
- 移動站在接收到改正參數資料後，會先將概略坐標輸入，以計算出該處之離散與非離散誤差，然後算出L1、L2觀測量之誤差改正，最後再與主參考站組成二次差分進行RTK定位

民用Civil-Net系統

- 森泰公司Civil-Net於2006年開始設置
- 可提供三種GNSS定位技術(DGPS、FKP及VRS)，但主要仍以FKP技術為基礎
- 全台設置有21處基準站
- 該系統未採分區方式組成，服務範圍涵蓋全台，採常態性運作，可24小時提供訊號服務
- 即將提供全星系服務

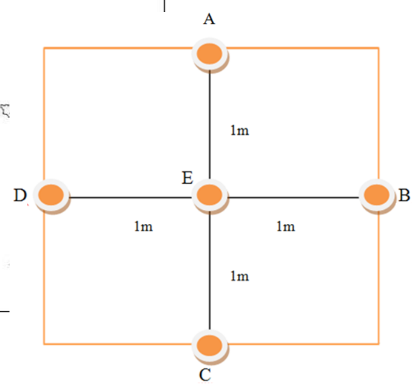


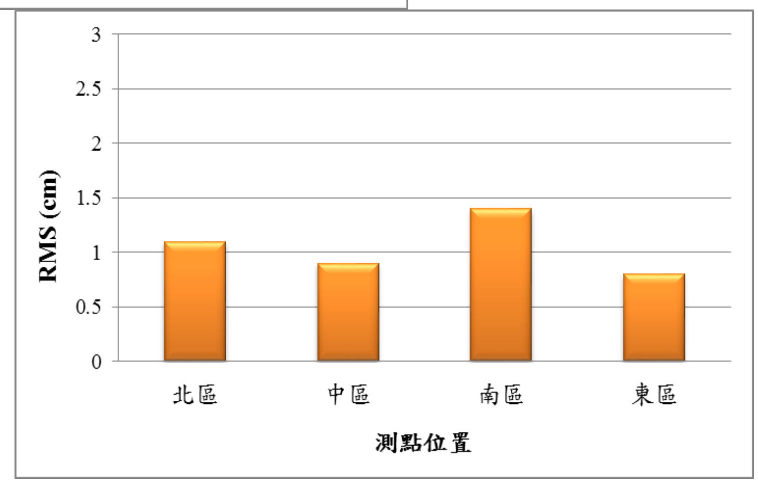
Civil-Net定位精度測試



上午時段

下午時段

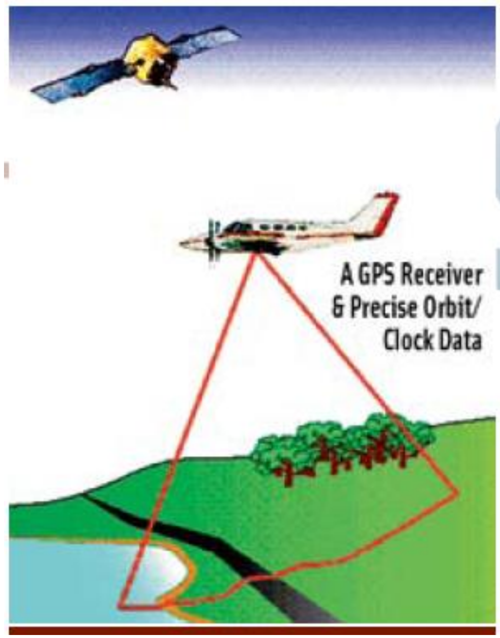


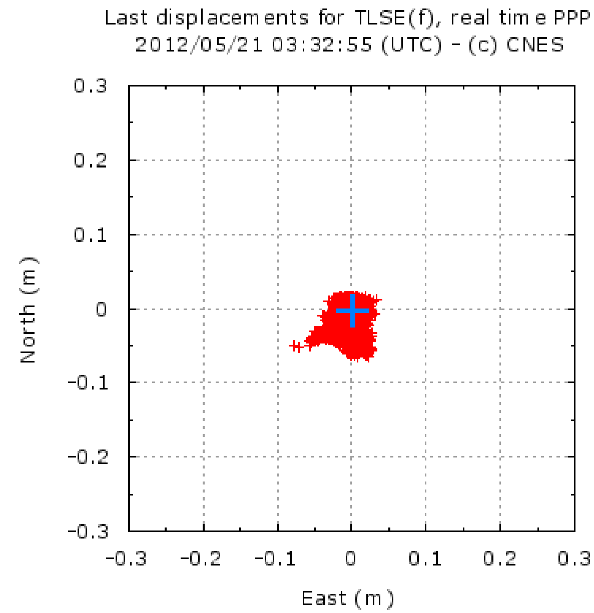


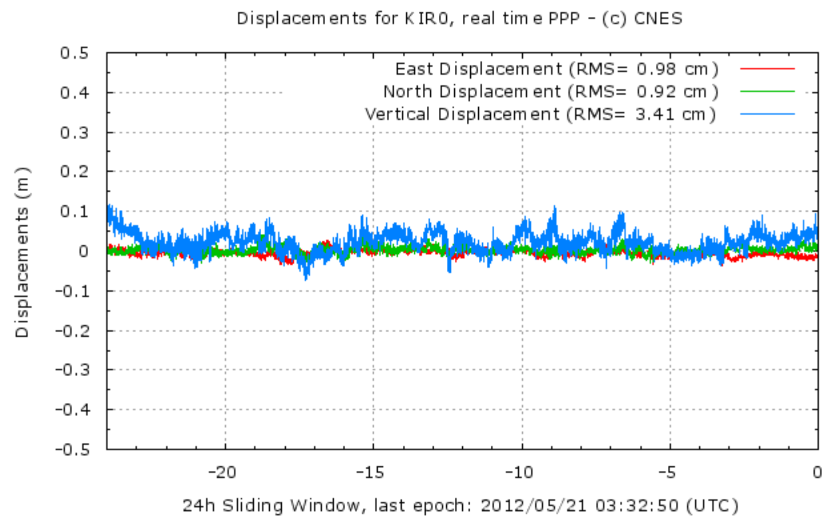
小型基線

➢ 可優於2 cm

精密單點定位(PPP)







PPP: Precise
Point
Positioning

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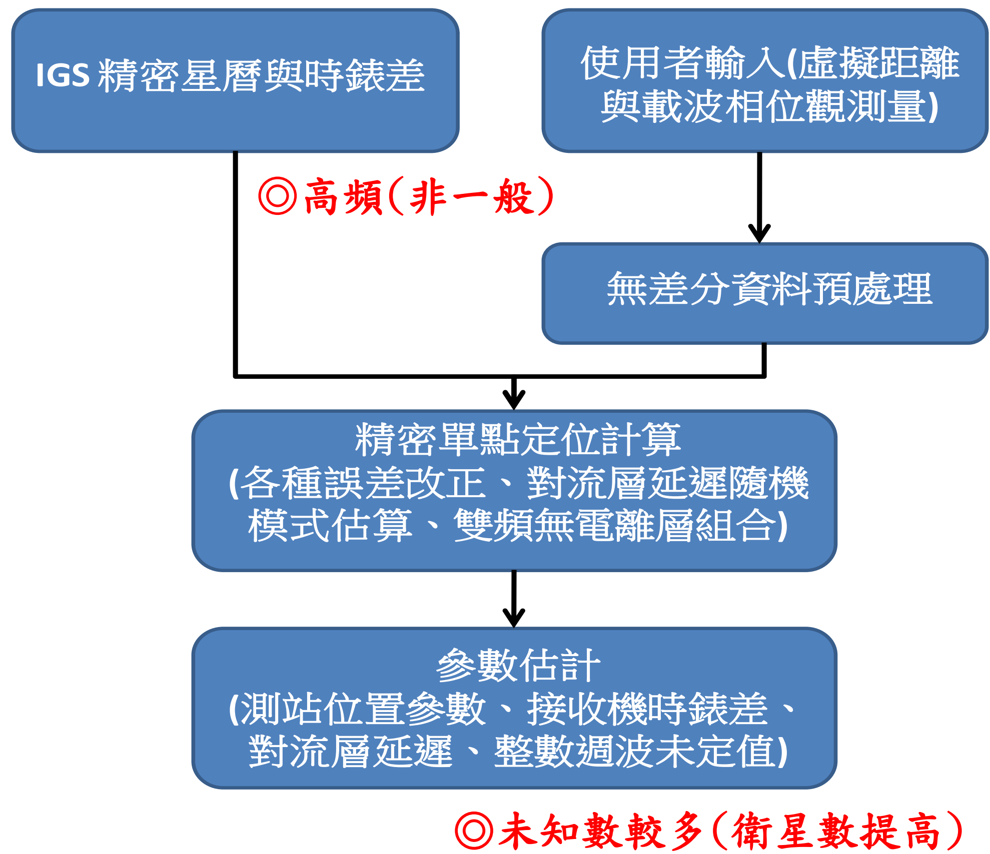
PPP數據處理

- PPP 考慮三類誤差來源：

■和衛星有關：衛星時錶差、軌道誤差、衛星天線相位中心偏差

■和訊號傳播有關：對流層延遲、電離層延遲、相對論效應、多路徑效應

■和接收儀/測站有關：接收儀時錶差、天線相位中心偏差、地球固體潮改正、海洋負載改正、地球自轉改正



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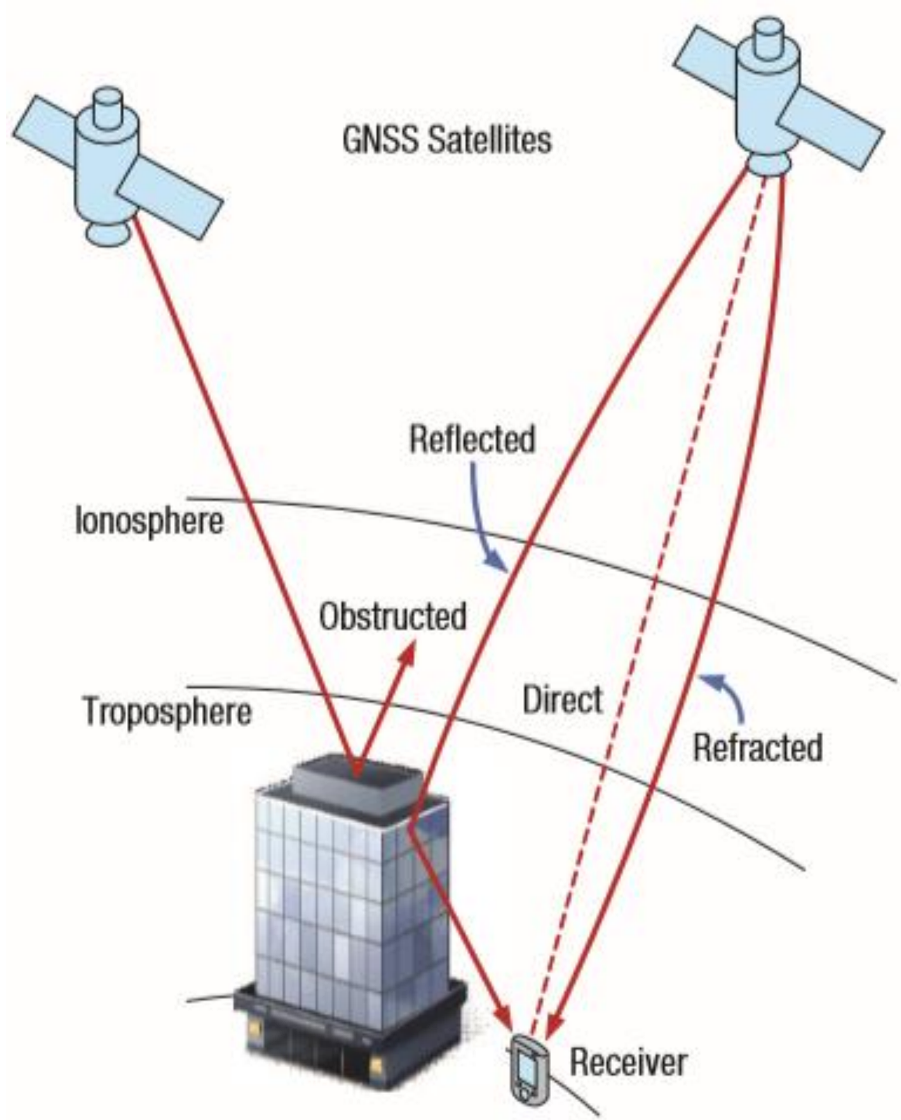
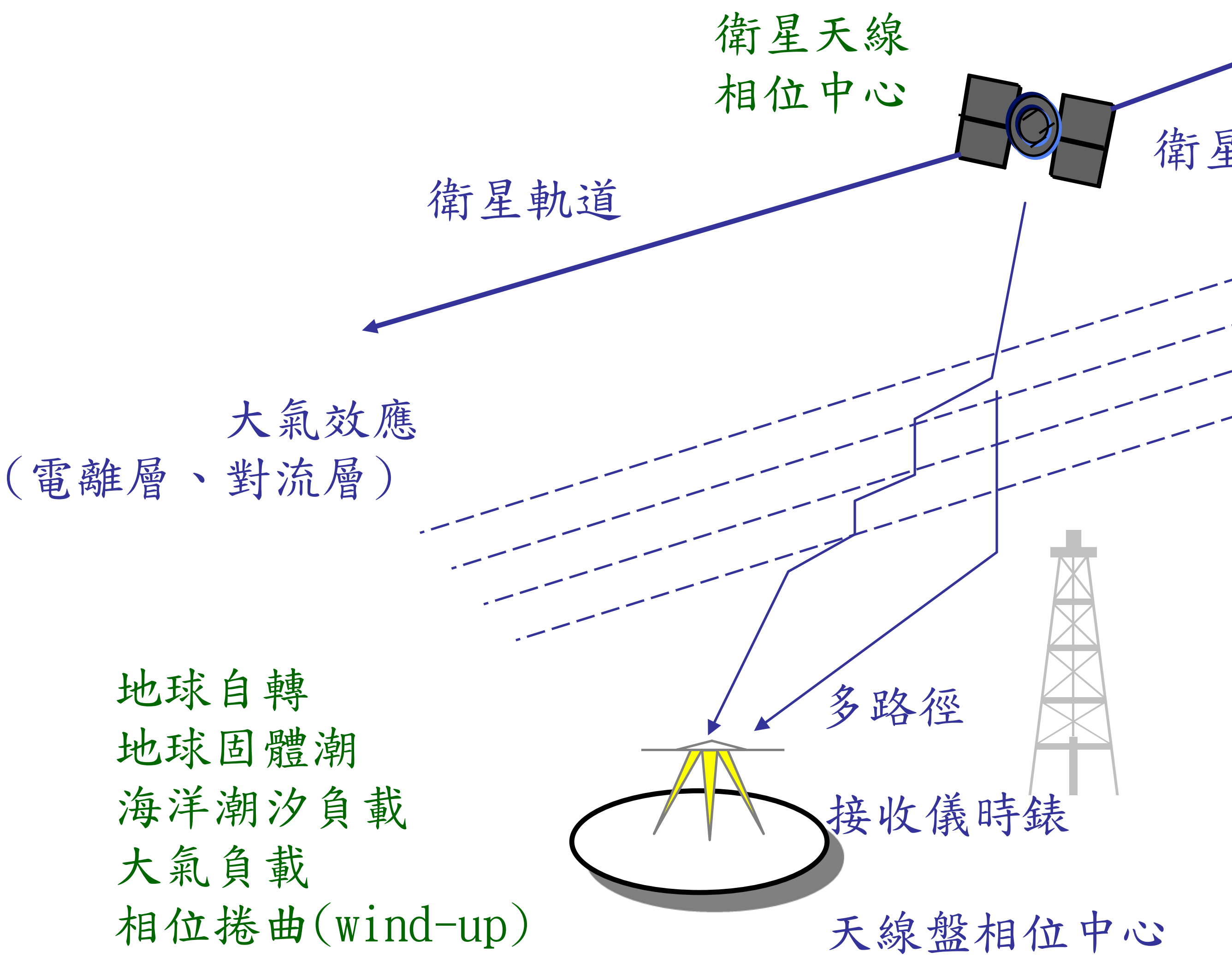
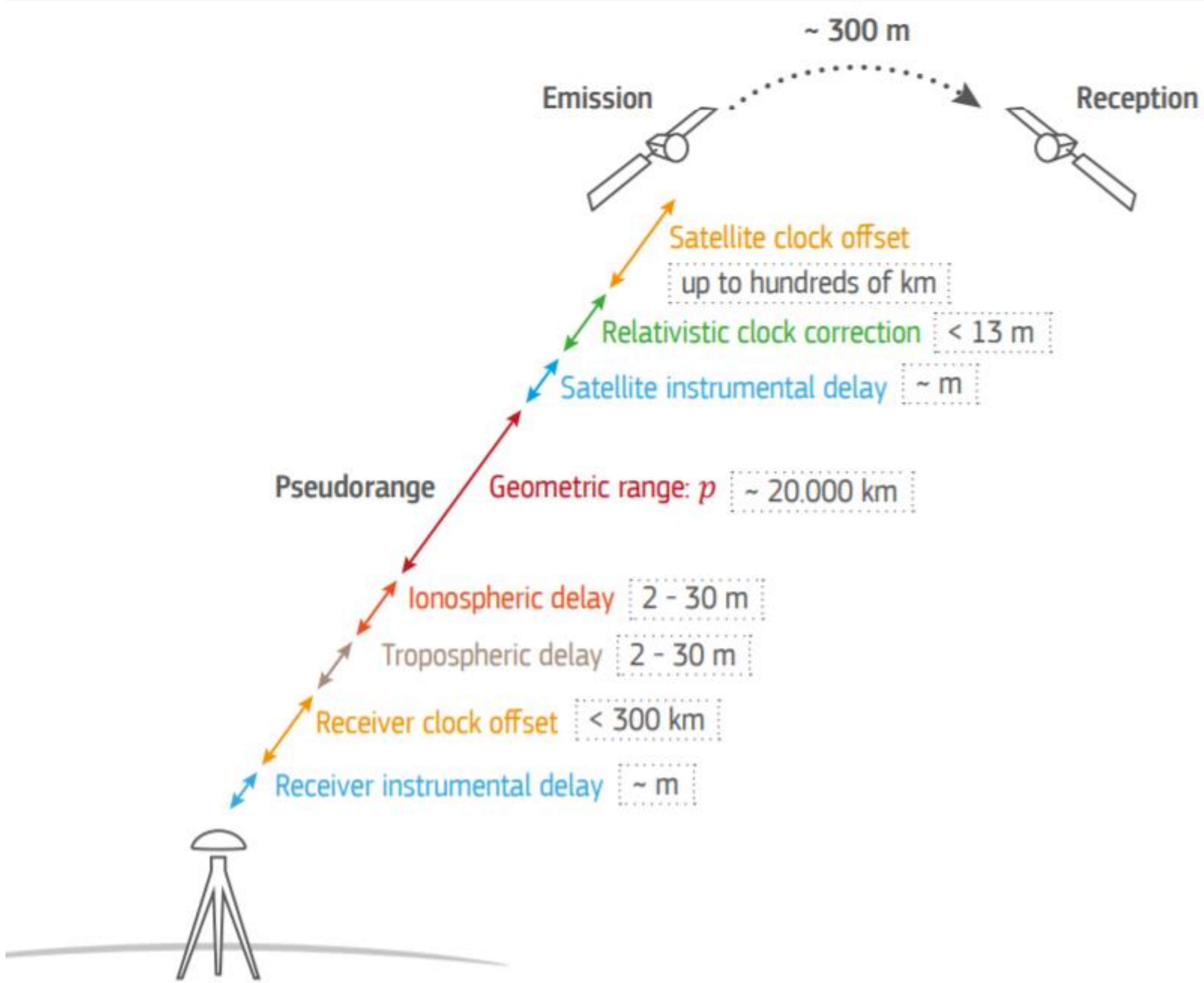
GPS信號傳遞


GNSS Satellites
Reflected
Ionosphere
Obstructed
Direct
Troposphere
Refracted
Receiver

GPS誤差來源


衛星天線
相位中心
衛星時錶
衛星軌道
大氣效應
（電離層 、對流層）
地球自轉
地球固體潮
海洋潮汐負載
大氣負載
相位捲曲(wind-up)
多路徑
接收儀時錶
天線盤相位中心

虛擬距離觀測誤差估值



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差分觀測誤差估值

Error cause	Error without DGPS	Error with DGPS
Ephemeris data	2.1m	0.1m
Satellite clocks	2.1m	0.1m
Effect of the ionosphere	4.0m	0.2m
Effect of the troposphere	0.7m	0.2m
Multipath reception	1.4m	1.4m
Effect of the receiver	0.5m	0.5m
Total RMS value	5.3m	1.5m
Total RMS value (filtered, i.e. slightly averaged)	**5.0m**	**1.3m**

雙站共通性誤差可抵銷/降低

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相位觀測量的線性組合

- 線性組合(linear combination)

$$\Phi = n_1\Phi_1 + n_2\Phi_2$$

- 窄巷(narrow lane)

$$\text{when } n_1 = n_2 = 1 \text{ then } \Phi_n = \Phi_1 + \Phi_2$$

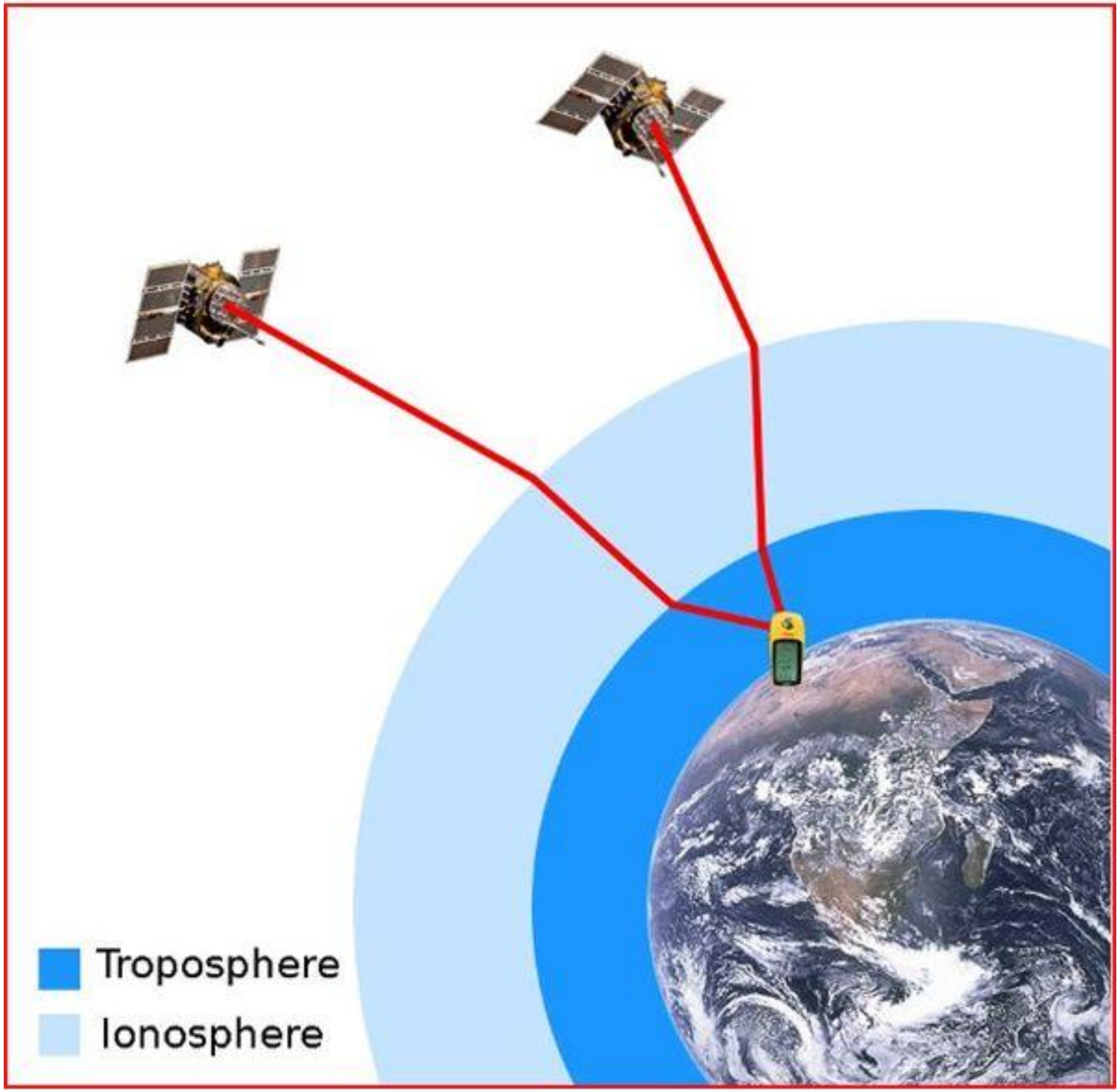
- 寬巷(wide lane)

$$\text{when } n_1 = 1, n_2 = -1 \text{ then } \Phi_w = \Phi_1 - \Phi_2$$

- 無電離層(ionosphere-free)

$$\Phi_{IF} = -\frac{f_1^2}{f_1^2 - f_2^2} \times \Phi_a^1 + \frac{f_2^2}{f_1^2 - f_2^2} \times \Phi_a^2$$

大氣延遲誤差



60-1000 km

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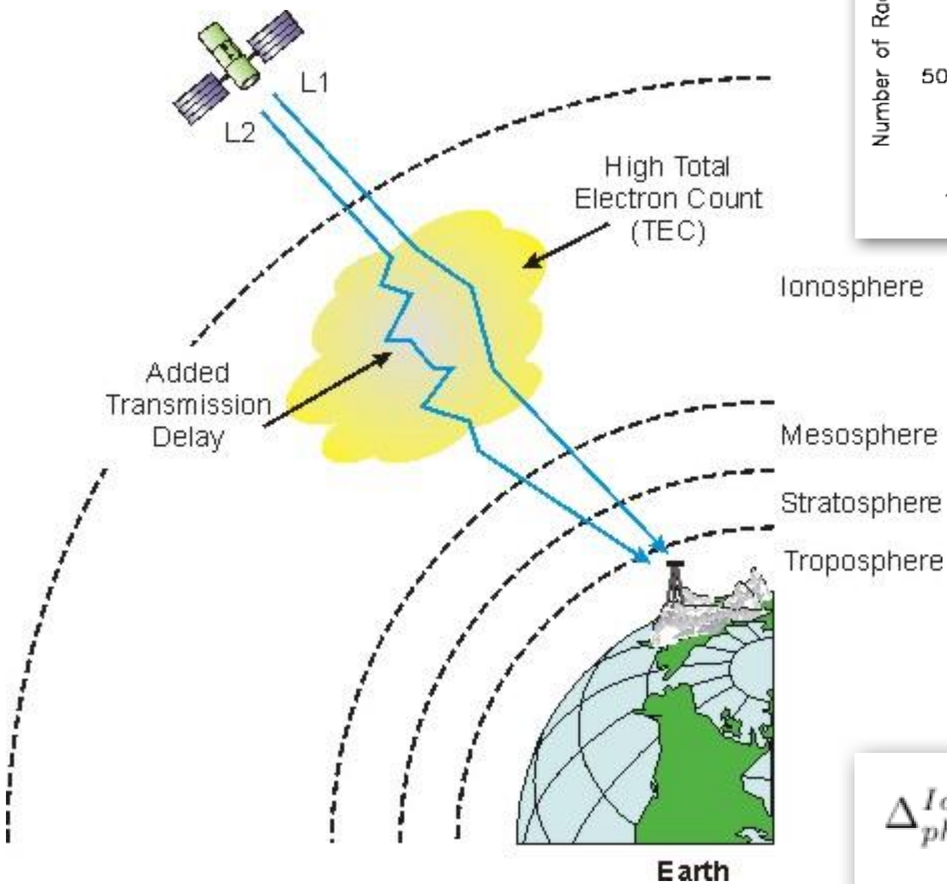
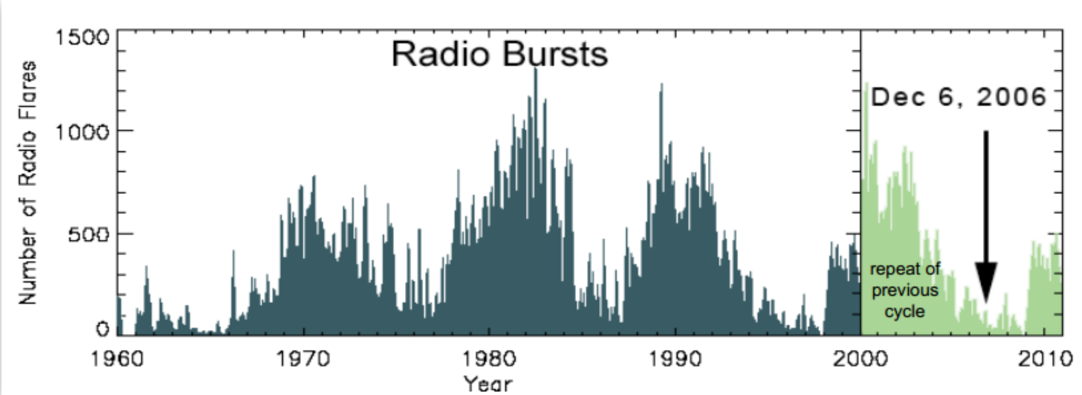
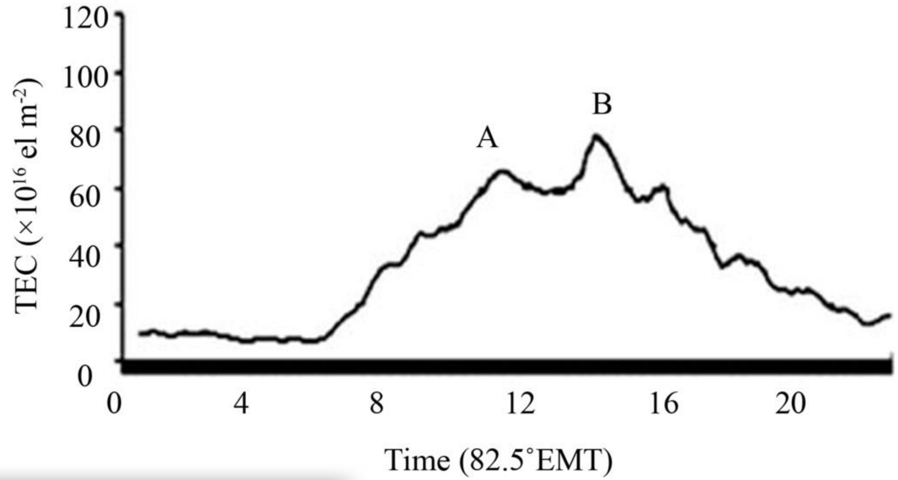
電離層延遲







$$\Delta_{ph}^{Iono} = -\frac{40.3}{f^2}TEC$$

$$\Delta_{gr}^{Iono} = \frac{40.3}{f^2}TEC$$

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電離層改正

- 導航-Klobuchar

$$\Delta T_v^{Iono} = A_1 + A_2 \cos\left(\frac{2\pi(t - A_3)}{A_4}\right)$$

where

$$A_1 = 5 \cdot 10^{-9}\ \mathrm{s} = 5\ \mathrm{ns}$$

$$A_2 = \alpha_1 + \alpha_2 \varphi_{IP}^m + \alpha_3 {\varphi_{IP}^m}^2 + \alpha_4 {\varphi_{IP}^m}^3$$

$$A_3 = 14^{\mathrm{h}}\ \text{local time}$$

$$A_4 = \beta_1 + \beta_2 \varphi_{IP}^m + \beta_3 {\varphi_{IP}^m}^2 + \beta_4 {\varphi_{IP}^m}^3 .$$

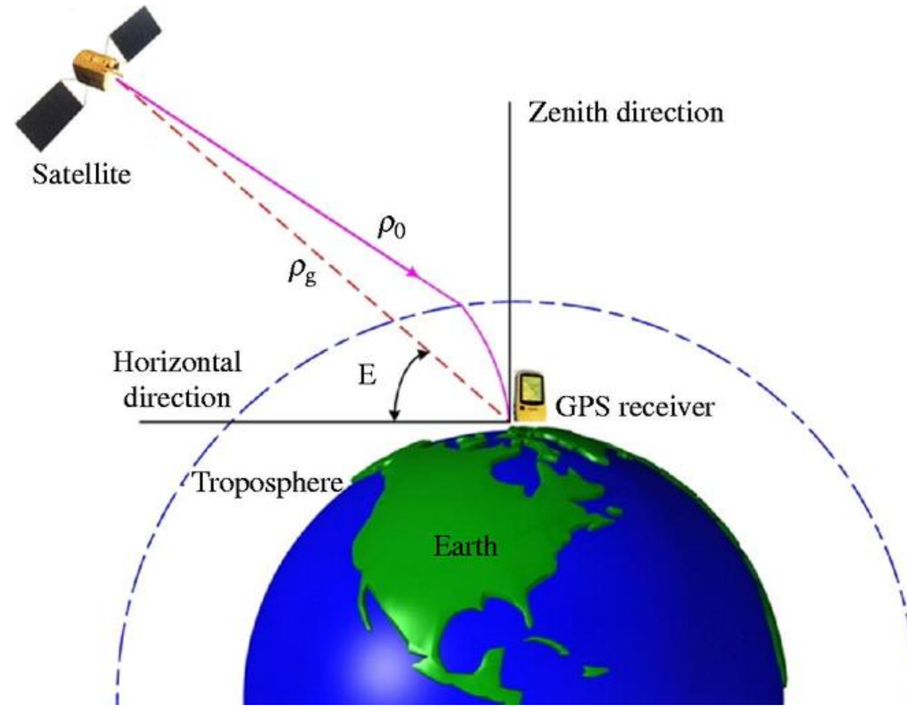
$$\cos \varphi_{IP}^m = \sin \varphi_{IP} \sin \varphi_P + \cos \varphi_{IP} \cos \varphi_P \cos(\lambda_{IP} - \lambda_P)$$

- 測量-L1/L2雙頻組合

$$\Phi_{IF} = -\frac{f_1^2}{f_1^2 - f_2^2} \times \Phi_a^1 + \frac{f_2^2}{f_1^2 - f_2^2} \times \Phi_a^2$$

對流層延遲

- 中性大氣層與信號頻率無關
- 天頂總延遲量約為2.5公尺
- 可分為乾延遲與溼延遲
- 乾延遲約佔90%-95%
- 乾延遲可由溫度與壓力模式化
- 溼延遲與水汽壓力有關



refractivity

$$N = (n-1)10^6$$

$$N = \left[\frac{77.6\,P}{T}\right] + \left[3.73 \times 10^5 \frac{e}{T^2}\right]$$

N_{dry} N_{wet}

對流層改正

- Saastamoinen 全球標準模式 (1973)

$$\Delta L = \frac{2.277 \cdot 10^{-3}}{\cos(90^\circ - \upsilon)}\left(P_0 + \left(\frac{1255}{T_0} + 0.05 \right) \cdot e_0 - 1.16 \cdot \tan^2(90^\circ - \upsilon) \right)$$

v: 垂直角　(天頂距 $z = 90^o - v$)

- 輸入參數:地表絕對溫度(T)、水氣偏壓(e)及大氣壓(P)
- 乾量估計:先驗地表氣壓、測站緯度及高度

標準大氣模型估計參數

- Berg et al. (1948)

$$T = T_0 - 0.065\ H$$

溫度

$$P = P_0(1 - 2.26 \times 10^{-5}\ H)^{5.225}$$

氣壓

$$RH = RH_0 \exp(-6.396 \times 10^{4}\ H)$$

相對溼度

對流層改正

- Modified Hopfield 全球標準模式 (1974)

$$D_i^{trop} = 10^{-12} N_i \left[\sum_{k=1}^{9} \frac{\alpha_{k,i}}{k} r_i^{\,k} \right]$$

其中

i：分別表示乾 ($i=d$) 或濕 ($i=wv$) 部分的分量

ε：衛星仰角 (=90°-天頂距)

$r_i = \sqrt{(R_E + h_i)^2 - (R_E \cos\varepsilon)^2} - R_E \sin\varepsilon$

其他參數的定義為：

$\alpha_{1,i} = 1$　　$\alpha_{2,i} = 4a_i$

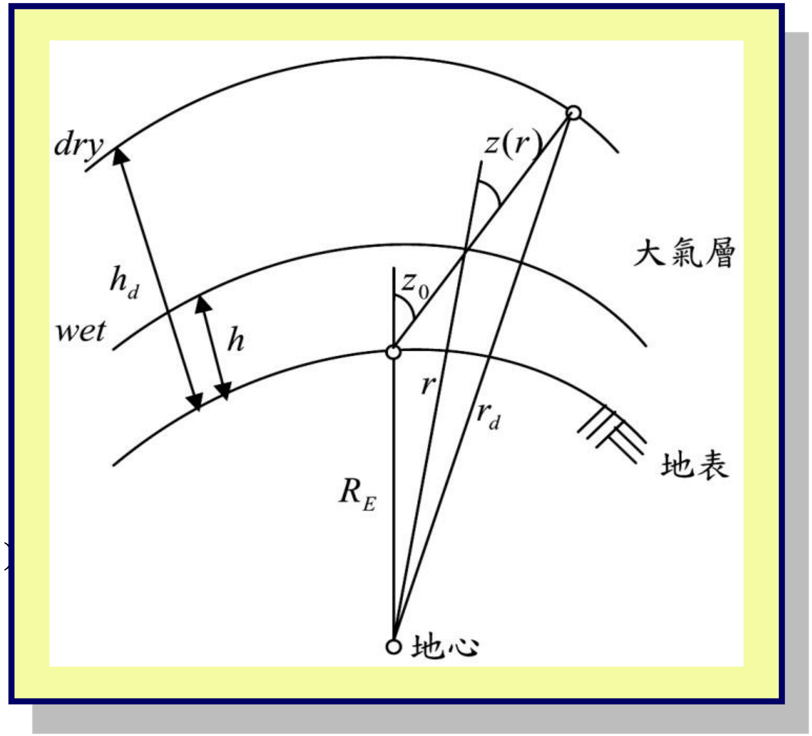
$\alpha_{3,i} = 6a_i^{\,2} + 4b_i$　　$\alpha_{4,i} = 4a_i(a_i^{\,2} + 3b_i)$

$\alpha_{5,i} = a_i^{\,4} + 12a_i^{\,2}b_i + 6b_i^{\,2}$　　$\alpha_{6,i} = 4a_i b_i(a_i^{\,2} + 3b_i)$

$\alpha_{7,i} = b_i^{\,2}(6a_i^{\,2} + 4b_i)$　　$\alpha_{8,i} = 4a_i b_i^{\,3}$

$\alpha_{9,i} = b_i^{\,4}$

其中　$a_i = -\dfrac{\sin\varepsilon}{h_i}$，$b_i = -\dfrac{\cos^2\varepsilon}{2h_i R_E}$



- 輸入參數：測站高度及衛星仰角

對流層改正

- Niell 模式 (1996)

$$D_{dry}^{trop}(\varepsilon)=\frac{\dfrac{1}{1+\dfrac{a_{dry}}{1+\dfrac{b_{dry}}{1+c_{dry}}}}}{\sin\varepsilon+\dfrac{a_{dry}}{\sin\varepsilon+\dfrac{b_{dry}}{\sin\varepsilon+c_{dry}}}}+\left[\frac{1}{\sin\varepsilon}-\frac{\dfrac{1}{1+\dfrac{a_{ht}}{1+\dfrac{b_{ht}}{1+c_{ht}}}}}{\dfrac{1}{\sin\varepsilon+\dfrac{a_{ht}}{\sin\varepsilon+\dfrac{b_{ht}}{\sin\varepsilon+c_{ht}}}}}\right]\times\frac{H}{100}$$

$$D_{wet}^{trop}(\varepsilon)=\frac{\dfrac{1}{1+\dfrac{a_{wet}}{1+\dfrac{b_{wet}}{1+c_{wet}}}}}{\sin\varepsilon+\dfrac{a_{wet}}{\sin\varepsilon+\dfrac{b_{wet}}{\sin\varepsilon+c_{wet}}}}$$

ε =衛星仰角

H =高程

$a_{ht}=2.53\times10^{-5}km$

$b_{ht}=5.49\times10^{-3}km$

$c_{ht}=1.14\times10^{-3}km$

而 a_{dry} 、b_{dry} 、c_{dry} 、a_{wet} 、b_{wet} 、c_{wet} 在各緯度的平均(average)係數數值可查表得。

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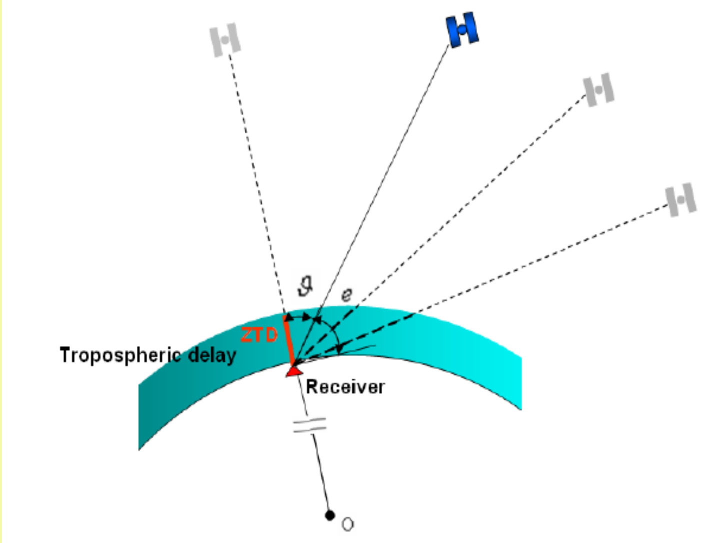
投影(映射)函數

- **Mapping Function**
  - 標準模型估值多是處於天頂方向
  - 但觀測到的GPS衛星分別處於不同高度，對流層延遲即會隨著衛星仰角而變化
  - 須利用映射函數把天頂方向的對流層延遲量(ZTD)映射到不同仰角衛星處的傾斜路徑上（slant path）的對流層延遲



(摘自Misra and Enge, 2001)

$$MF(\varepsilon) = 1.001 \Big/ \sqrt{(0.001)^2 + 0.002 + \sin^2 \varepsilon}$$

(Black and Eisner, 1984)

基本函數: 1/sin (v)

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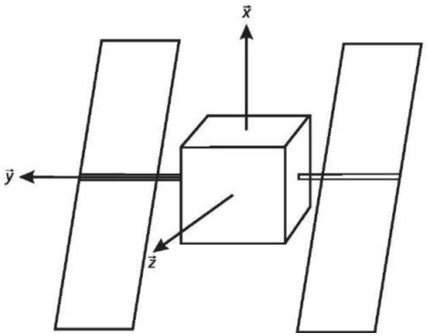
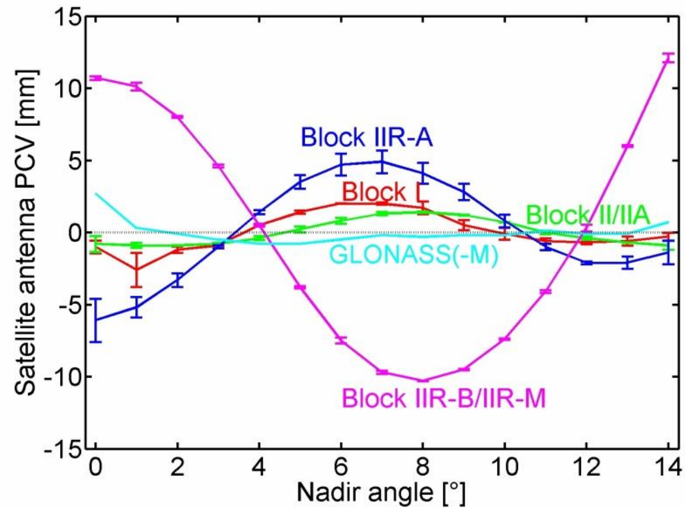
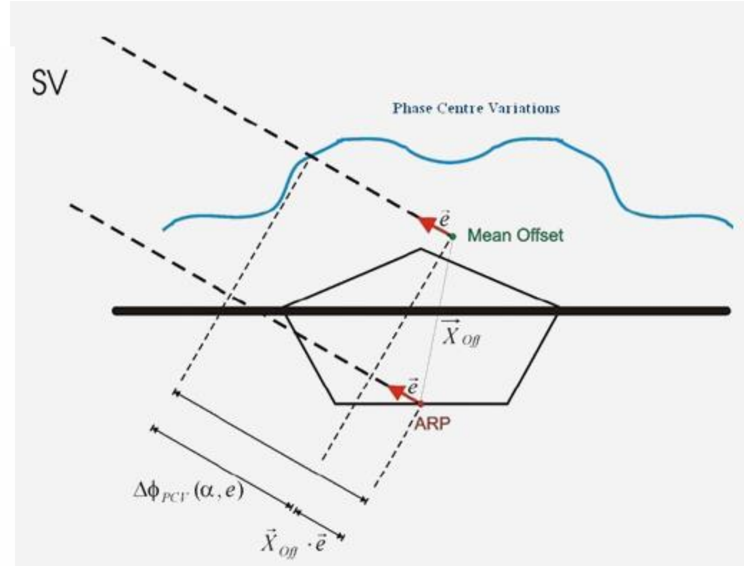
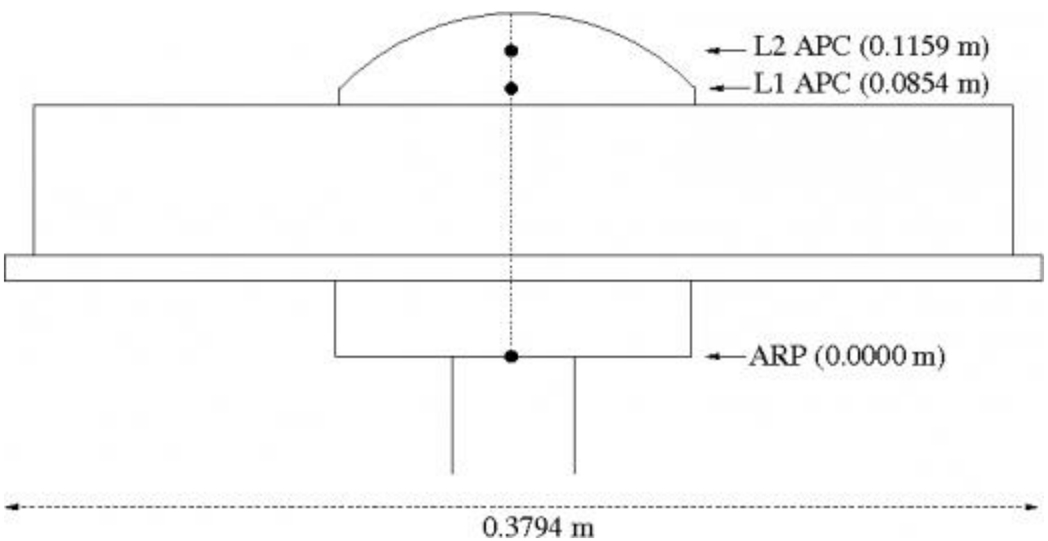
天線相位中心









igs08.atx 改正模式

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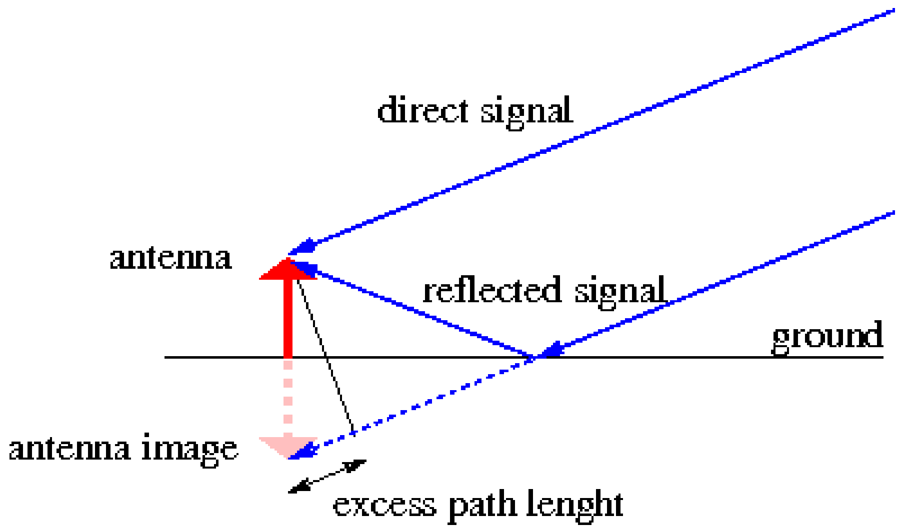
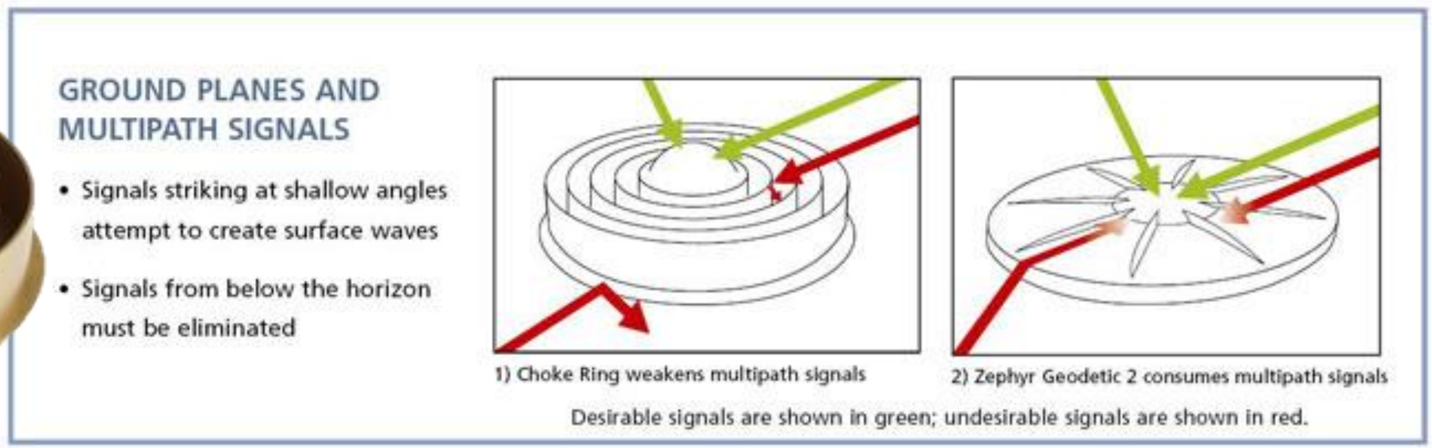
多路徑效應



teqc

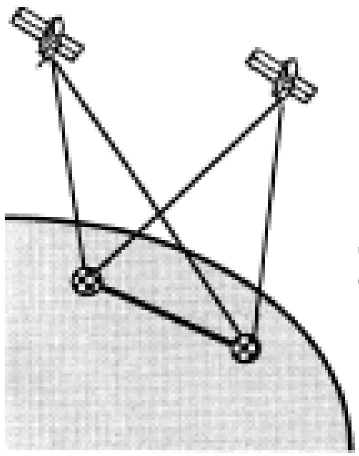
$$MP1 \equiv p_1 - \left(1 + \frac{2}{\alpha - 1}\right)\Phi_1 + \left(\frac{2}{\alpha - 1}\right)\Phi_2$$

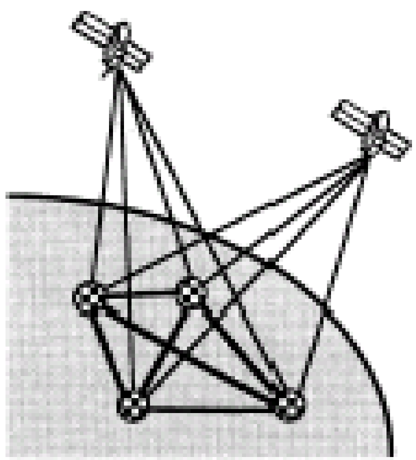
$$MP2 \equiv p_2 - \left(\frac{2\alpha}{\alpha - 1}\right)\Phi_1 + \left(\frac{2\alpha}{\alpha - 1} - 1\right)\Phi_2$$

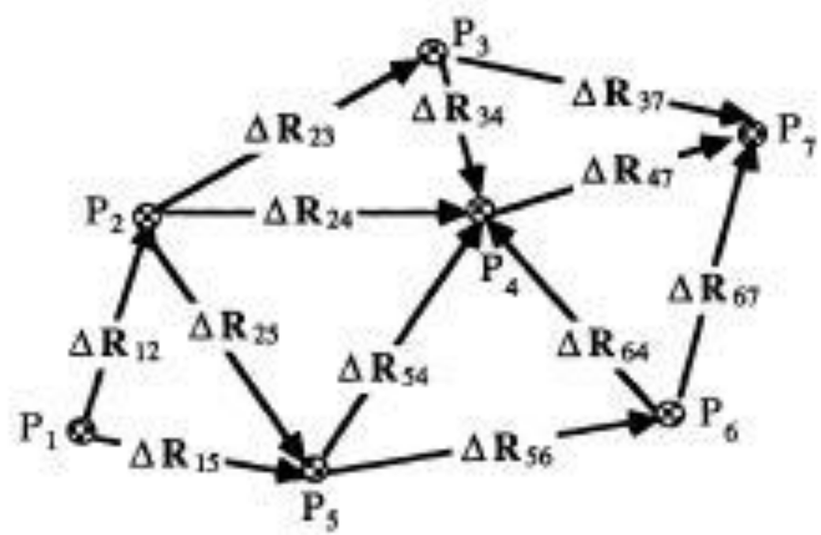


chock ring 天線盤

基線與網形







Provided all ΔR_{ij} are in the same coordinate system as R_1 we have (for example):

$$R_7 = R_1 + \Delta R_{12} + \Delta R_{24} + \Delta R_{47}$$

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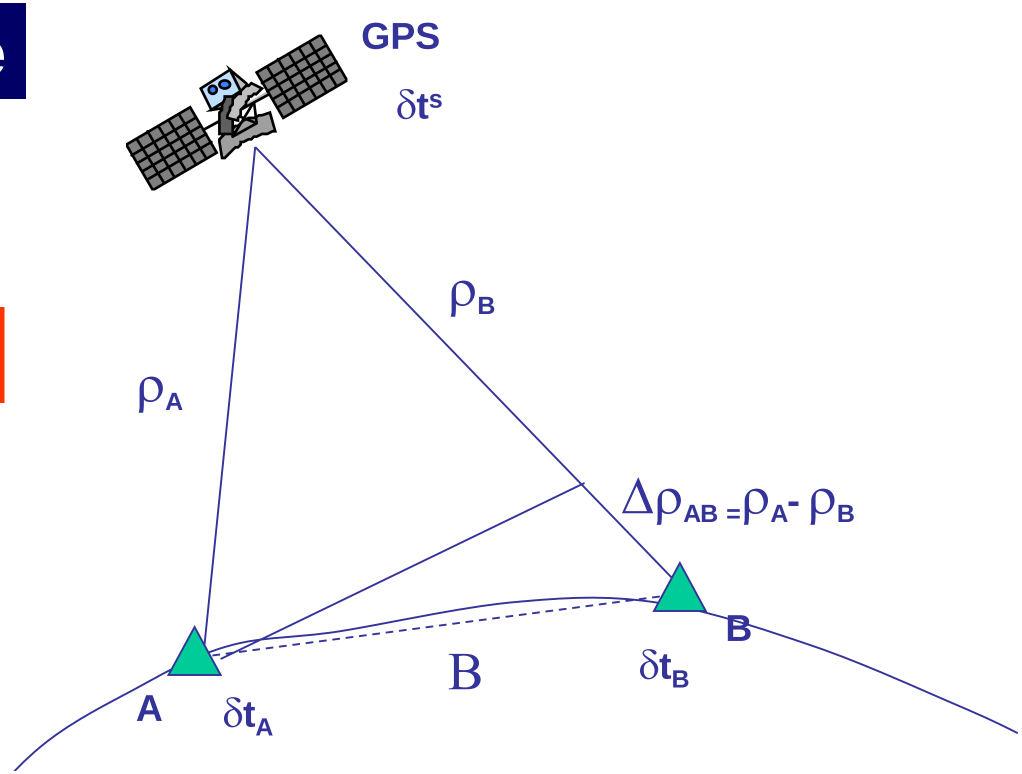
一次差觀測

Single Difference

衛星錶差　可消除



$$\Delta(\bullet) = (\bullet)_{receiver\ 2} - (\bullet)_{receiver\ 1}$$

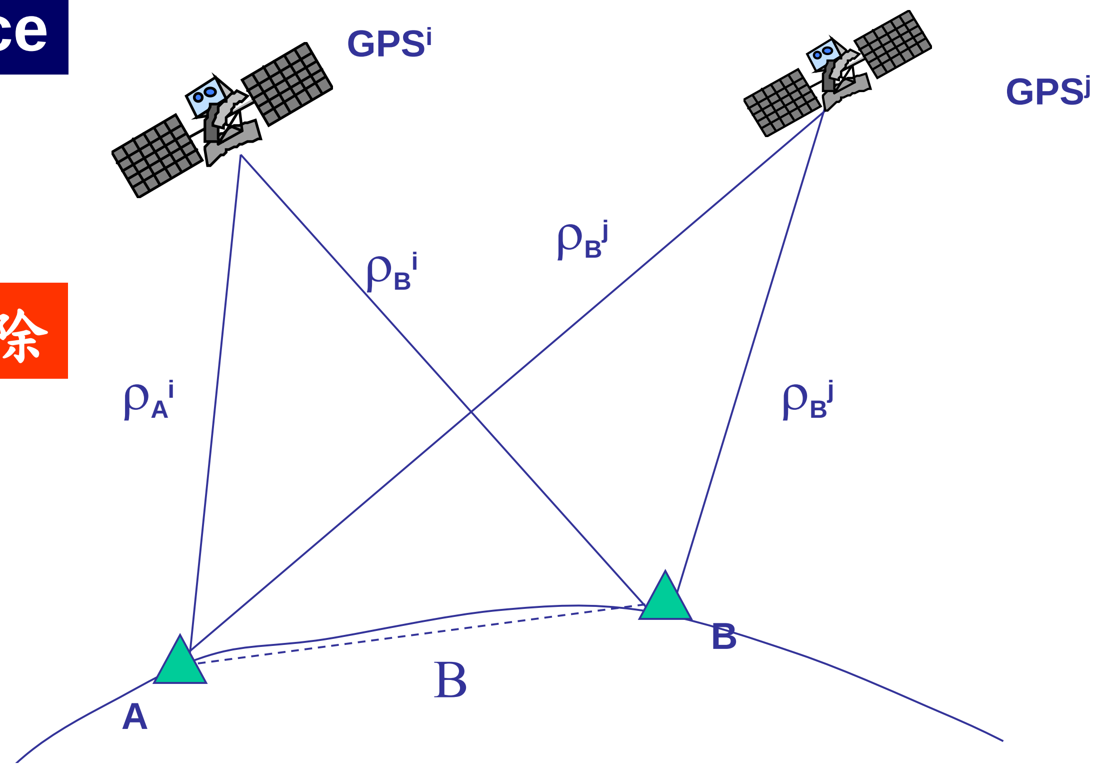
$$\Delta p = \Delta\rho - c\cdot\Delta dT + \Delta d_{ion} + \Delta d_{trop}$$

$$\Delta\Phi = \Delta\rho - c\cdot\Delta dT + \lambda\cdot\Delta N - \Delta d_{ion} + \Delta d_{trop}$$

二次差觀測

Double Difference

接收器錶差 可消除



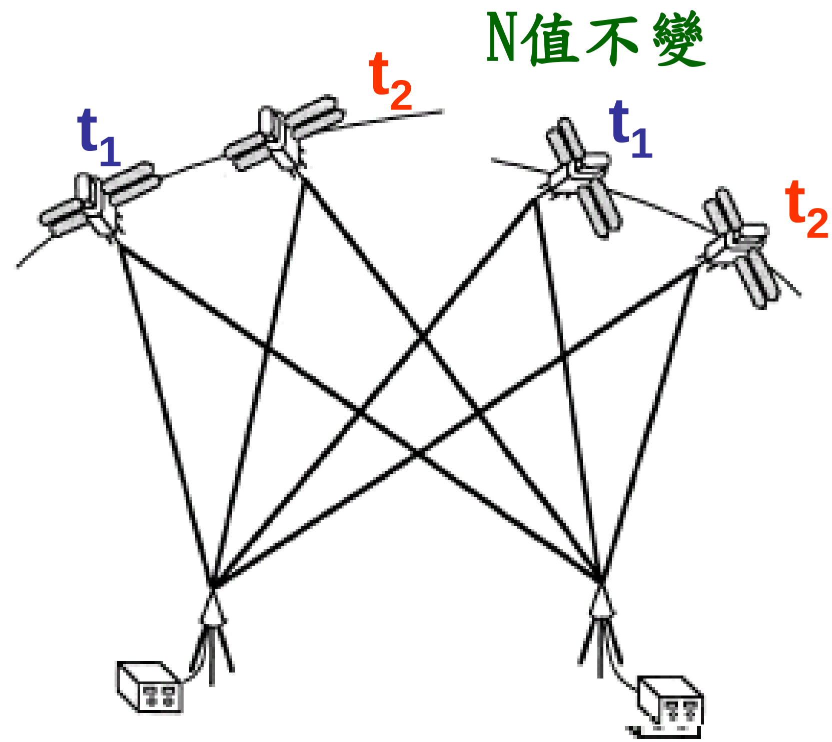
$$\nabla\Delta p = \nabla\Delta \rho + \nabla\Delta d_{ion} + \nabla\Delta d_{trop}$$

$$\nabla\Delta\Phi = \nabla\Delta \rho + \lambda \cdot \nabla\Delta N - \nabla\Delta d_{ion} + \nabla\Delta d_{trop}$$

三次差觀測

Triple Difference

相位未定值　可消除



$$\delta\nabla\Delta p = \delta\nabla\Delta\rho + \delta\nabla\Delta\, d_{ion} + \delta\nabla\Delta\, d_{trop}$$

$$\delta\nabla\Delta\Phi = \delta\nabla\Delta\rho - \delta\nabla\Delta\, d_{ion} + \delta\nabla\Delta\, d_{trop}$$

全球GNSS服務(IGS)

International GNSS Service (2005.03)

508測站(2019)

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IGS運作架構

http://www.igs.org

- Governing Board (GB)
- Central Bureau (CB)
- IGS Network
- Analysis Centers (ACs)
- Data Centers (DCs)
- Working Groups (WGs)

IGS全球資料中心(DCs)

Institution	Abbreviation	Country
Wuhan University	WHU	China
Institut Geographique National	IGN	France
Korean Astronomy and Space Science Institute	KASI	Korea
European Space Agency / ESAC	ESA / ESAC	Spain
Crustal Dynamics Data Information System	CDDIS	United States
Scripps Institution of Oceanography	SIO	United States

IGS分析中心(ACs)

Institution	Abbreviation	Country
Natural Resources Canada	EMR	Canada
Wuhan University	WHU	China
Geodetic Observatory Pecny	GOP-RIGTC	Czech Republic
Space geodesy team of the CNES	GRG	France
European Space Agency/ESOC	ESA/ESOC	Germany
GeoForschungsZentrum	GFZ	Germany
Center for Orbit Determination in Europe	CODE	Switzerland
Jet Propulsion Laboratory	JPL	USA
Massachusetts Institute of Technology	MIT	USA
NOAA/National Geodetic Survey	NGS	USA
Scripps Institution of Oceanography	SIO	USA
U.S. Naval Observatory	USNO	USA

IGS資料產品

- GNSS 衛星星曆
- 地球旋轉參數
- 全球追蹤站坐標及速度
- 衛星及追蹤站時表資訊
- 天頂向對流層路徑延遲量估計值
- 全球電離層地圖

IGS支援的科學服務

- 精進及擴充由IERS所維護的ITRF
- 監測地球的地殼變形
- 監測地球旋轉
- 監測對流層及電離層
- 測算科學衛星軌道及其它應用

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IGS資料品質

GPS Satellite Ephemerides / Satellite & Station Clocks

Type		Accuracy	Latency	Updates	Sample Interval
Broadcast	orbits	~100 cm	real time	--	daily
	Sat. clocks	~5 ns RMS ~2.5 ns SDev			
Ultra-Rapid (predicted half)	orbits	~5 cm	real time	at 03, 09, 15, 21 UTC	15 min
	Sat. clocks	~3 ns RMS ~1.5 ns SDev			
Ultra-Rapid (observed half)	orbits	~3 cm	3 - 9 hours	at 03, 09, 15, 21 UTC	15 min
	Sat. clocks	~150 ps RMS ~50 ps SDev			
Rapid	orbits	~2.5 cm	17 - 41 hours	at 17 UTC daily	15 min
	Sat. & Stn. clocks	~75 ps RMS ~25 ps SDev			5 min
Final	orbits	~2.5 cm	12 - 18 days	every Thursday	15 min
	Sat. & Stn. clocks	~75 ps RMS ~20 ps SDev			Sat.: 30s Stn.: 5 min

IGS資料品質

GLONASS Satellite Ephemerides

Type	Accuracy	Latency	Updates	Sample Interval
Final	~3 cm	12 - 18 days	every Thursday	15 min

Geocentric Coordinates of IGS Tracking Stations

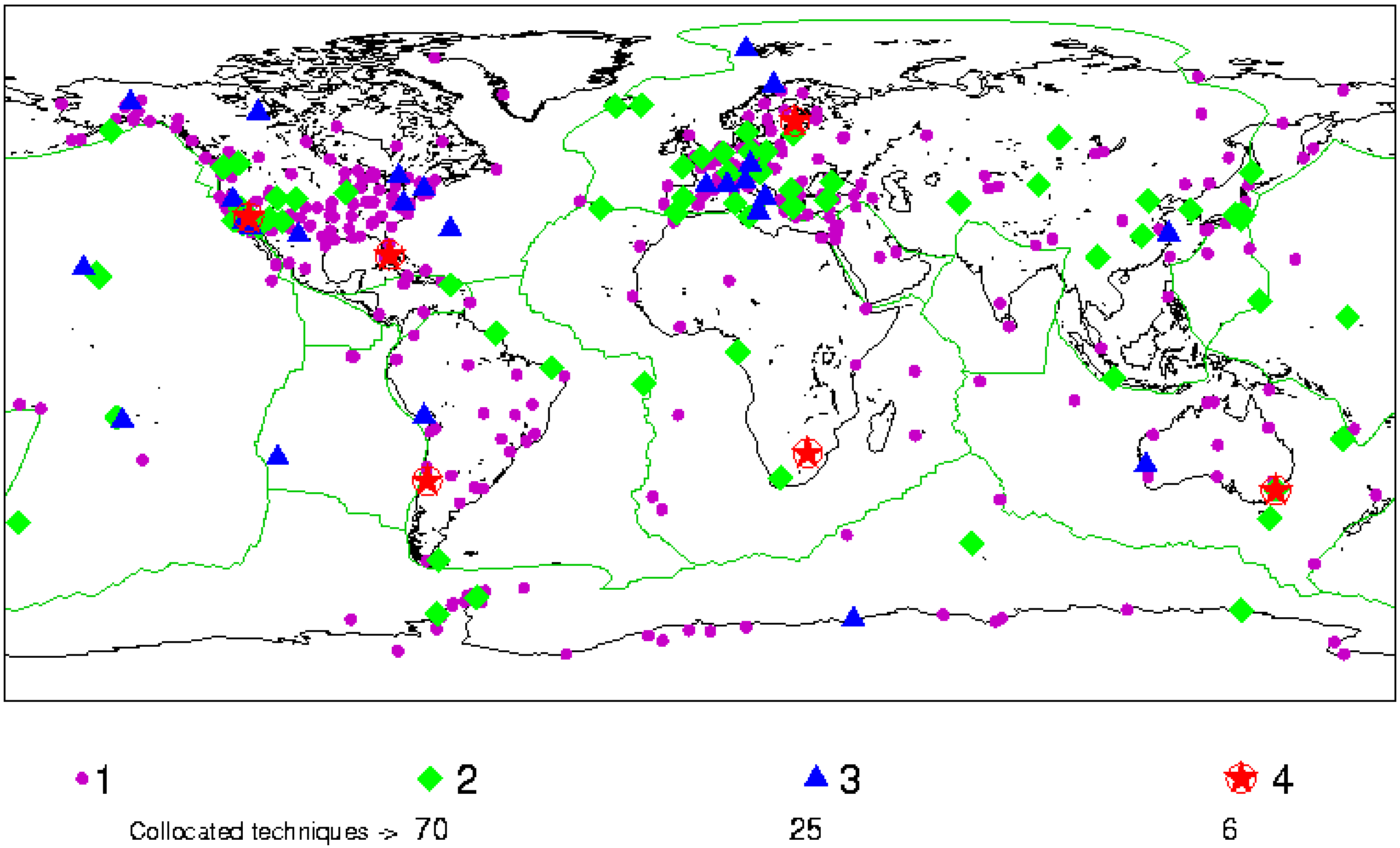
Type		Accuracy	Latency	Updates	Sample Interval
Final positions	horizontal	3 mm	11 - 17 days	every Wednesday	weekly
	vertical	6 mm			
Final velocities	horizontal	2 mm/yr	11 - 17 days	every Wednesday	weekly
	vertical	3 mm/yr			

Atmospheric parameters

Type	Accuracy	Latency	Updates	Sample Interval
Final tropospheric zenith path delay with N, E gradients	4 mm (ZPD)	< 4 weeks	daily	5 minutes
Final ionospheric TEC grid	2-8 TECU	~11 days	weekly	2 hours; 5 deg (lon) x 2.5 deg (lat)
Rapid ionospheric TEC grid	2-9 TECU	<24 hours	daily	2 hours; 5 deg (lon) x 2.5 deg (lat)

全球坐標參考框架(ITRF)

IERS Terrestial Reference Frame



IERS已更名International Earth Rotation and Reference Systems Service (2003)

ITRF提供的坐標資訊

ITRF2000 STATION POSITIONS AT EPOCH 1997.0 AND VELOCITIES

GPS STATIONS

DOMES NB.	SITE NAME	TECH.	ID.	X/Vx	Y/Vy	Z/Vz	Sigmas			SOLN
				----------------------m/m/y	------------------------------	------------------------------				
10002M006	GRASSE	GPS	GRAS	4581691.012	556114.680	4389360.696	.002	.001	.002	
10002M006				-.0131	.0189	.0101	.0003	.0001	.0004	
10003M004	TOULOUSE	GPS	TOUL	4627846.128	119629.178	4372999.723	.002	.001	.002	
10003M004				-.0134	.0187	.0088	.0009	.0003	.0008	
10004M002	BREST	GPS	7604	4228877.078	-333104.179	4747181.000	.005	.001	.006	
10004M002				-.0133	.0184	.0085	.0021	.0004	.0022	

GPS相關資料格式-1

File Type	Version	Version Date	File Name	Description
Observation	2.10	10 December 2007	Observation Rinex v2.10.html	RINEX format for GPS and GLONASS observations.
	2.11	10 December 2007	Observation Rinex v2.11.html	RINEX format for GPS and GLONASS observations.
	3.01	22 June 2009	Observation Rinex v3.01.html	RINEX format for GPS and GLONASS observations.
Navigation	2.11	10 December 2007	GLONASS Navigation Rinex v2.11.html	RINEX format for GLONASS Navigation Message File.
	2.11	10 December 2007	GPS Navigation Rinex v2.11.html	RINEX format for GPS Navigation Message File.
	3.01	22 June 2009	SBAS Navigation Rinex v3.01.html	RINEX format for the complete broadcast data of Space-Based Augmentation Systems (SBAS).

RINEX 3.04 19 Dec 2018 support new signals for GNSS

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GPS相關資料格式-2

Ionospheric	1.00	25 February 1998	IONEX v1.0.html	IONEX format for ionosphere models determined by processing data of a GNSS tracking network.
Clocks	3.00	14 November 2006	RINEX CLOCKS v3.00.html	RINEX format for satellite and receiver clock offsets determined by processing data of a GNSS tracking network.
Antenna	1.3	20 September 2006	ANTEX v1.3.html	ANTEX format for Phase Center Offsets (PCOs) and Phase Center Variations (PCVs) of geodetic GNSS antennae.
Precise Products	C	12 February 2007	SP3 Version C.html	SP3 format for GNSS orbit and clock solutions.

GPS資料交換格式(RINEX)

Receiver Independent Exchange Format

```
 2.10          OBSERVATION DATA    M (MIXED)           RINEX VERSION / TYPE
RinExp V.2.0.2      TESTUSER           00-02-04 09:30                    PGM / RUN BY / DATE
                                            COMMENT
The file contains L1 pseudorange and phase data of the                   COMMENT
geostationary AOR-E satellite (PRN 120 = S20)                            COMMENT
                                                                         COMMENT
TLSE D                                                                   MARKER NAME
ESTB                TESTAGENCY                                           OBSERVER / AGENCY
SGL98030069         Novatel Millennium  HW3-1 SW 4.45/2.3                REC # / TYPE / VERS
                    ASH701073.1                                          ANT # / TYPE
 4629365.0750   112100.1790  4371619.4160              APPROX POSITION XYZ
       0.0000        0.0000        0.0000                                ANTENNA: DELTA H/E/N
   1    1                                                                WAVELENGTH FACT L1/2
   4    C1    L1    L2    P2                                             # / TYPES OF OBSERV
   1                                                                      INTERVAL
 2000    1   13   14   45    0.000000     GPS                            TIME OF FIRST OBS
 2000    1   13   15    0    0.000000     GPS                             TIME OF LAST OBS
   0                                                                     RCV CLOCK OFFS APPL
                                                                         END OF HEADER

 00 01 13 14 45  0.0000000  0  7G25G17G06G05G24G29G30
 21839900.207     -236148.877 9   -184047.71049  21839901.4384
 25151926.413     -161002.900 9   -125509.72447  25151935.8274
 20531103.515      763336.059 9    594797.53149  20531105.0114
 23001624.801     -432989.642 9   -337436.50348  23001628.1684
 23610349.510     -384890.728 9   -299952.38848  23610354.3504
 23954474.398     -151982.173 9   -118480.96847  23954481.1994
 20622367.016     -332628.466 9   -259214.55249  20622367.8754
```

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RINEX v2 觀測檔命名原則

ssssdddf.yyt

ssss: 測站之點名

ddd: 每年之日數(1-365)

f: 當天觀測之序號(1-9)

0: 全天之資料組(追蹤站)

yy: 西元年之後二碼

t: 檔案型式

O: 觀測資料檔

N: 導航(廣播星曆)資料檔

M: 氣象資料檔

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RINEX v3 觀測檔命名原則

RINEX3檔案命名原則	
欄位名稱	內容說明
Name	共9個字元，代表站名（4）、接收儀與天線盤代碼（2）、國家（3）
S	代表資料來源
Start Time	共11個字元，以YYYYDDDHHMM代表該檔案起始時間
Period	共3個字元，代表資料觀測長度
OBS.Freq	共3個字元，代表資料觀測頻率
Content	共2個字元，代表資料內容
Format	共3個字元，代表資料格式
Compression	2~3個字元，代表資料壓縮格式

範例說明；
本系統提供之壓縮檔案格式為****.crx.gz，解壓縮完為****.RNX
如LSB000TWN_S_20181790000_01D_01Z_MO.RNX
代表LSB0基準站從2018年6月28日（Day of year 179）GPS time 00時00分起觀測1天，觀測頻率為1Hz的衛星觀測資料。

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精密星曆資料格式(SP3)

```
#aV1993  1 29  0  0  0.00000000      96     d ITR91 FIT  JPL
##  681 432000.00000000    900.00000000 49016 0.0000000000000
+    19      1  2   3 12 13 14 15 16 17 18 19 20 21 23 24 25 26
+          27 28  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
+           0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
+           0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
+           0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
++         10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10 10
++         10 11  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
++          0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
++          0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
++          0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0  0
%c cc cc ccc ccc cccc cccc cccc cccc ccccc ccccc ccccc ccccc
%c cc cc ccc ccc cccc cccc cccc cccc ccccc ccccc ccccc ccccc
%f  0.0000000  0.000000000  0.00000000000  0.000000000000000
%f  0.0000000  0.000000000  0.00000000000  0.000000000000000
%i    0    0    0    0      0      0      0      0         0
%i    0    0    0    0      0      0      0      0         0
/* CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
/* CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
/* CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
/* CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
*  1993  1 29  0  0  0.00000000
P  1  14722.638510   6464.319150 -21020.844810     -8.059218
V  1  -1196.628800  26950.022500   7502.277100      0.000000
P  2 -24023.155300 -11843.563990  -1675.647210    -10.813964
V  2   -769.152700  -3247.508000  31255.023300      0.000000
P  3   2074.555420  19025.998840  17928.366120   -430.859048
V  3  -6873.932300  22421.664200 -23147.529600      0.000000
```

Version c with GPS & GLONASS solutions

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SP3星曆檔編碼原則

iiiwwwwf.sp3

iii: 測算星曆之單位(如igs…)

wwww: GPS週數(如1280…)

f: 當週之日數(0-6)

0: 星期日…餘類推

SP3: 固定之格式代號

衛星軌道參數

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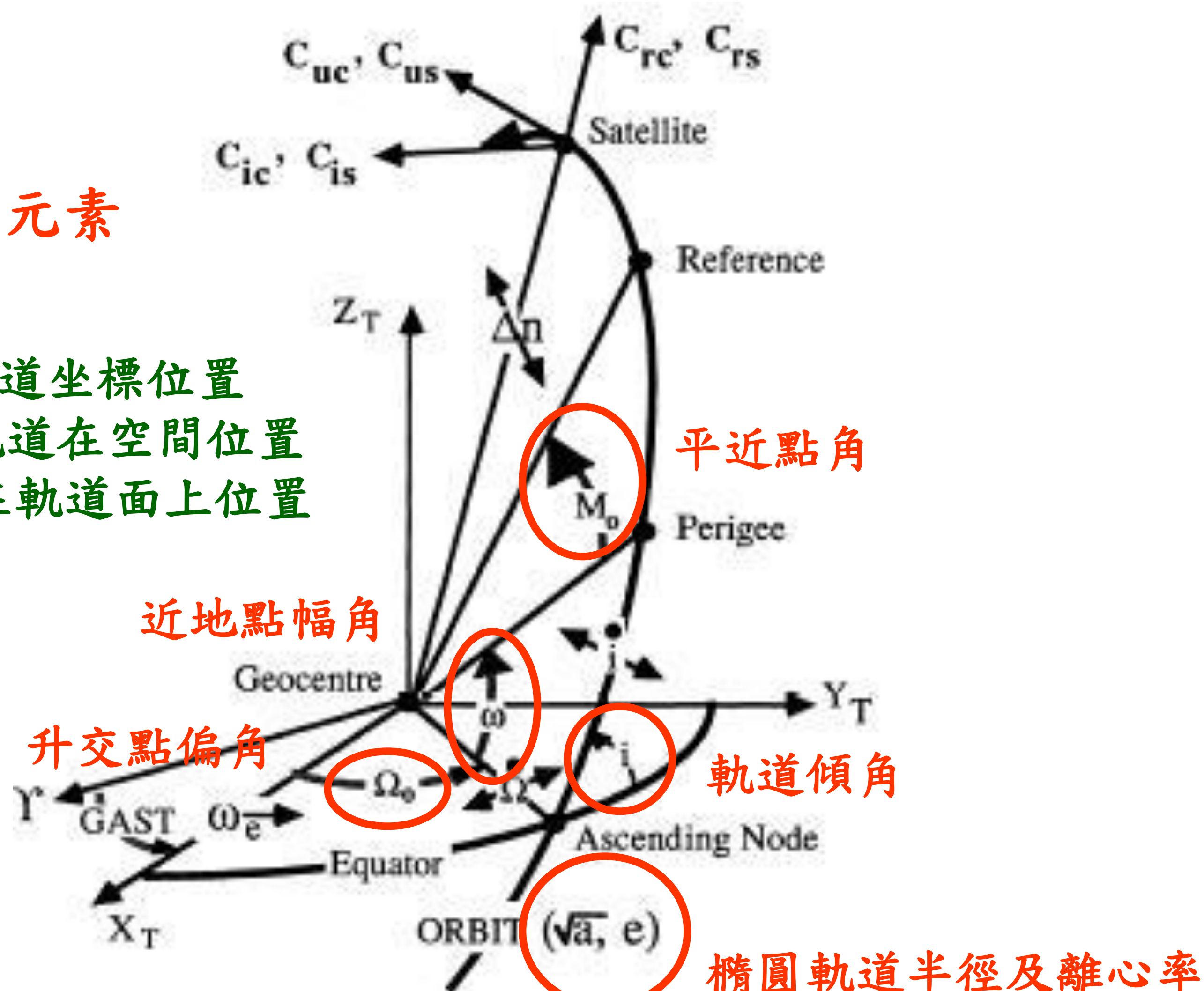
克卜勒軌道六元素

(Ω, i)描述軌道在赤道坐標位置
(Ω, ω, i)描述橢圓軌道在空間位置
(a, e, M)描述衛星在軌道面上位置



廣播星曆軌道參數

t_{oe}	軌道參數的參考時刻	時間參數 1 項
$\sqrt{a}$	a:軌道半長軸	Kepler軌道元素 6 項
M_0	參考時刻的平近點角	
e	軌道的離心率	
ω	參考時刻的近地點角距	
i_0	參考時刻的軌道傾角	
Ω_0	參考時刻的升交點經度	
⊿n	平均角速度修正量	軌道攝動改正參數 9 項
$\dot{i}$	軌道傾角的變化率	
$\dot{\Omega}$	升交點經度的變化率	
C_{uc}、C_{us}	升交點角距的攝動改正量	
C_{rc}、C_{rs}	衛星向量的攝動改正量	
C_{ic}、C_{is}	軌道傾角的攝動改正量	

廣播星曆資料格式

```
     2.10           N: GPS NAV DATA                                         RINEX VERSION / TYPE
XXRINEXN V2.10      AIUB                3-SEP-99 15:22                      PGM / RUN BY / DATE
EXAMPLE OF VERSION 2.10 FORMAT                                              COMMENT
     .1676D-07   .2235D-07  -.1192D-06  -.1192D-06                          ION ALPHA
     .1208D+06   .1310D+06  -.1310D+06  -.1966D+06                          ION BETA
     .133179128170D-06  .107469588780D-12   552960     1025                 DELTA-UTC: A0,A1,T,W
    13                                                                      LEAP SECONDS
                                                                            END OF HEADER
 6 99  9  2 17 51 44.0 -.839701388031D-03 -.165982783074D-10  .000000000000D+00
     .910000000000D+02  .934062500000D+02  .116040547840D-08  .162092304801D+00
     .484101474285D-05  .626740418375D-02  .652112066746D-05  .515365489006D+04
     .409904000000D+06 -.242143869400D-07  .329237003460D+00 -.596046447754D-07
     .111541663136D+01  .326593750000D+03  .206958726335D+01 -.638312302555D-08
     .307155651409D-09  .000000000000D+00  .102500000000D+04  .000000000000D+00
     .000000000000D+00  .000000000000D+00  .000000000000D+00  .910000000000D+02
     .406800000000D+06  .000000000000D+00
```

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廣播星曆資料內容

```
Toc → 1   4 10 16   3 59 60.0 3.682738170028D-04 1.932676241267D-12 0.000000000000D+00
   PRN year mon day h m s          a0(sec)                a1(sec/sec)            a2(sec/sec2)
     2.020000000000D+02-6.281250000000D+01 3.607650178594D-09-2.339087658676D+00

        IODE                 Crs(m)              Δn (rad/sec)           M0(rad)
     -3.246590495110D-06 5.403156625107D-03 1.281313598156D-05 5.152644205093D+03

        Cuc (rad)            e                   Cus (rad)              (a)^(1/2)
     5.328000000000D+05 9.685754776001D-08 5.116999100123D-01-4.097819328308D-08

        Toe(sec)             Cic (rad)           Ω0(rad)                Cis (rad)
     9.813694784808D-01 1.457500000000D+02-1.694602396272D+00-7.385307476682D-09

        io (rad)             Crc (m)             w (rad)                dotΩ(rad/sec)
     2.253665309926D-10 1.000000000000D+00 1.292000000000D+03 0.000000000000D+00

       dot i (rad/sec)                 GPS Week # (to go with Toe) Continuous number, not mod(1024)!
     0.000000000000D+00 0.000000000000D+00-3.725290298462D-09 2.020000000000D+02
       SV accuracy(m)        SV health           Tgd(sec)               IODC
     5.328000000000D+05
```

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衛星ECEF位置計算

MATLAB Programming

```
deltatsv=a0+a1*(tsv-toc)+a2*((tsv-toc)^2)-tgd;
t=tsv-deltatsv;
tk=t-toe;
n0 = (sqrtu)/(sqrta ^ 3);
n = n0 + deltan;
Mk = Mo + n * tk;
Ek = Mk;
error=1;
while error > 0.0000000001,
        Eo = Ek;
                Ek = Ek-(Ek - Mk - e * sin(Ek)) / (1 - e * cos(Ek));
                error = abs(Ek - Eo);
end
cosvk = (cos(Ek)-e)/(1-e*cos(Ek));
sinvk = (sqrt(1-e^2))*sin(Ek)/(1-e*cos(Ek));
vk = atan2(sinvk,cosvk)
fik=vk+w;
deltauk = Cus*sin(2* fik)+Cuc*cos(2* fik)
uk = fik + deltauk
deltark = Crs*sin(2* fik)+Crc*cos(2* fik)
rk = (sqrta^2)*(1-e*cos(Ek))+deltark
deltaik = Cis*sin(2* fik)+Cic*cos(2* fik)
ik = io+di*tk+deltaik
deltalk = ((Omega_dot-Omega_e)*tk)-(Omega_e*toe);
lk = Omega_0 + deltalk
xkpla = rk*cos(uk)
ykpla = rk*sin(uk)
X = xkpla*cos(lk)-ykpla*cos(ik)*sin(lk);
Y = xkpla*sin(lk)+ykpla*cos(ik)*cos(lk);
Z = ykpla*sin(ik);
```

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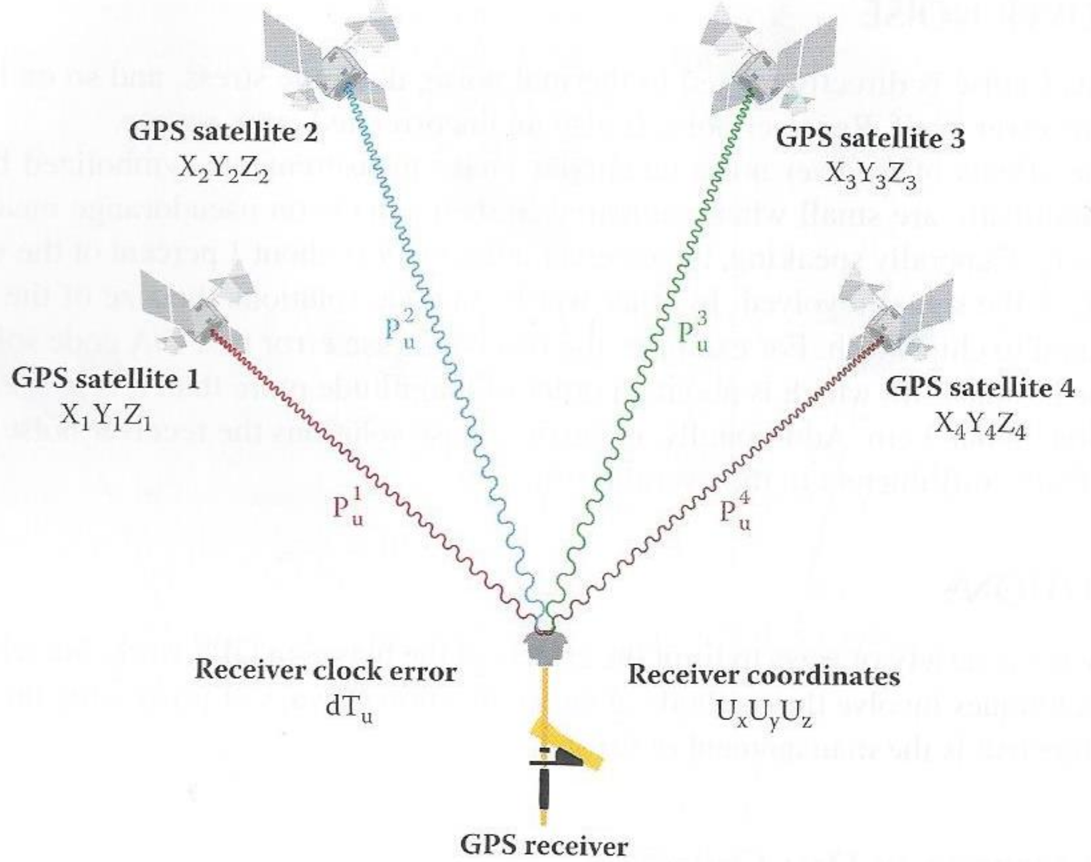
單點(導航)定位



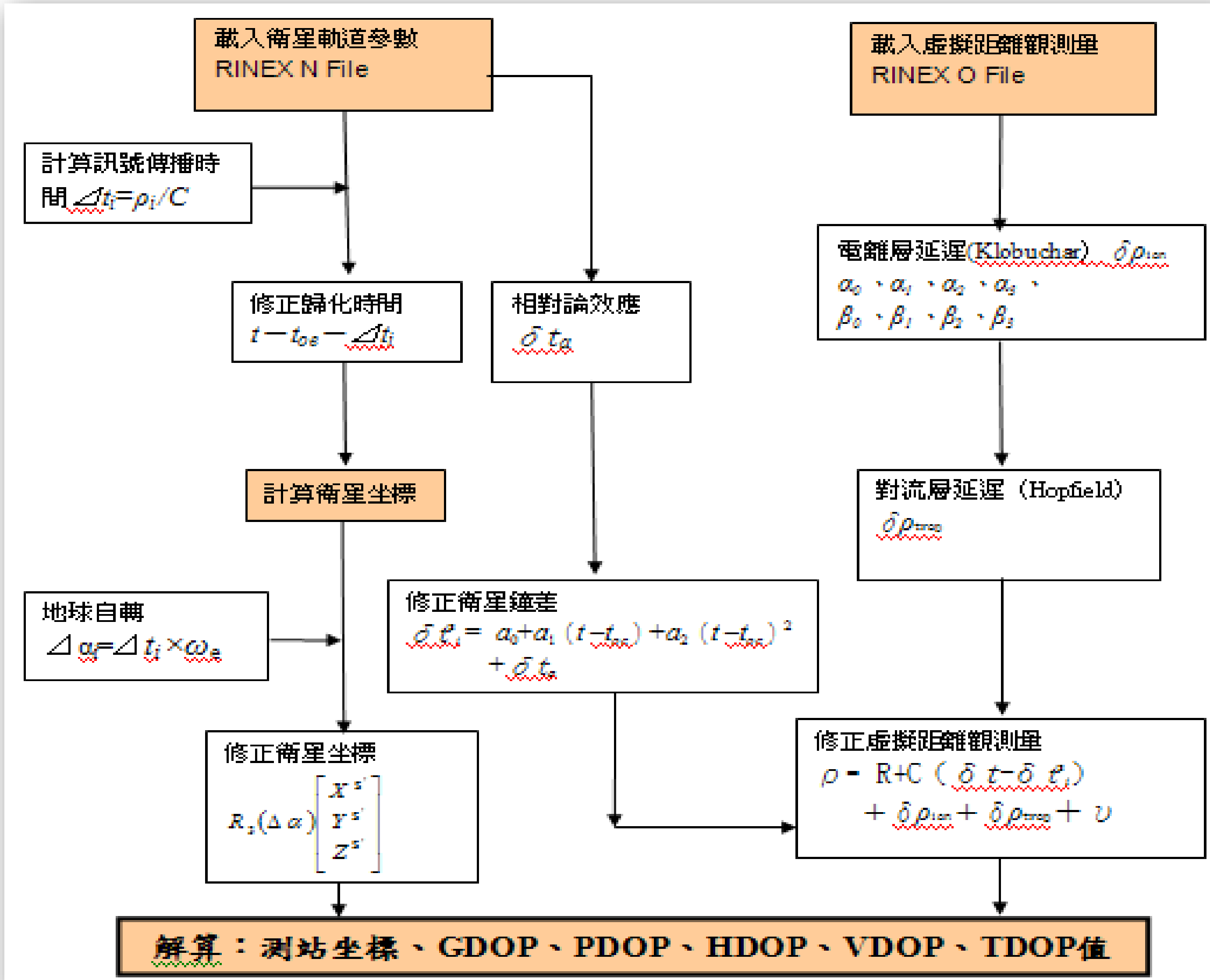
$$p_u^1 = \sqrt{(X_1-U_x)^2+(Y_1-U_y)^2+(Z_1-U_z)^2}+c(dT_u)$$

$$p_u^2 = \sqrt{(X_2-U_x)^2+(Y_2-U_y)^2+(Z_2-U_z)^2}+c(dT_u)$$

$$p_u^3 = \sqrt{(X_3-U_x)^2+(Y_3-U_y)^2+(Z_3-U_z)^2}+c(dT_u)$$

$$p_u^4 = \sqrt{(X_4-U_x)^2+(Y_4-U_y)^2+(Z_4-U_z)^2}+c(dT_u)$$

單點(導航)定位計算



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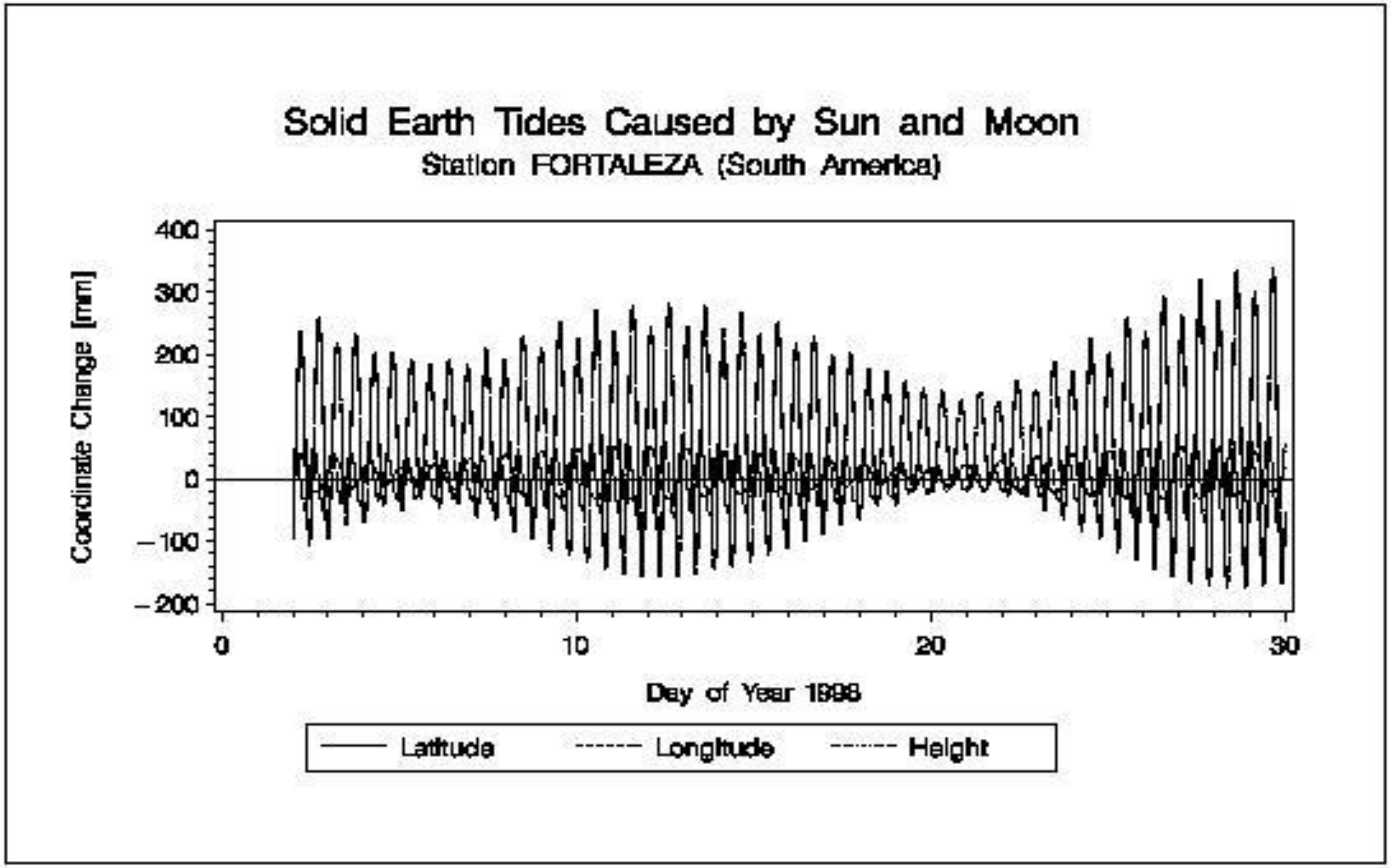
地球固體潮位移效應



高程位移可達30公分　經緯度位移可達5公分

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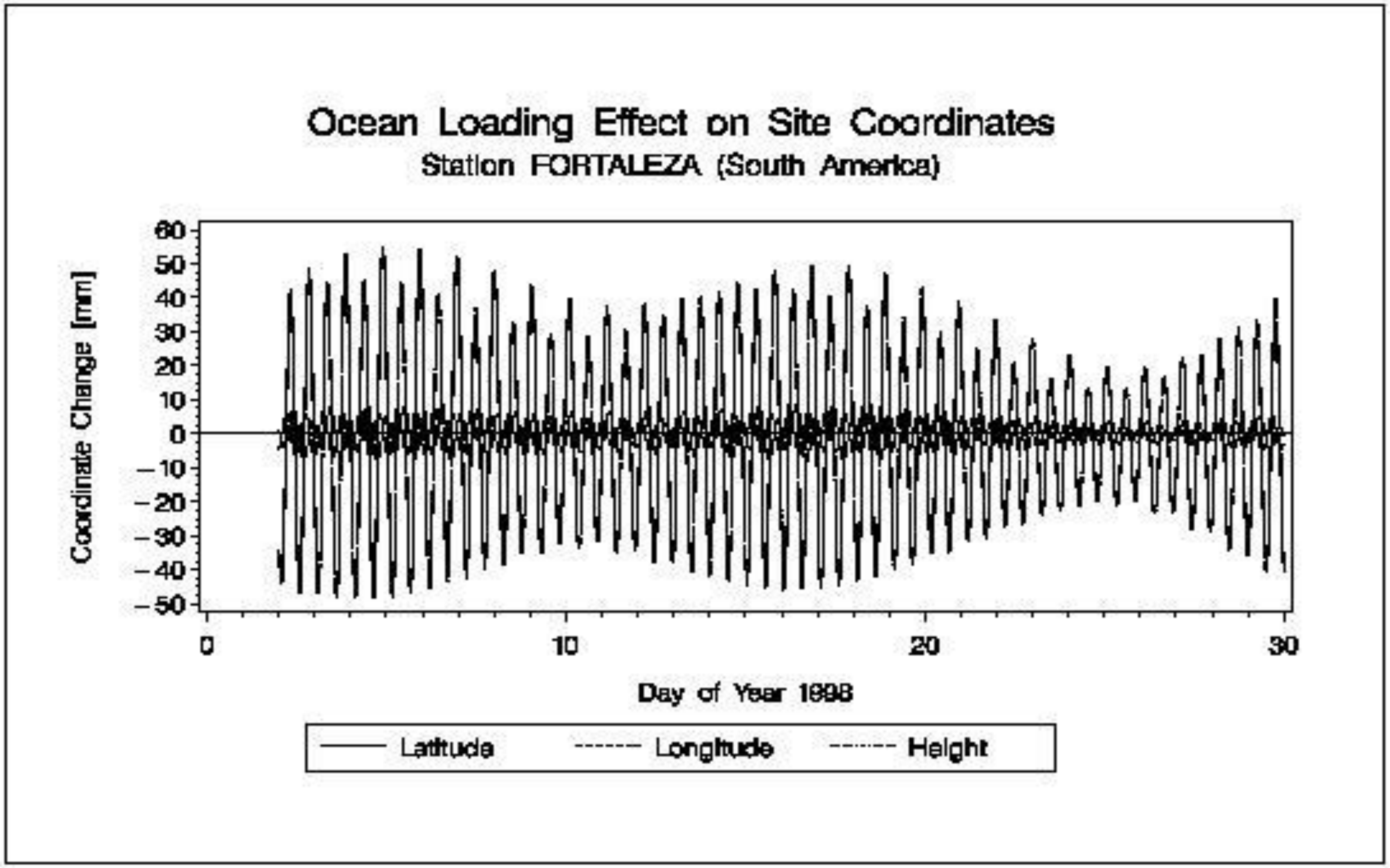
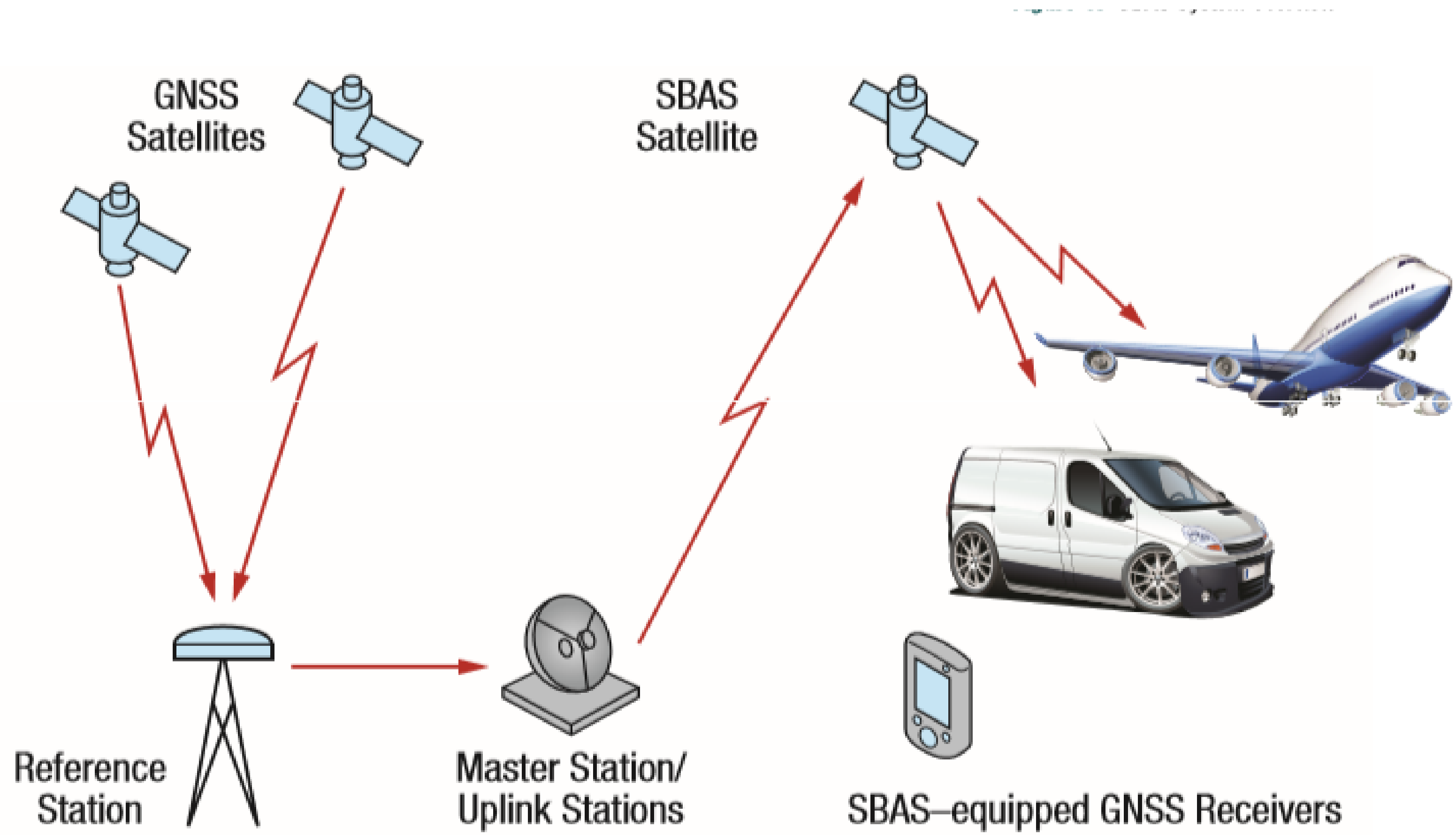
海潮負載位移效應

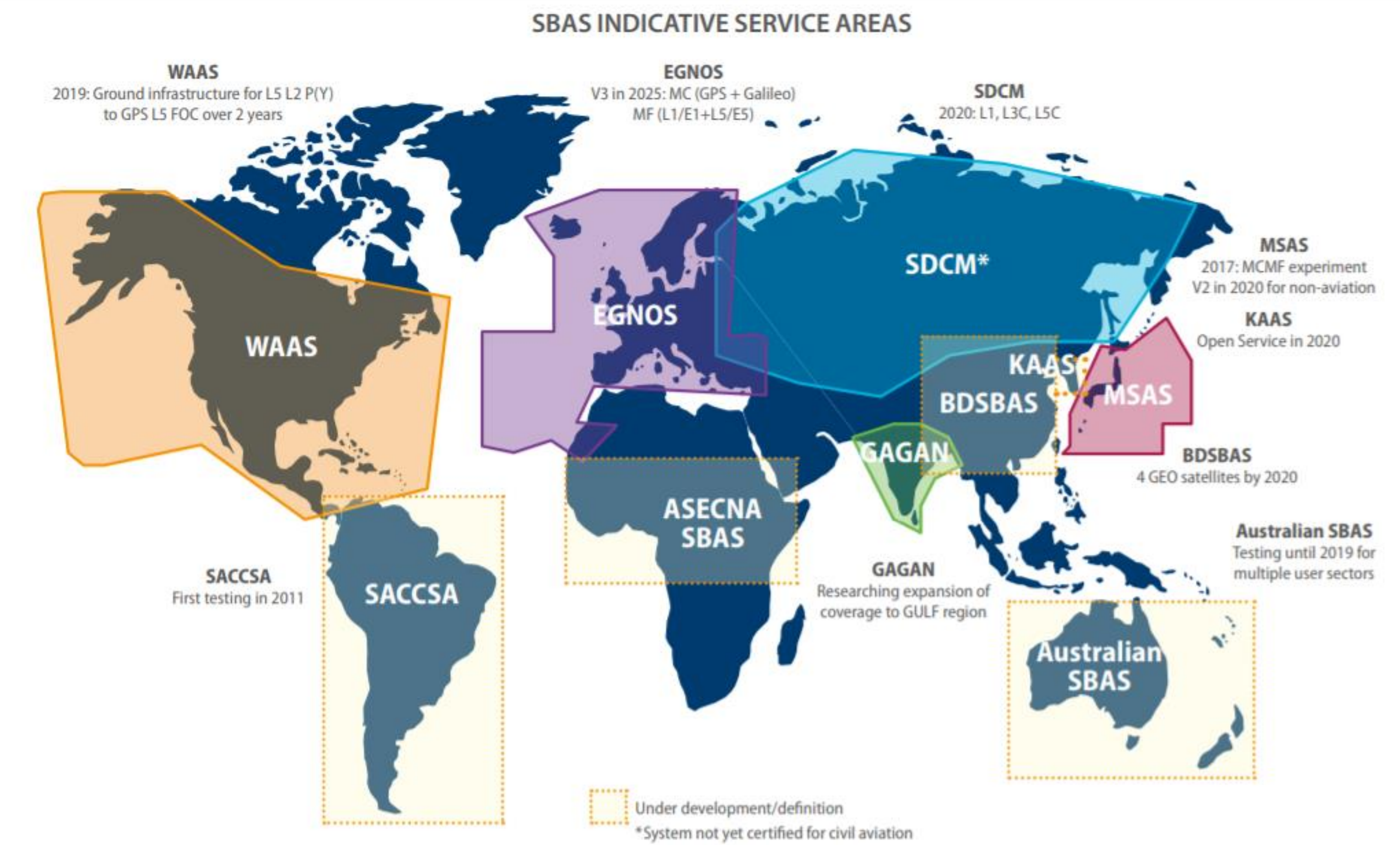


高程位移可達5公分　經緯度位移可達1公分

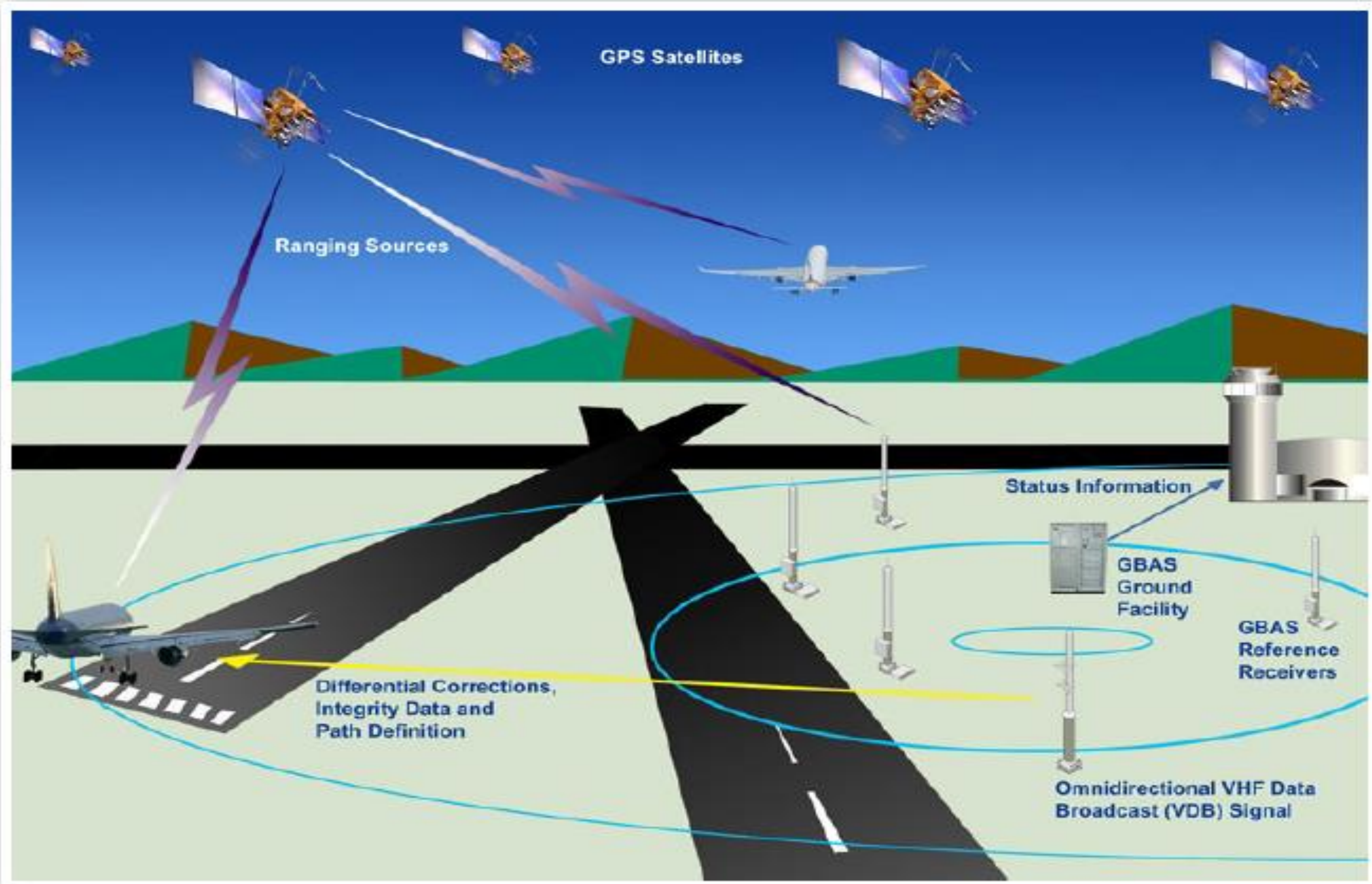
衛星增益系統(SBAS)


GNSS
Satellites
SBAS
Satellite
Reference
Station
Master Station/
Uplink Stations
SBAS–equipped GNSS Receivers

SBAS服務


SBAS INDICATIVE SERVICE AREAS
WAAS
2019: Ground infrastructure for L5 L2 P(Y) to GPS L5 FOC over 2 years
EGNOS
V3 in 2025: MC (GPS + Galileo) MF (L1/E1+L5/E5)
SDCM
2020: L1, L3C, L5C
MSAS
2017: MCMF experiment V2 in 2020 for non-aviation
KAAS
Open Service in 2020
BDSBAS
4 GEO satellites by 2020
Australian SBAS
Testing until 2019 for multiple user sectors
GAGAN
Researching expansion of coverage to GULF region
SACCSA
First testing in 2011
WAAS
EGNOS
SDCM*
KAAS
BDSBAS
MSAS
GAGAN
ASECNA SBAS
SACCSA
Australian SBAS
Under development/definition
*System not yet certified for civil aviation

地面增益系統(GBAS)



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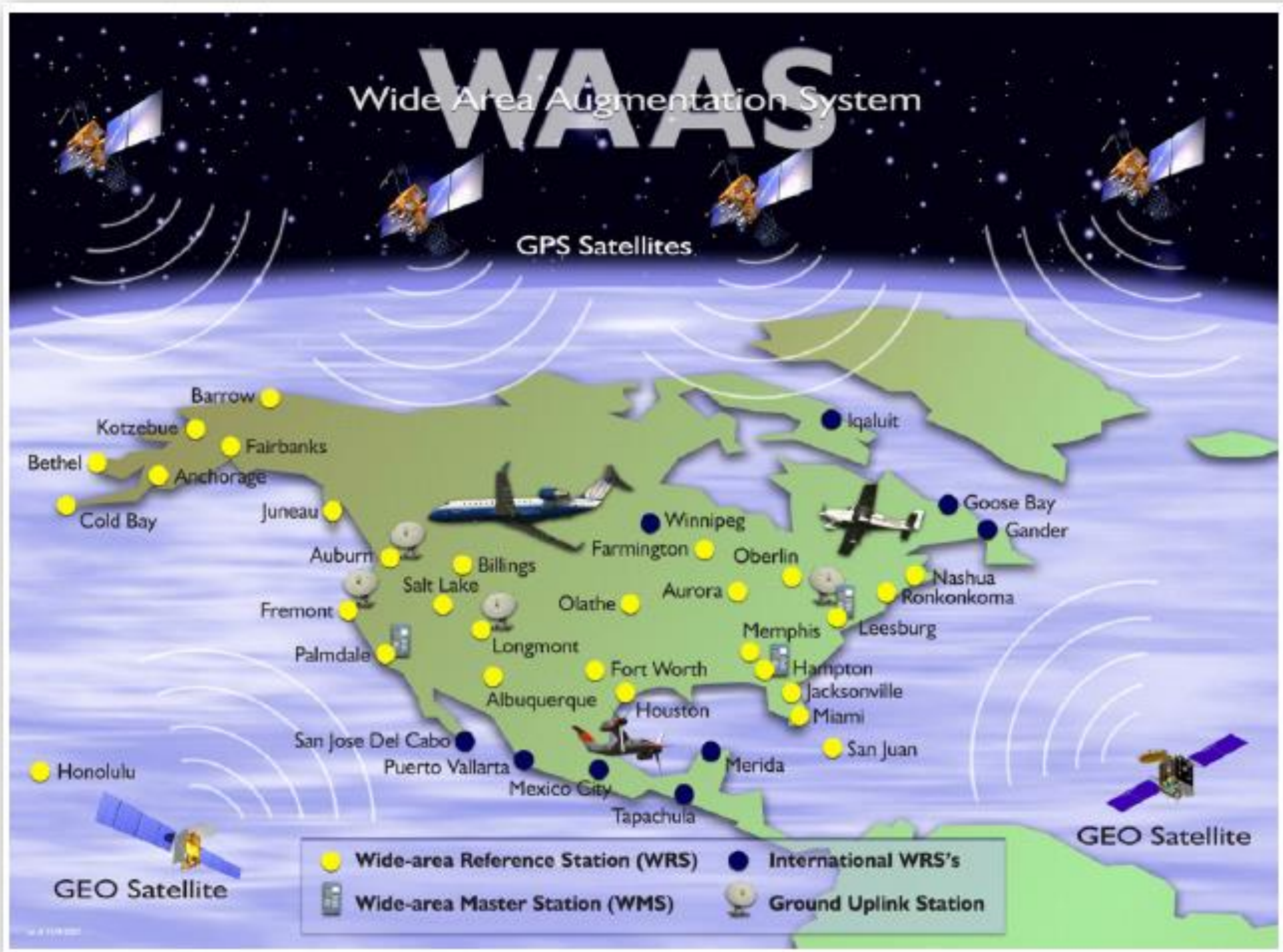
廣域增益系統(WAAS)



導航定位安全性評估

SAFETY- AND LIABILITY-CRITICAL KEY PERFORMANCE PARAMETERS

Key Performance Parameter (KPP)***	Transport Safety- and Liability Critical Solutions
Availability	● High priority
Accuracy	● High priority
Continuity	● High priority
Integrity	● High priority
Robustness	● High priority
Indoor penetration	● Low priority
Time To First Fix (TTFF)	● High priority
Latency	● High priority
Power consumption****	● Medium priority

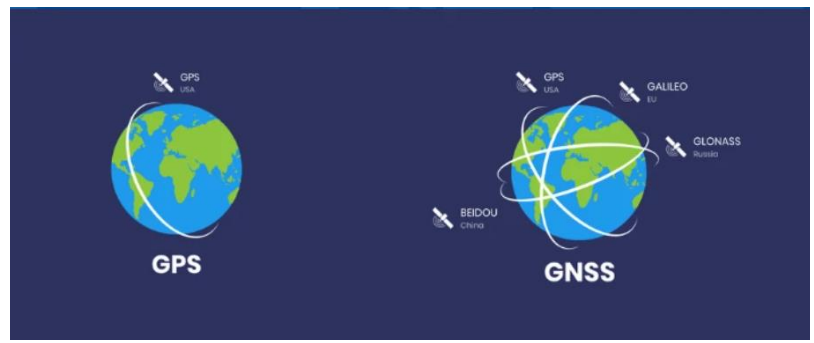
● Low priority ● Medium priority ● High priority

GNSS的發展

Global Navigation Satellite System (GNSS)

Global Navigation Satellite Systems

- Global Positioning System (GPS, USA)
- GLObal Navigation Satellite System (GLONASS, Russia)
- Galileo (EU)
- BeiDou (BDS, China)



Regional Augmentation Systems

- Quasi Zenith Satellite System (QZSS, Japan)
- Indian Regional Navigation Satellite System (IRNSS, India)

GNSS發展現況

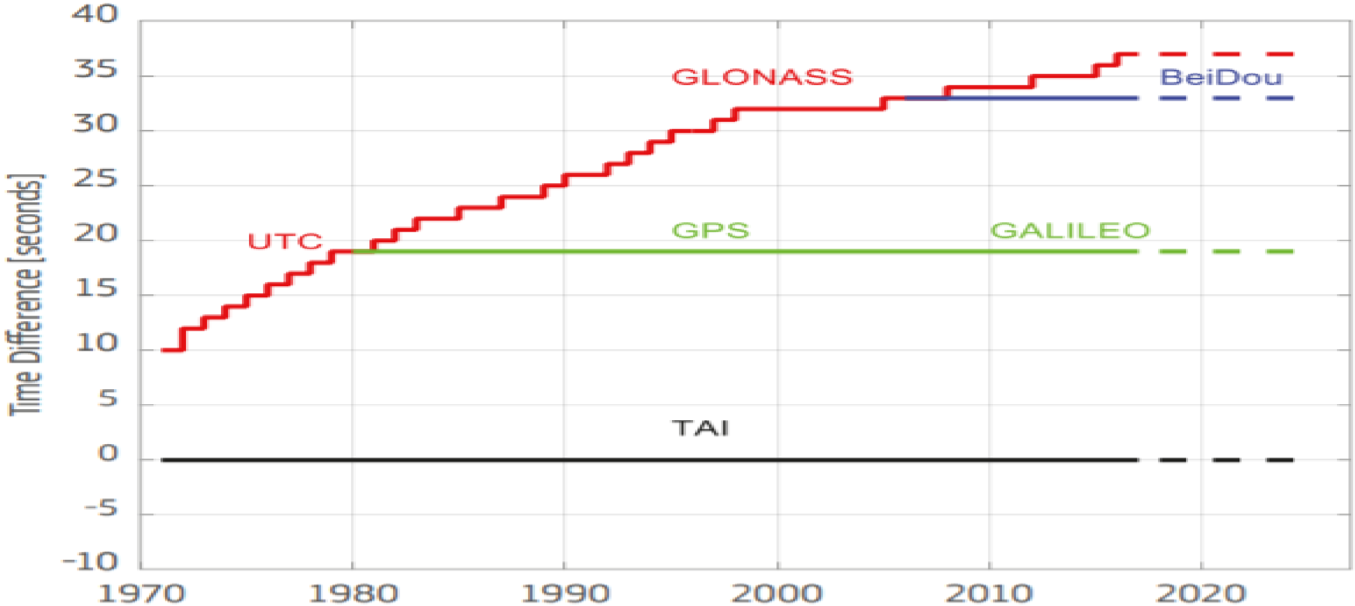
- Global Constellations
  - **GPS (24+3)**
  - GLONASS (24+)
  - GALILEO (24+3)
  - BDS/BEIDOU (27+3 IGSO + 5 GEO)

- Regional Constellations
  - QZSS (4+3)
  - IRNSS (7)
- Satellite-Based Augmentations
  - **WAAS (3)**
  - MSAS (2)
  - EGNOS (3)
  - GAGAN (2)
  - SDCM (3)

GNSS系統比較

Parameter	GPS	GLONASS	Galileo	BeiDou
Orbital Period	11hrs 58min	11hrs 15mins	14hrs 04mins	12hrs 37min
Orbital Height	22,200 Km	19,100 Km	23,222 Km	21,150 Km
Inclination	55°	64,8°	56°	55°
Number of Orbital Planes	6	3	3	6
Number of satellites	24 operational + 6 spares	21 operational + 3 spares	24 operational + 6 spares	27 MEOs + 5 GEOs + 3 IGSOs
Reference frame	WGS-84	PZ90	GTRF	CGCS 2000
Reference time	GPS Time (GPST)	GLONASS Time (GLONASST)	Galileo System Time (GST)	BeiDou Time (BDT)

時間系統比較



Systems	Relationship
GPST - TAI	$TAI = GPST + 19s$
GST - TAI	$TAI = GST + 19s$
GLONASST - TAI	$TAI = GLONASST - 3h + leapsecond_{UTC\text{-}TAI}$
UTC - TAI	$UTC = TAI - leapsecond_{UTC\text{-}TAI}$
BDT-TAI	$TAI = BDT + 33s$

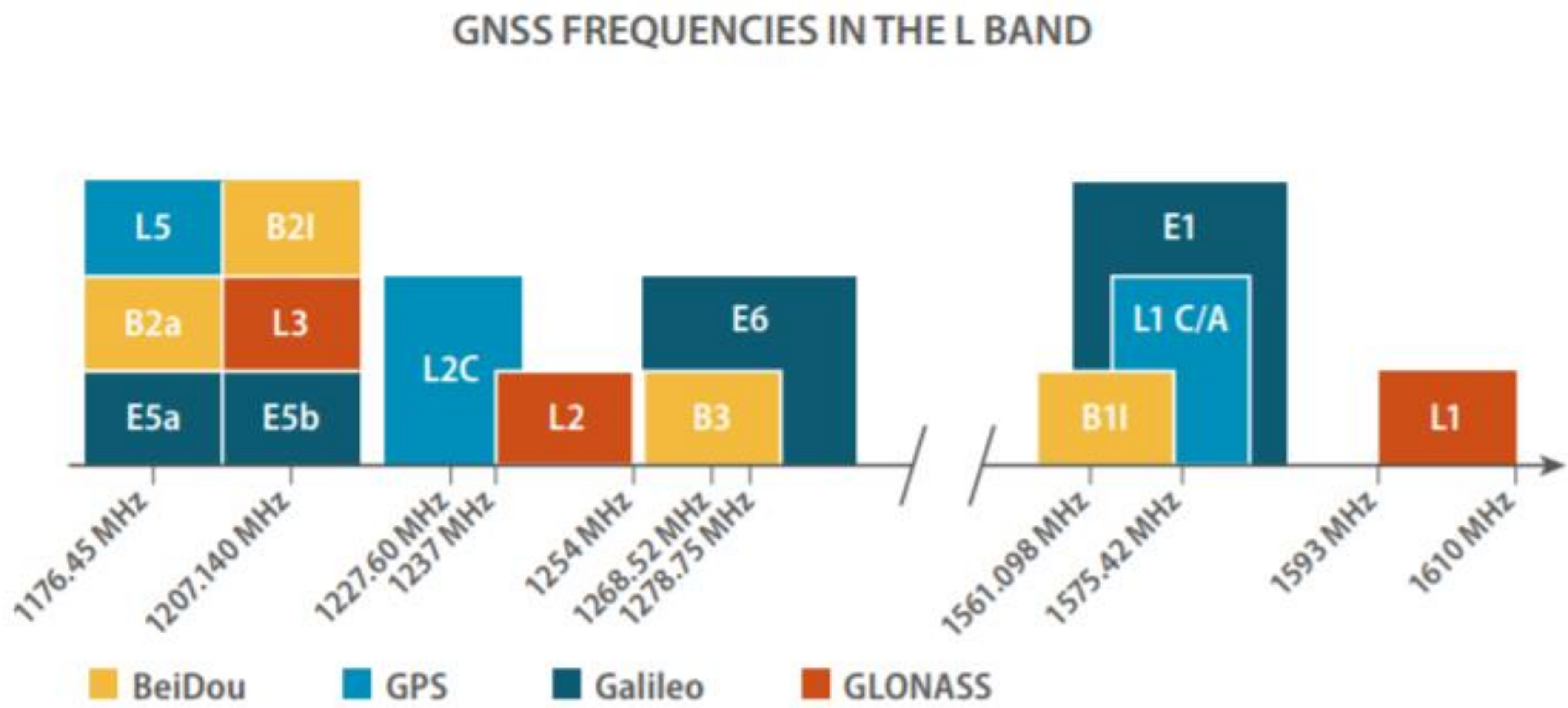
GNSS使用頻道

	L5 / L5OC / E5a / B2a	L2 / L2C / L2OC	E6 / LEX	L1 / L1OC / E1 / B1
GPS	30	30		30
GLONASS	24	24		24
Galileo	30		30	30
BeiDou	35		35	35
QZSS	3	3	3	3
IRNSS	7			
	129	← ARNS* Bands	→	122

Frequency band used by the system, with N = number of satellites

Frequency band not used by the system

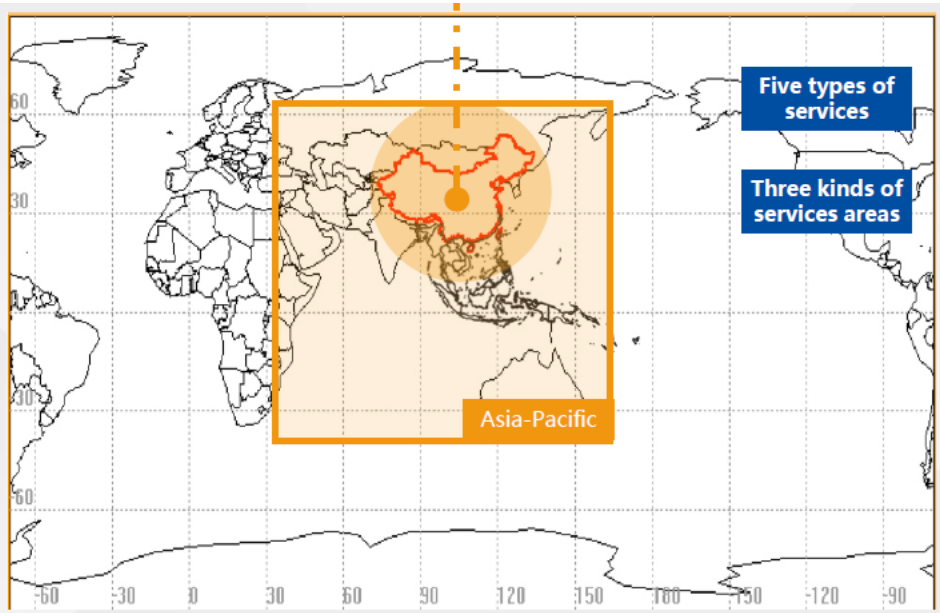
GNSS頻道分布


GNSS FREQUENCIES IN THE L BAND
L5
B2I
B2a
L3
E5a
E5b
L2C
L2
E6
B3
E1
L1 C/A
B1I
L1
1176.45 MHz
1207.140 MHz
1227.60 MHz
1237 MHz
1254 MHz
1268.52 MHz
1278.75 MHz
1561.098 MHz
1575.42 MHz
1593 MHz
1610 MHz
BeiDou
GPS
Galileo
GLONASS

中國大陸 BeiDou系統 (BDS)

- The BDS-3 space constellation, consisting of 30 satellites (24MEOs+3GEOs+3IGSOs), were successfully deployed between November 5, 2017 and June 23, 2020.
- There are 15 operational BDS-2 satellites (5GEOs + 7IGSOs + 3MEOs, with open service navigation signals B1I/B2I/B3I, using PRN from 1 to 15, at the moment.

Type of service		Signal frequency	Satellite
Basic navigation services		B1I, B3I, B1C, B2a	3IGSO+24MEO
		B1I, B3I	3GEO
BDSBAS		BDSBAS-B1C, BDSBAS-B2a	3GEO
Short-message communication services	Regional	L (uplink) S (downlink)	3GEO
	Global	L (uplink)	14MEO
		B2b (downlink)	3IGSO+24MEO
International search and rescue service		UHF (uplink)	6MEO
		B2b (downlink)	3IGSO+24MEO
Precise Point Positioning service		B2b	3GEO



Navigation, Positioning and Timing / GSMCS / SAR

地區增益型-日本QZSS與印度IRNSS

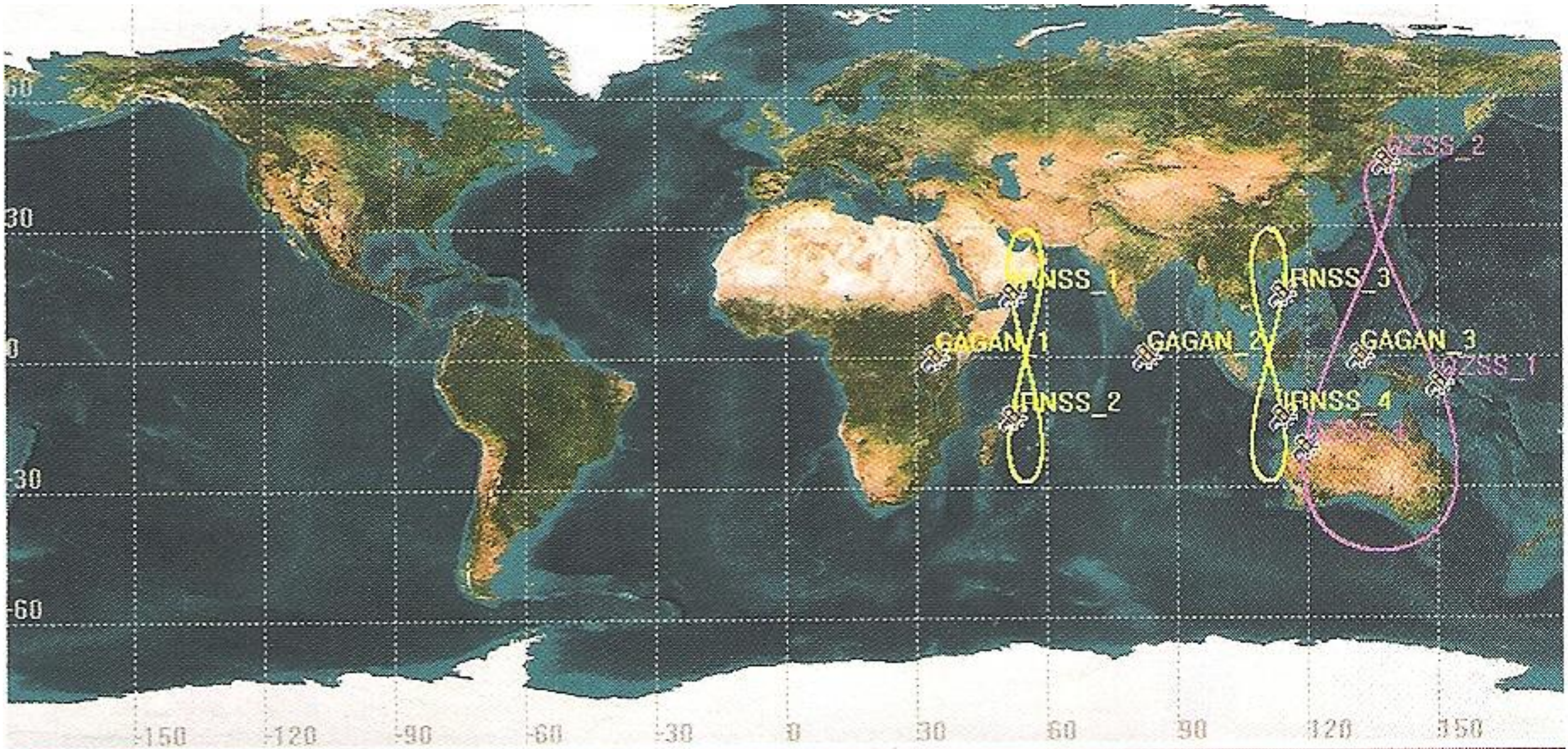
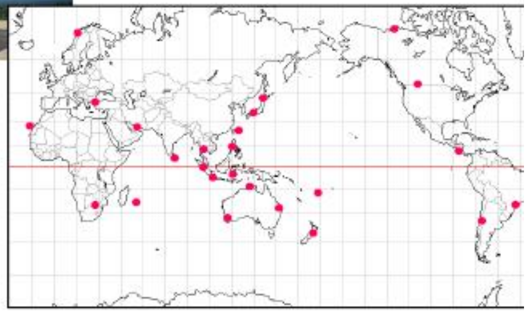


FIGURE 5 Ground Tracks of QZSS and IRNSS.

日本QZSS

- **_Constellation:_**
  - 1 GEO Satellite, 127E
  - 3 QZO Satellite (IGSO)
- **_Ground System_**
  - 2 Master Control Stations
    - Hitachi-Ota and Kobe
  - 7 Satellite TTC Stations
    - Located south-western islands
  - Over 30 Monitor Stations around the world



Cabinet Office

Department of Applied Geomatics, Chien-Hsin University, Taiwan

GNSS運作效益

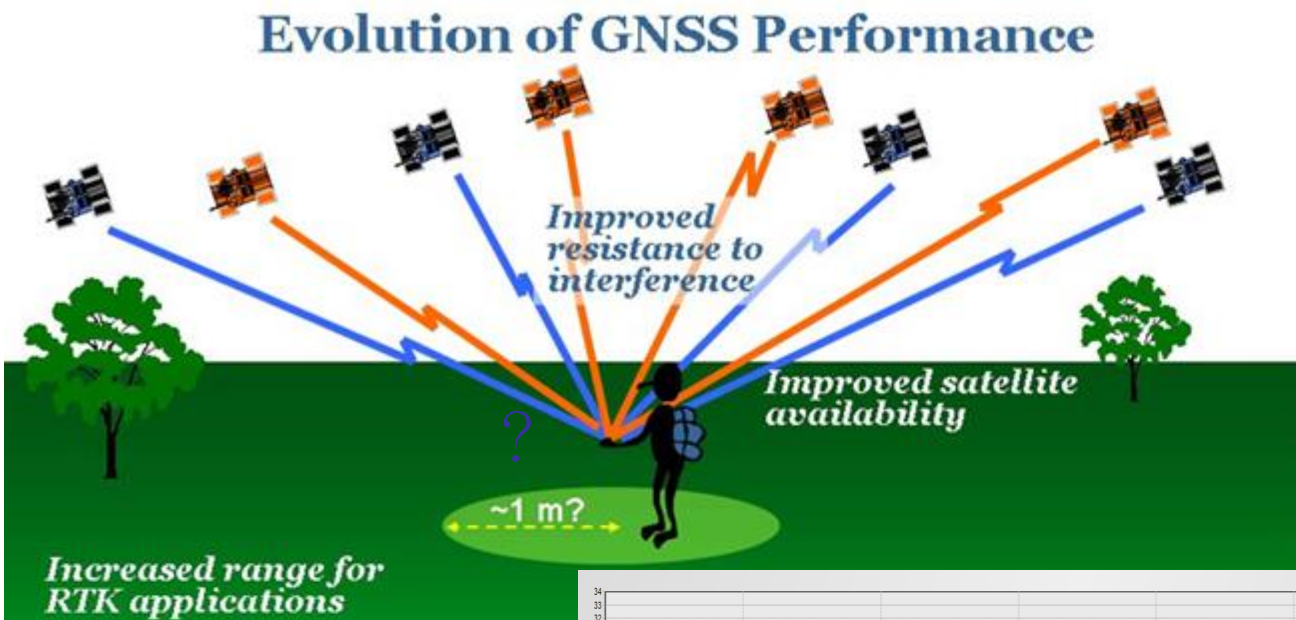
抗干擾性提升

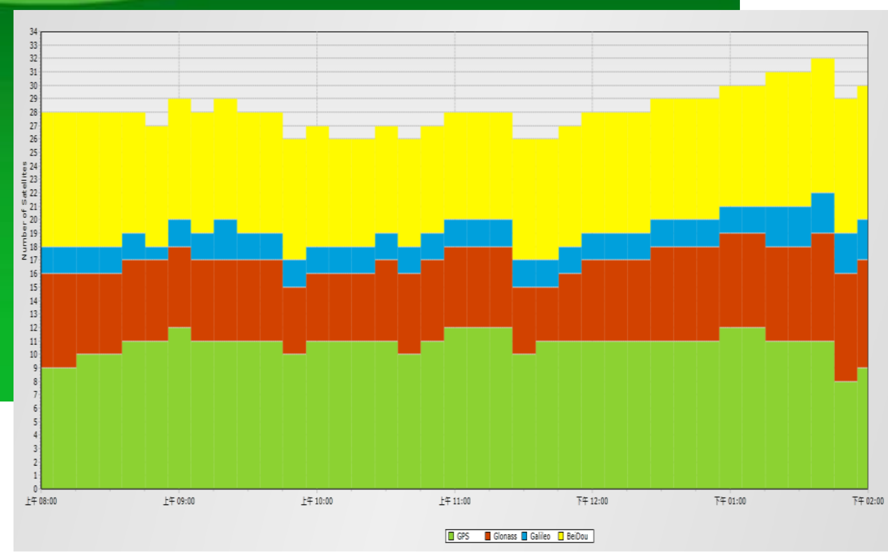
可用性增加

定位距離增長

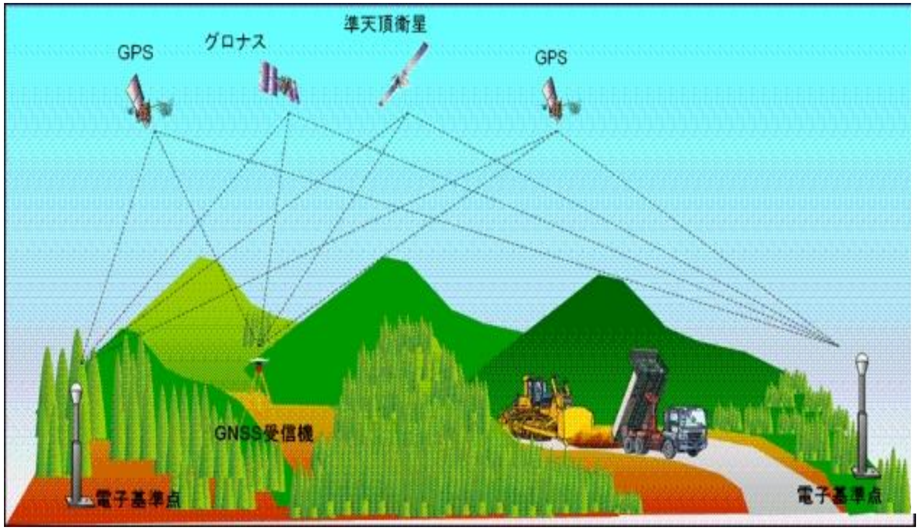
解算時間縮短

定位精度提升





GNSS可用性增加



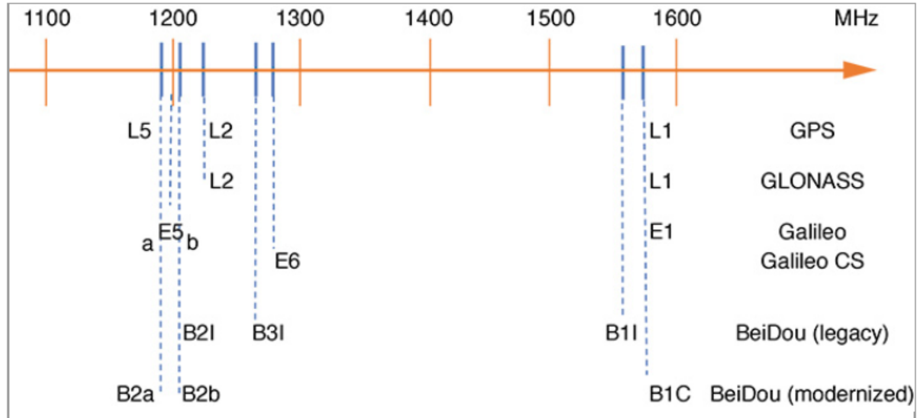
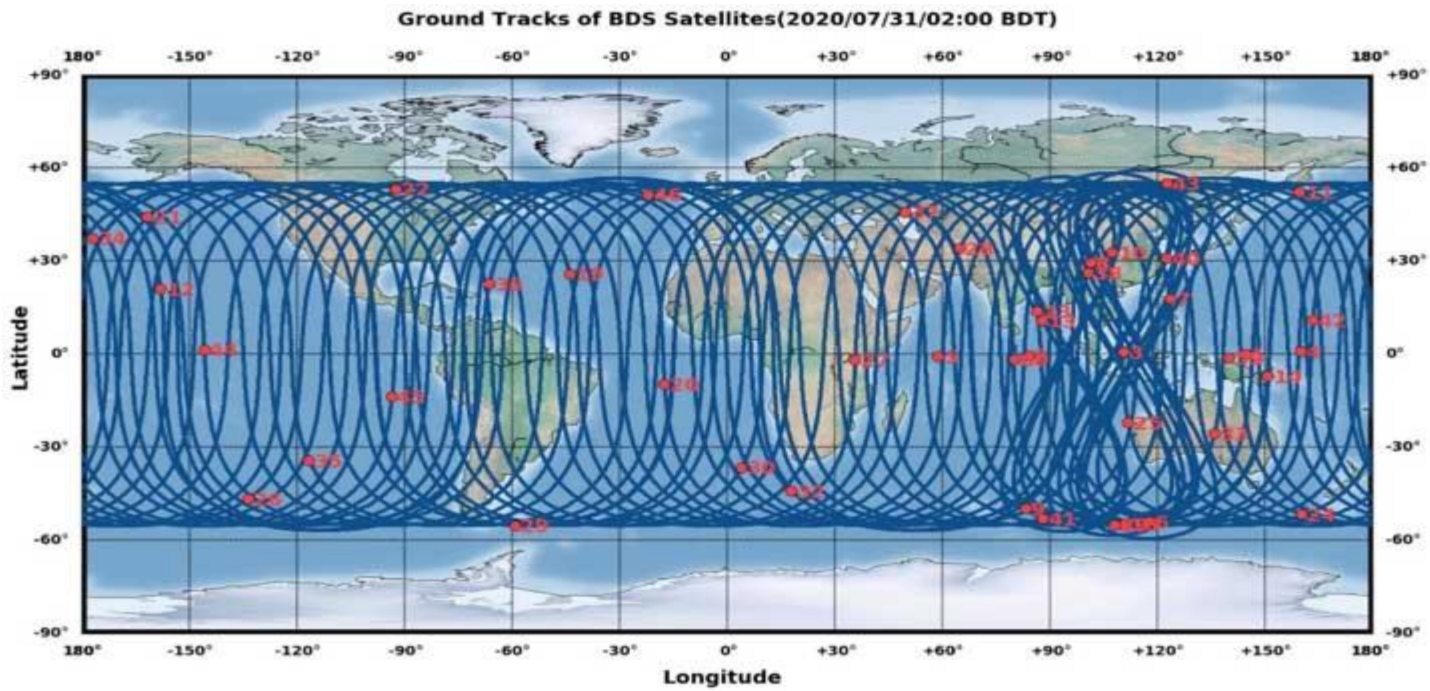


FIGURE 1. GNSS open signals (as of May 2018). (Image: authors)



北斗軌跡

多星系/多頻信號之運作特性

	優點	待克服點
多星系	• 增加遮蔽區的可用性 • 提升DOP值 • 提供較佳的可靠性	GNSS間之基準及時間尺度差異
多頻信號	• 消除電離層誤差(雙頻消除一階項/三頻消除二階項) • 平均掉多路徑誤差 • 增加抗干擾性	• 移除電離層處理所增加的雜訊 • 接收儀所增加的多重前置器 • 信號頻率間的偏差

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GNSS動態定位評估量

- 衛星數(satellite usage): 截取角以上的接收衛星數量
- 可用性(availability):觀測時段內取得固定解相對於全數解之比例
- 精度(accuracy):固定解位置與較高精度地面真值的偏離量
- 可靠度(reliability):位置誤差小於3倍品質指標之比例
- 固定解需時(time to fix):信號未斷訊下取得固定解之所需時間

RTK固定解收斂時間

空曠區 10km內基線	單星系 (GPS)	雙星系(GPS/ GLONASS)	多星系 (GPS/GLONASS /BDS/Galileo)
單頻	1-10分鐘	30秒-5分鐘	3分鐘內
雙頻	10秒-1分鐘	**10秒**	1秒
三(多)頻	未定	1秒	1秒內

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GNSS觀測量整合問題

- 接收機各星系間之射頻偏差
- 各星系之坐標系統不一致
- 各星系之時間系統不一致

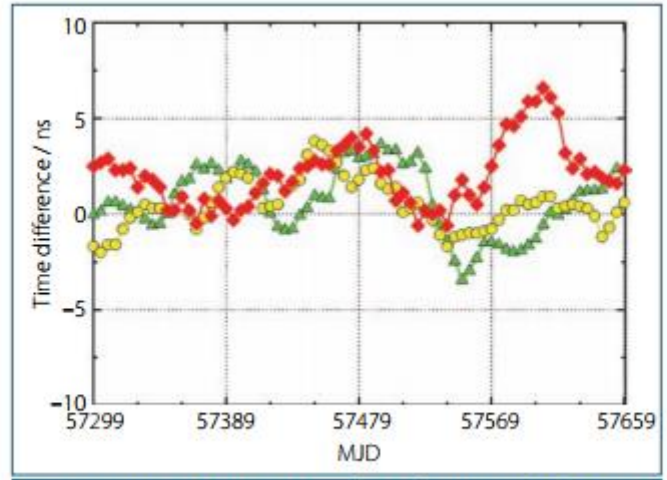

FIGURE 1 Reference time scales for GPS (yellow), GLONASS (red) and Galileo (green) in comparison with UTC during one year, ending at Modified Julian Day (MJD) 57659, September, 28 2016.

$$\begin{bmatrix} R^1 - \rho_0^1 \\ \vdots \\ R^n - \rho_0^n \end{bmatrix} = H \cdot \begin{bmatrix} dx \\ dy \\ dz \\ c \cdot dt_r \\ c \cdot d\tau_{GPS/GLONASS} \\ c \cdot d\tau_{GPS/Galileo} \\ c \cdot d\tau_{GPS/BeiDou} \end{bmatrix}.$$

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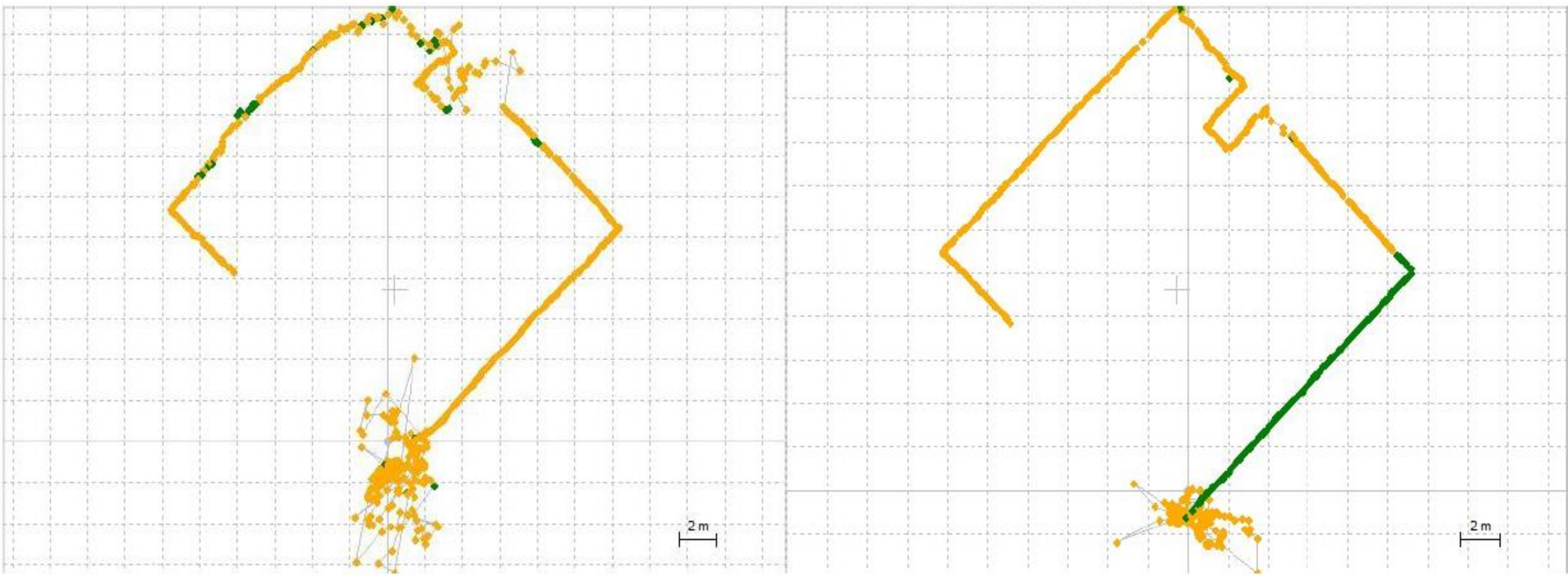
運用效益(手機案例)

Post-Processing Output: GPS L1 vs GPS + GAL+ BDS + QZS L1/L5



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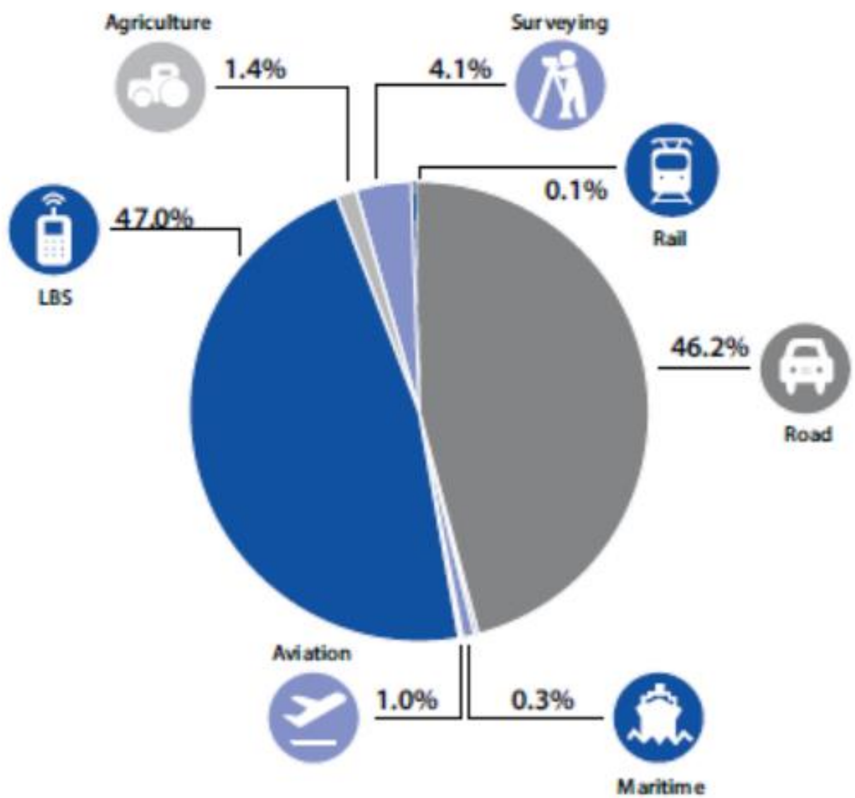
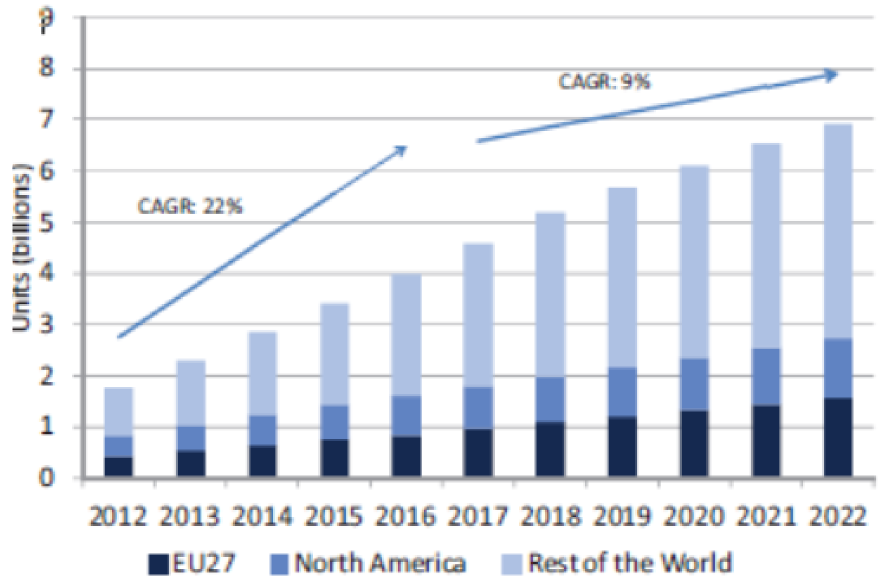
GNSS市場趨勢





Constellation capability of GNSS receivers[1]