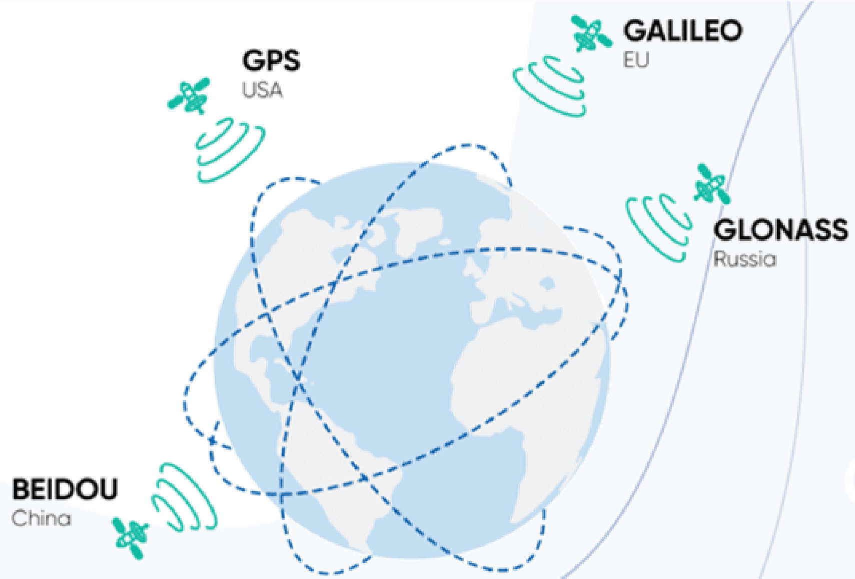
中央氣象署113年三十八屆天氣分析與預報研討會

利用全球衛星導航系統訊號進行定位偏差與電離層狀態分析

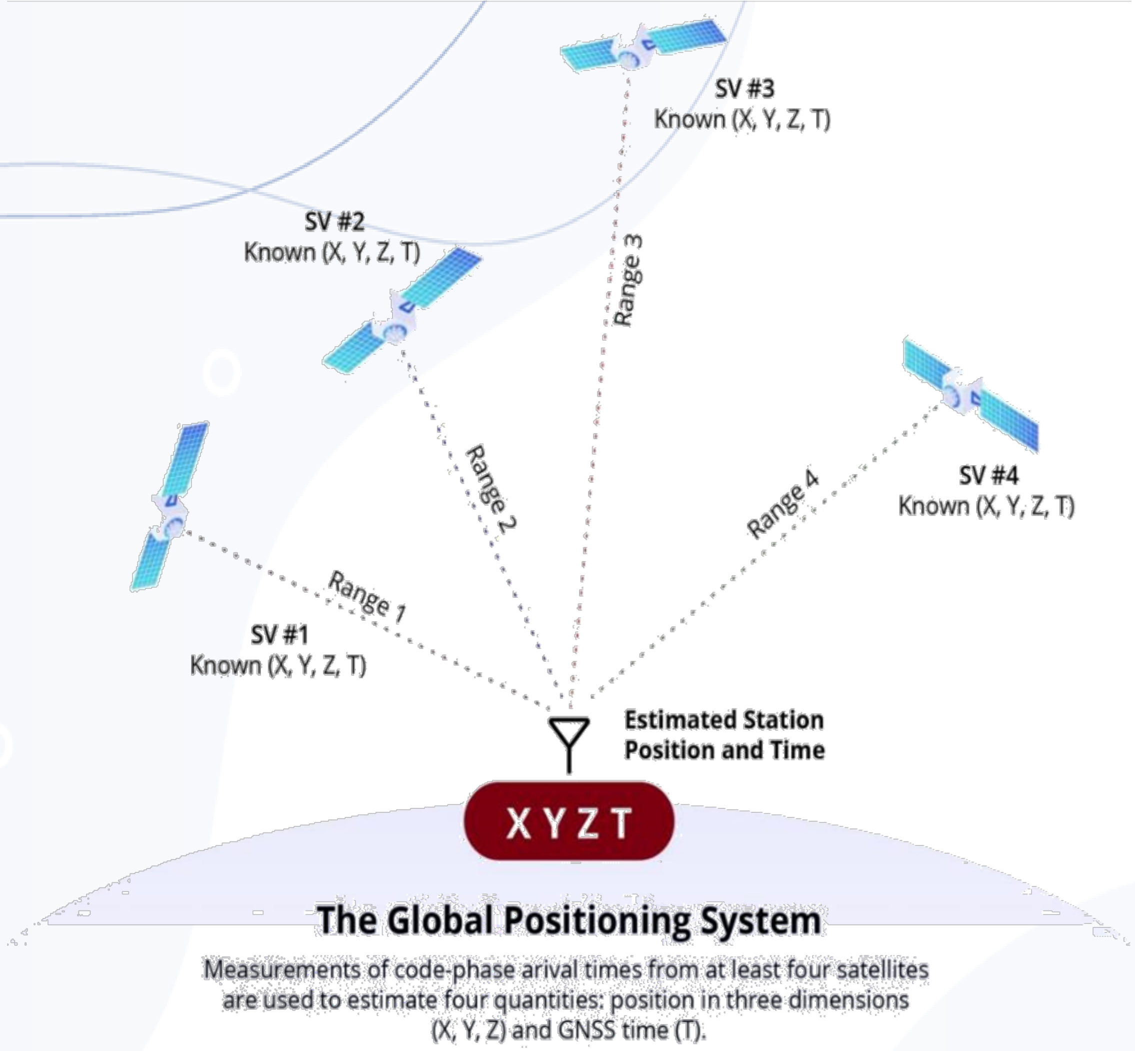
李奕德[1] (itlee@tasa.org.tw), 黃俊穎[2]
1.國家太空中心衛星操控組, 2.中央氣象署數值資訊組

報告大綱

- 全球導航衛星系統觀測
- 資料比對與分析
  - ◆衛星使用數量與水平定位精度
  - ◆水平偏差時段分布
  - ◆電離層不規則體影響
  - ◆定位數據資料短缺分析
- 討論與總結

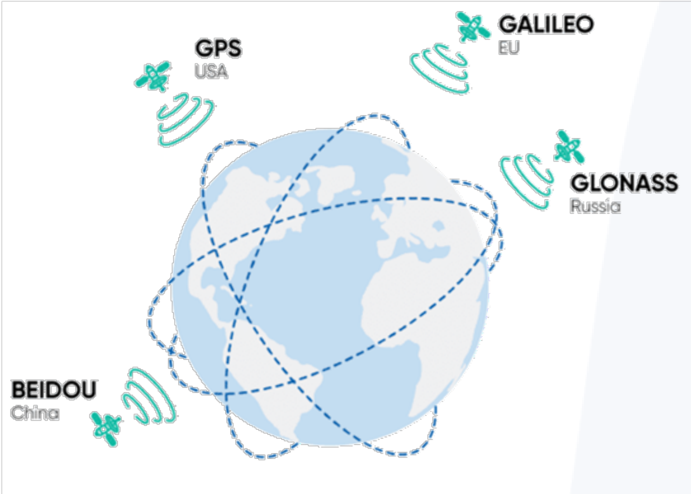

GPS
USA
GALILEO
EU
GLONASS
Russia
BEIDOU
China

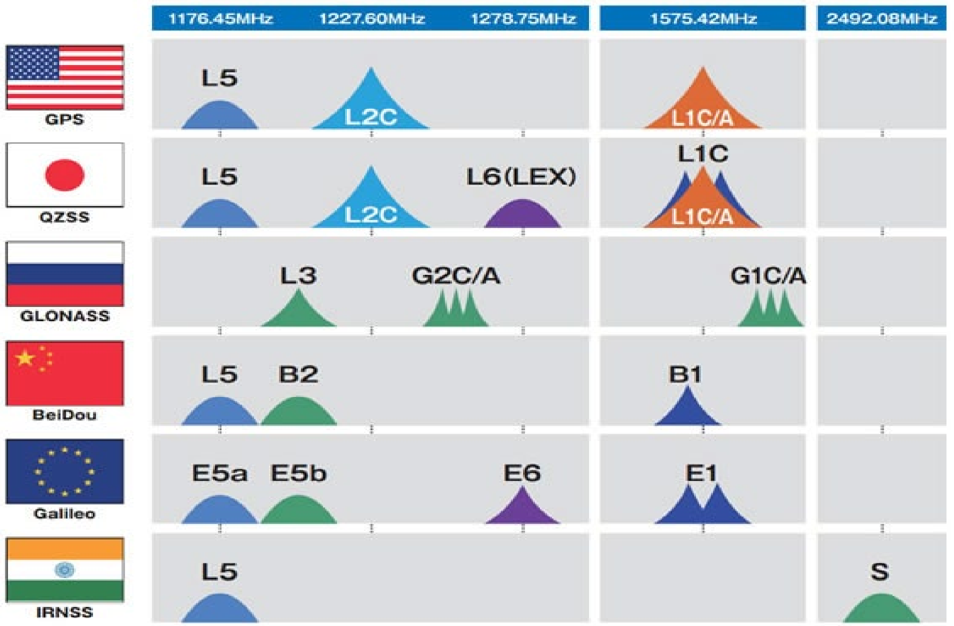
全球導航衛星系統(GNSS)


SV #3
Known (X, Y, Z, T)
SV #2
Known (X, Y, Z, T)
SV #4
Known (X, Y, Z, T)
SV #1
Known (X, Y, Z, T)
Range 1
Range 2
Range 3
Range 4
Estimated Station Position and Time
X Y Z T

The Global Positioning System

Measurements of code-phase arival times from at least four satellites are used to estimate four quantities: position in three dimensions (X, Y, Z) and GNSS time (T).


GPS
USA
GALILEO
EU
GLONASS
Russia
BEIDOU
China

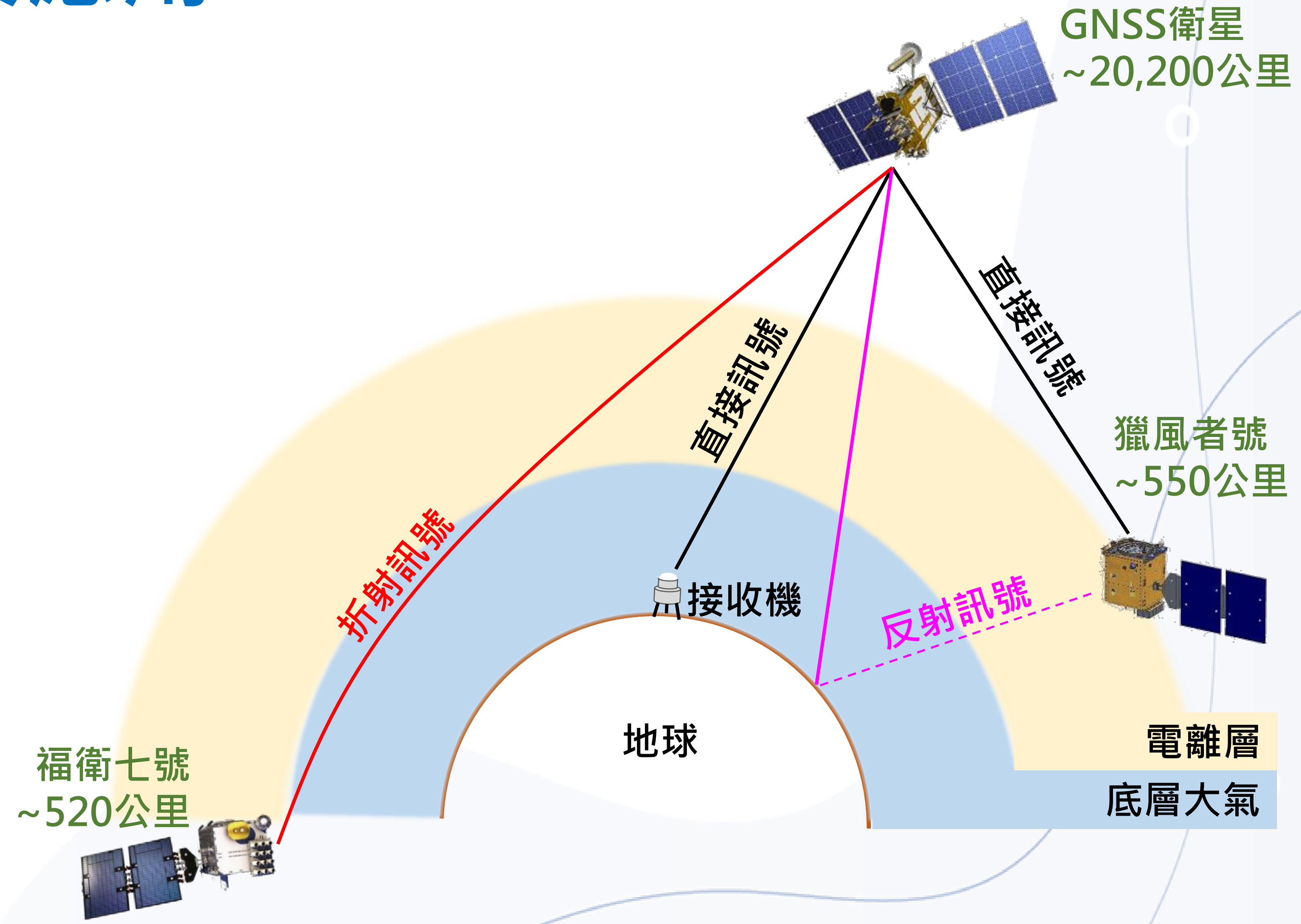


https://www.tallysman.com/gnss-positioning-techniques/
https://www.advancednavigation.com/

GNSS訊號接收及應用

■地基接收設備
- ●精準單點定位(PPP)
- ●RTK參考站
- ●時間校正
- ●地球觀測(EO)

■星基接收酬載
- ●軌道定位 (POD)
- ●時間校正
- ●掩星觀測(RO)
- ●反射觀測(GNSS-R)


GNSS衛星
~20,200公里
直接訊號
直接訊號
獵風者號
~550公里
折射訊號
接收機
反射訊號
地球
電離層
底層大氣
福衛七號
~520公里

應用GNSS的相關產業

資料來源：EUSPA EO and GNSS Marker Report, 2024

農業
透過衛星定位技術引導機械，強化自動化與監控系統。

漁業與水產養殖
管制捕撈與紀錄漁場位置，配合系統提升漁船安全。

水上交通
導航與自動化導引系統的發展，提升安全及經濟效應。

航空與無人機
透過衛星定位技術導航、協助起降與飛航監控。

能源與原料採及
支援礦場監控、資產追蹤與機械導引。

鐵道運輸
資產管理與安全性應用，並提升運輸效率。

氣候與生物多樣性
地球環境量測及動物信號標監測應用。

林業
供應鏈管理及追蹤、輔助相關監測設備。

陸面運輸
優化運輸效能、提供行車紀錄與緊急援助。

旅遊與健康
穿戴裝置與行動裝置的支援和應用。

基礎設施
支援校時服務使各項設備能夠同步作用。

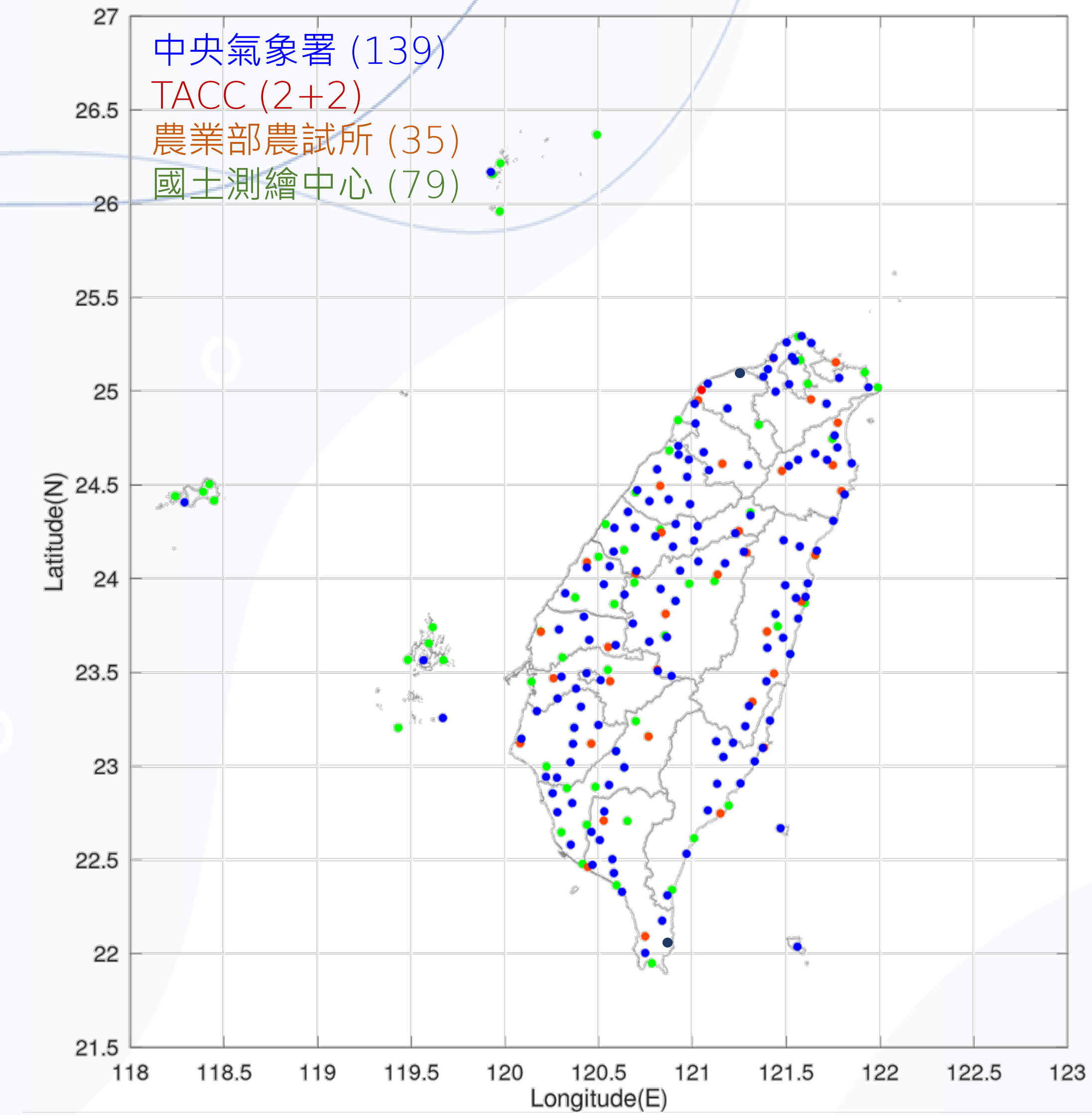
太空飛行體
衛星定位及校時服務，並用來進行地球觀測。

緊急救援
救援定位及運送、環境變異監測提供早期應變。

保險與金融
支援校時服務使全球金融交易具有準確時間戳記。

城市發展與文化遺產
都市及交通網絡規劃，協助相關記錄及修復工作。

台灣地面GNSS接收站網


中央氣象署 (139)
TACC (2+2)
農業部農試所 (35)
國土測繪中心 (79)
Latitude(N)
Longitude(E)
27
26.5
26
25.5
25
24.5
24
23.5
23
22.5
22
21.5
118
118.5
119
119.5
120
120.5
121
121.5
122
122.5
123

■ 中央氣象署

- ● 地震測報中心即時資料約100站
  - 機型為Trimble NetR9
- ● TACC即時資料3站
  - 機型為Septentrio PolaRx5s、mosaic-x5和 PolaRx4。

■ 農業部農試所

- ● 即時資料為35站
  - 機型為Trimble BD990

■ 內政部國土測繪中心

- ● 近即時資料約71站，資料類型為接收機原始T02格式
- ● 資料解析度1Hz、資料延遲時間約1小時

■ 經濟部地質調查及礦業管理中心

- ● 全台約有86站，型號與資料傳輸狀態未知

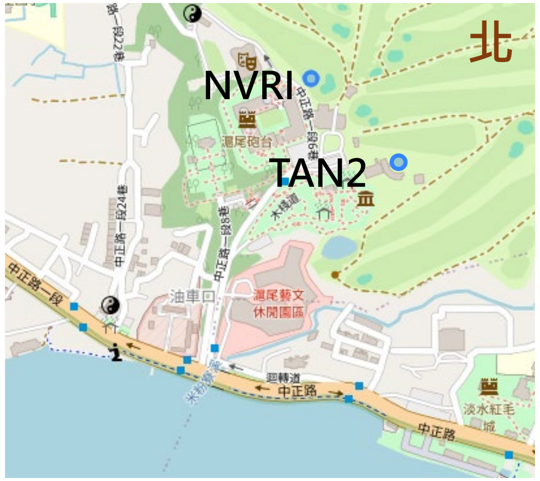
■ 學研與其他單位

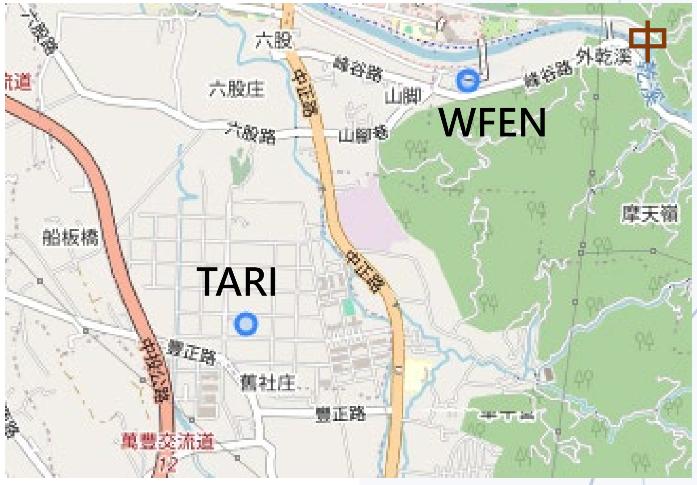
- ● 中央研究院、中央大學、成功大學、清華大學等
- ● 民間業者

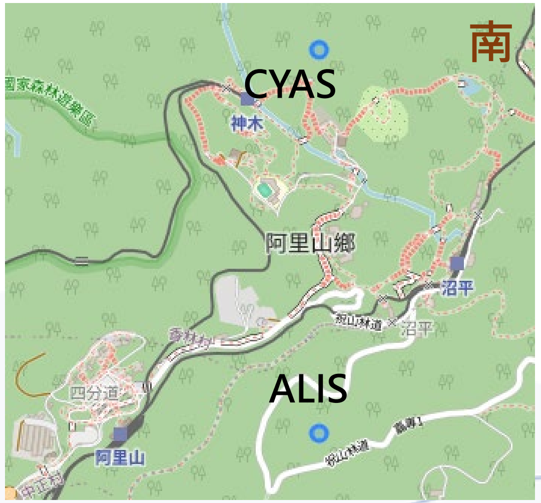
氣象署與農試所地面站觀測比對

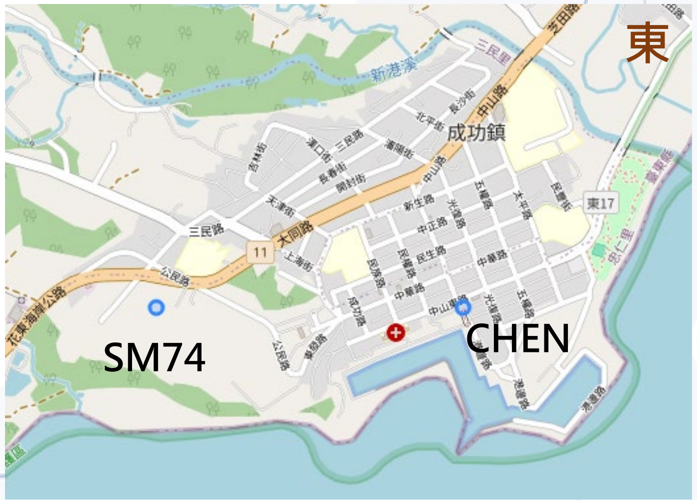
- ■雙系統觀測資料比對
  - ●接收器型號是否具有差異
  - ●分析是否具有區域差異
  - ●分析是否受電離層影響

Trimble	NetR9	BD990
Technology	Maxwell 6	Maxwell 7
Channels	440	336
GPS	L1, L2, L5	L1, L2, L5
GLONASS	L1, L2, L3	L1, L2, L3
Galileo	E1, E5a, E5b	E1, E5a, E5b, E6
QZSS	L1, L2, L5	L1, L2, L5
Max. Update Rate	50Hz	50Hz

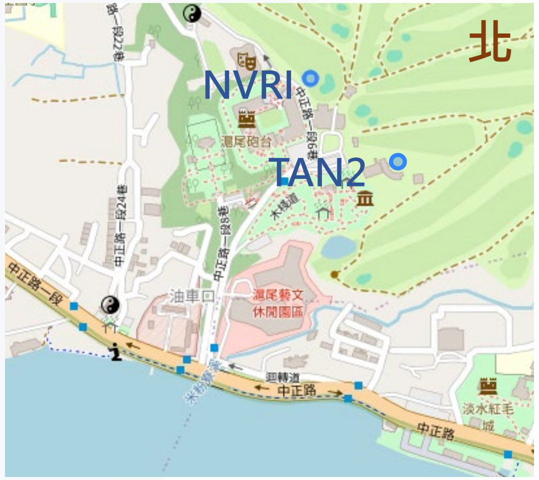

北
NVRI
TAN2
滬尾砲台
滬尾藝文休閒園區
中正路

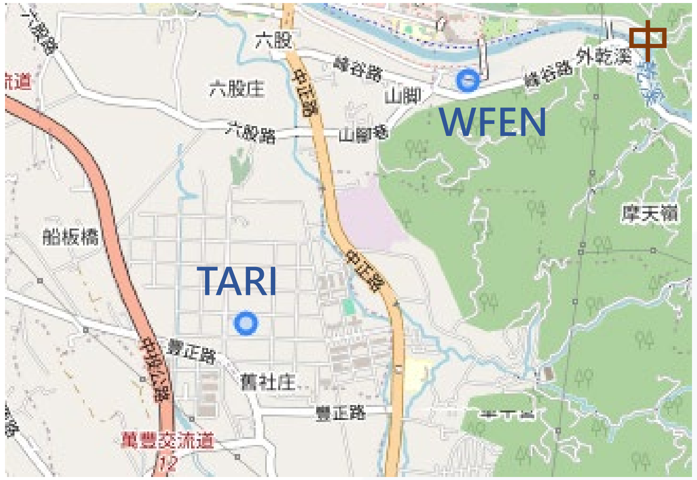

中
WFEN
TARI
六股
六股庄
山腳
峰谷路
船板橋
豐正路
舊社庄
豐正路
萬豐交流道
摩天嶺

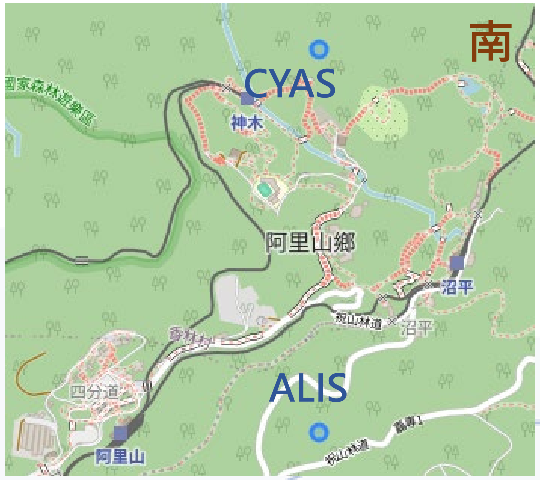

南
CYAS
ALIS
神木
阿里山鄉
沼平
阿里山
四分道

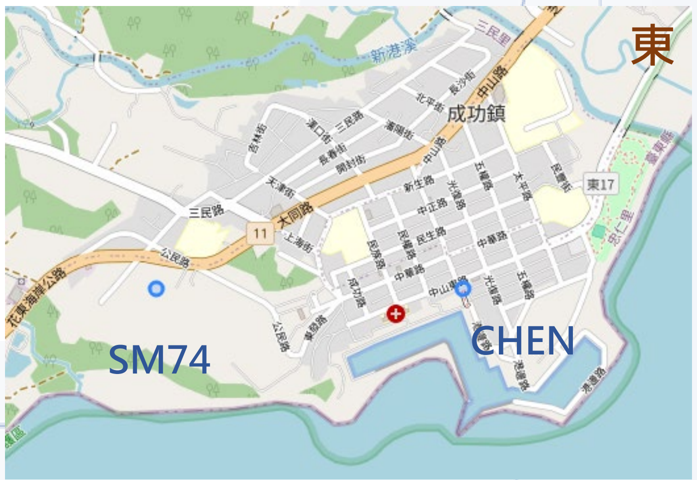

東
SM74
CHEN
成功鎮
新港溪
大同路
中山路

區域	地點	站名	緯度(度)	經度(度)	高度(公尺)	接收機	傳輸方式
北區	淡水	TAN2	25.17849943	121.43136306	68.4370	Trimble NetR9	NTRIP, FTP
		NVAI	25.17637344	121.43077908	47.0580	Trimble BD990	NTRIP
中區	霧峰	WFEN	24.04194638	120.69947788	102.8850	Trimble NetR9	NTRIP, FTP
		TARI	24.02893235	120.69379402	111.9220	Trimble BD990	NTRIP
南區	阿里山	ALIS	23.50817036	120.81329719	2438.3940	Trimble NetR9	NTRIP, FTP
		CYAS	23.51569561	120.81088770	2240.6600	Trimble BD990	NTRIP
東區	成功	CHEN	23.09741773	121.37357515	60.3450	Trimble NetR9	NTRIP, FTP
		SM74	23.10021002	121.38050043	55.4330	Trimble BD990	NTRIP


北
NVRI
TAN2
中正路
淡水紅毛城

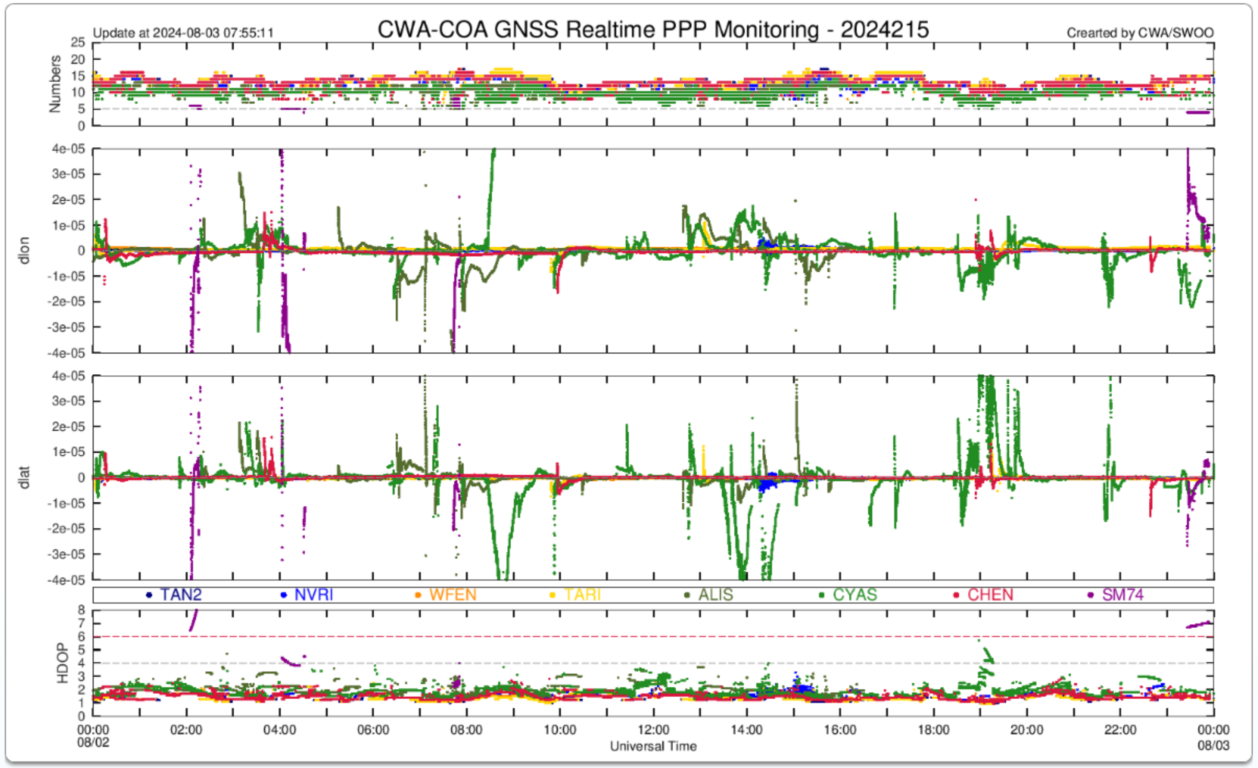

中
WFEN
TARI
六股
峰谷路
中正路
萬豐交流道

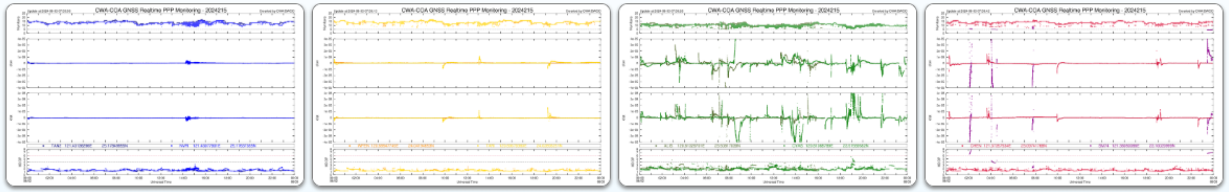

南
CYAS
ALIS
阿里山鄉
沼平
阿里山


東
SM74
CHEN
成功鎮

資料比對-單點精確定位輸出資訊

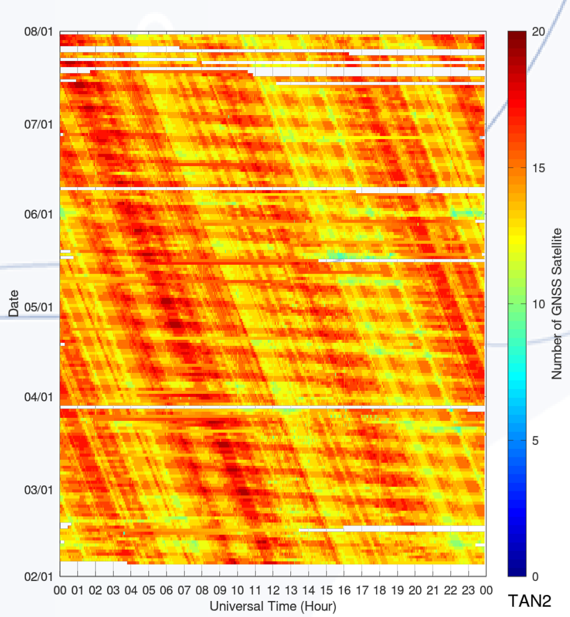
- ■觀測資料利用德國聯邦地理測繪局軟體(BKG Ntrip Client, BNC)計算單點精確定位結果
- ■可輸出NMEA檔案並從中擷取資訊
  - **衛星使用數量**
  - **地理緯度座標**
  - **地理經度座標**
  - **水平定位精度(HDOP)**
    - dilution of precision，又稱精度衰減因子。
    - 要滿足所有的應用需求的理論數值應小於4。
- ■資料分析時間2024.032-2024.213

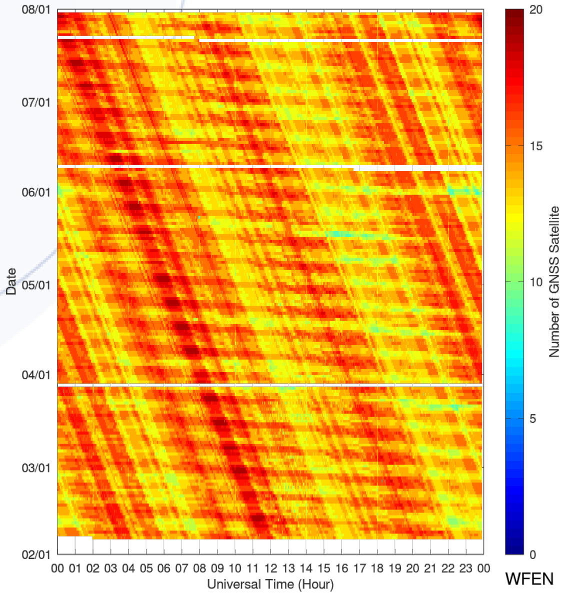


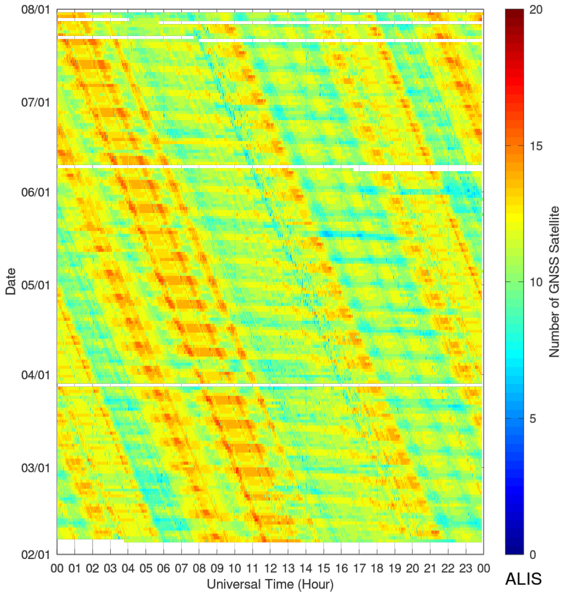


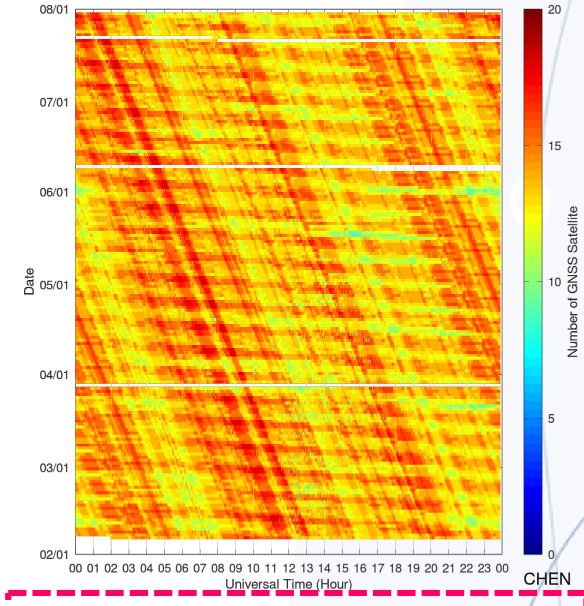
比對結果-衛星使用數量

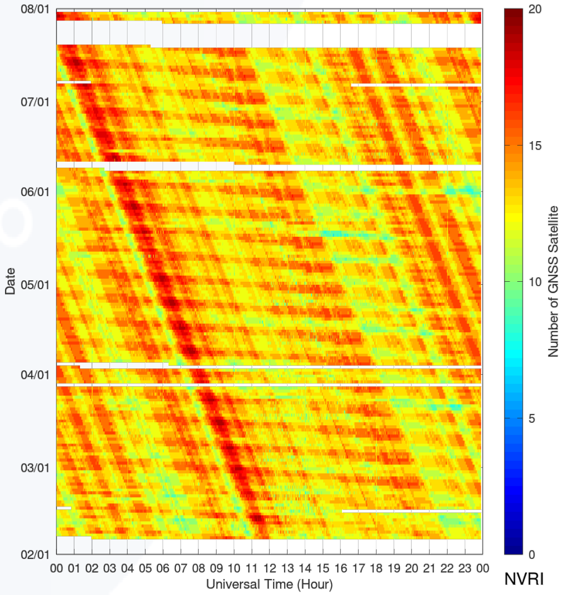
嘉義山區站店明顯偏低

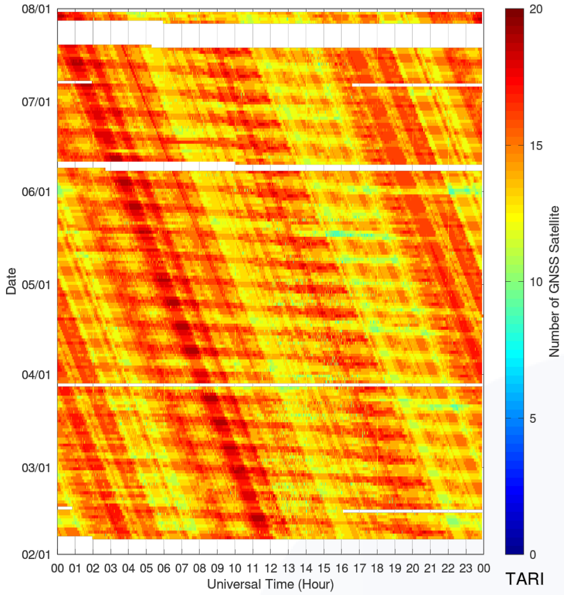


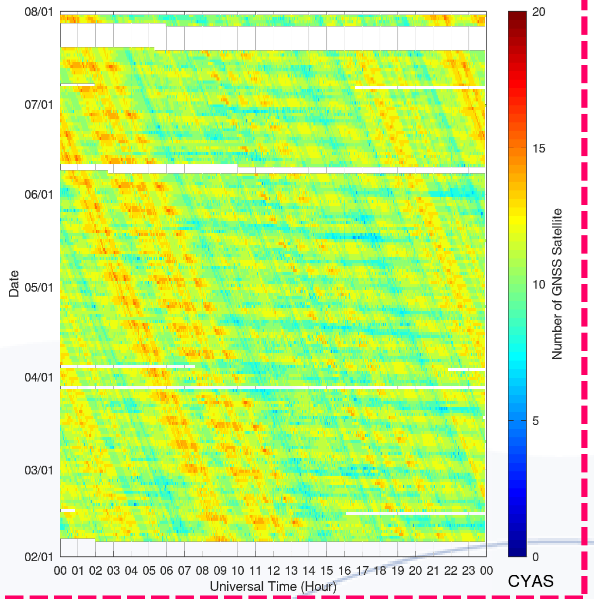


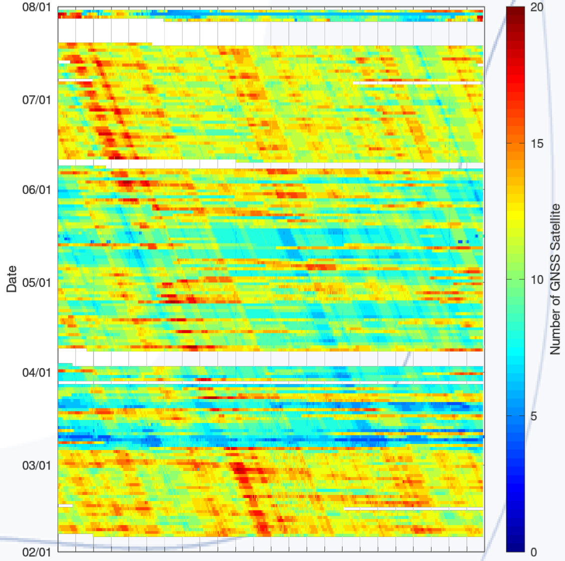






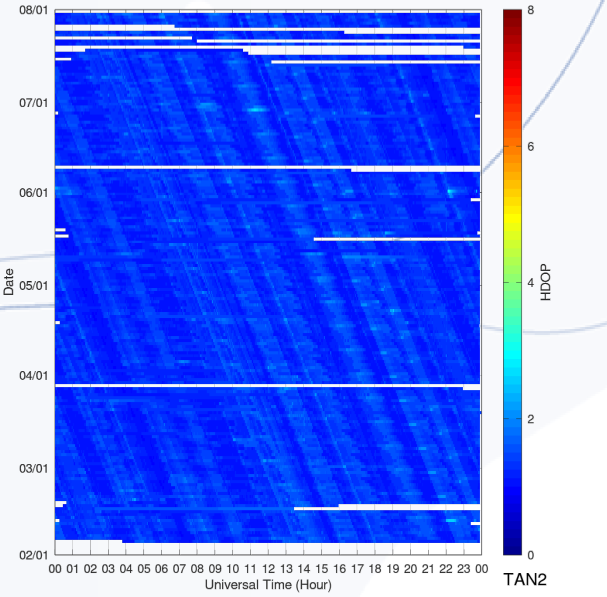


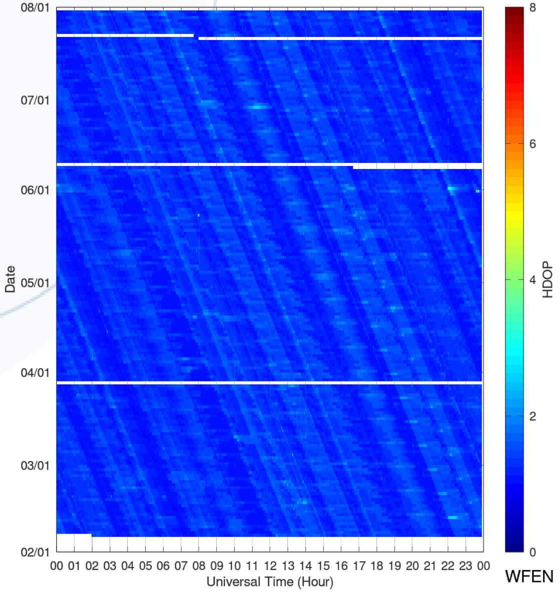


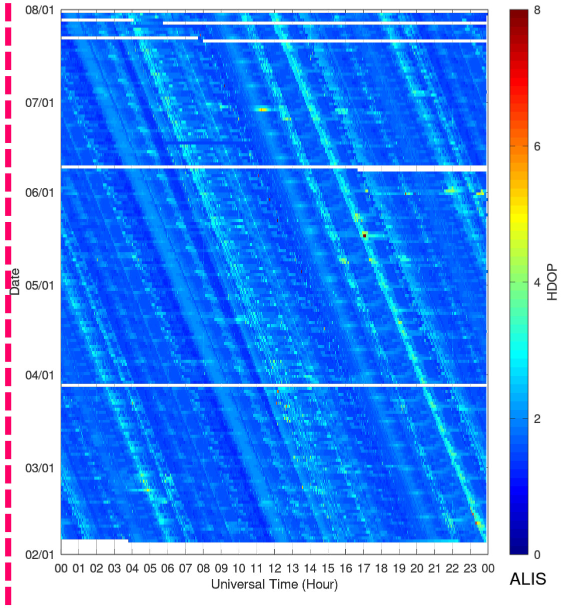


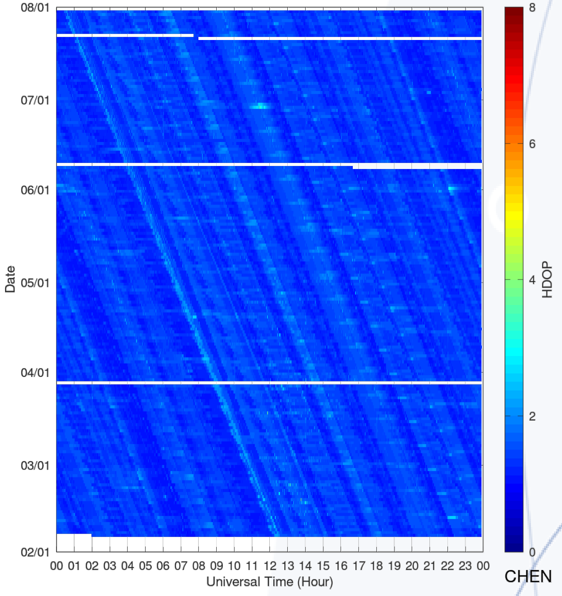
比對結果-水平定位精度

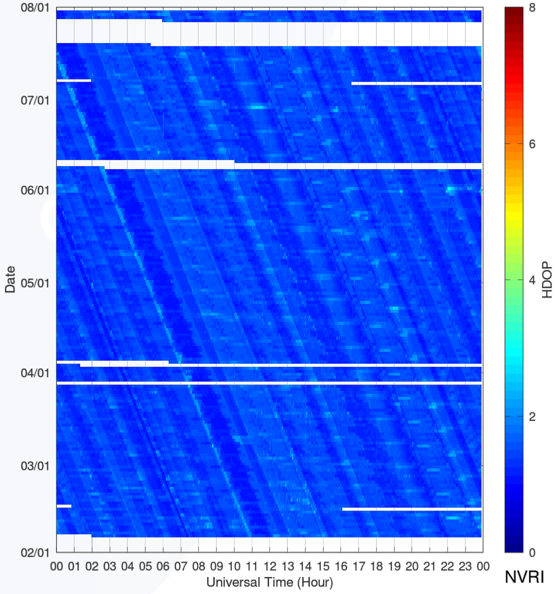
嘉義山區站店相對較高

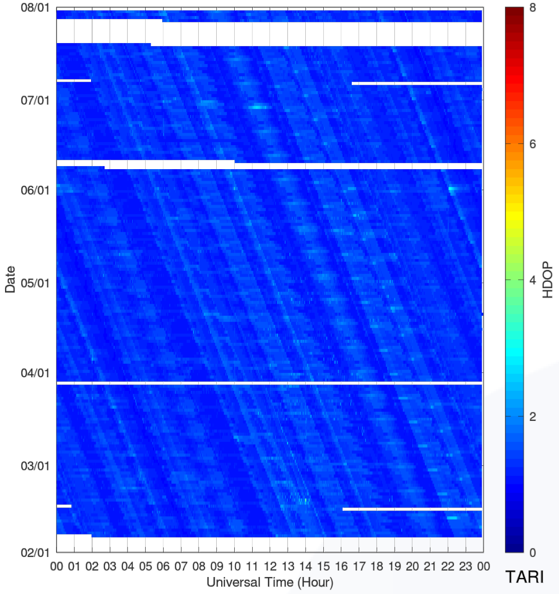


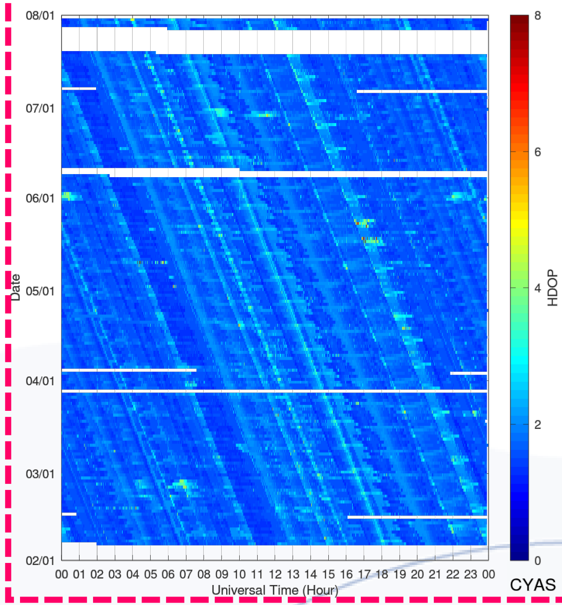


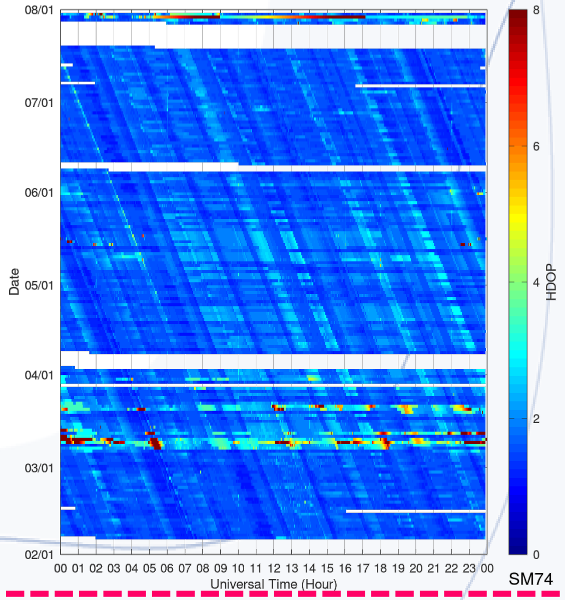






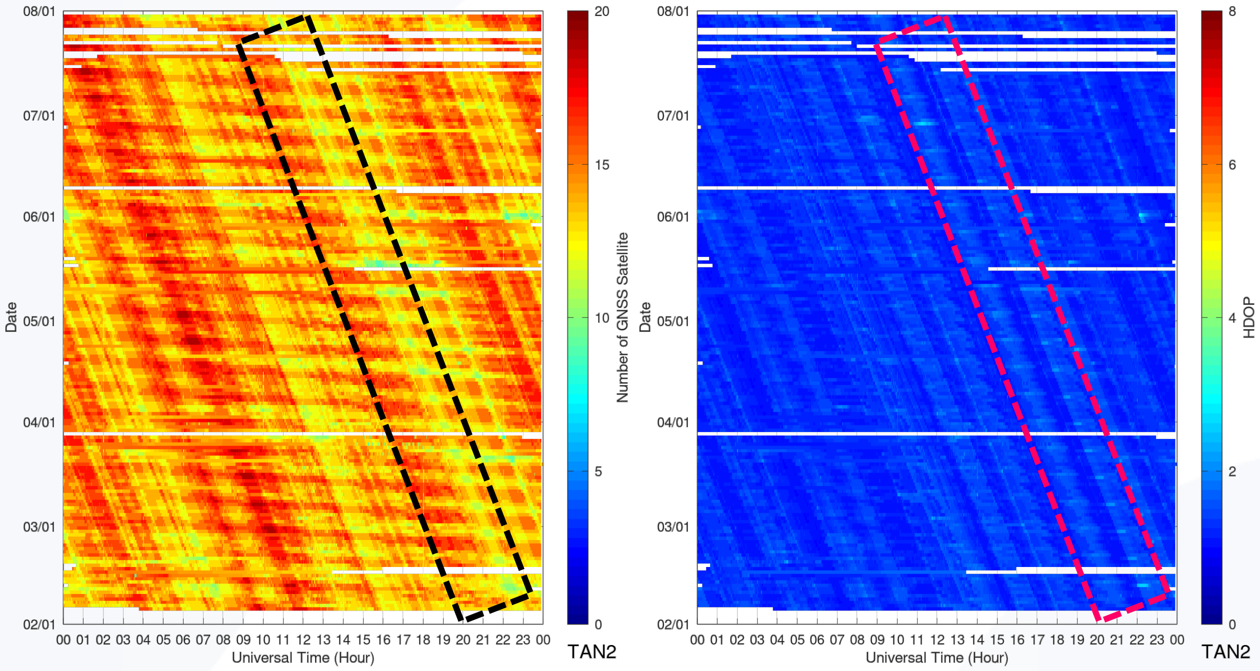


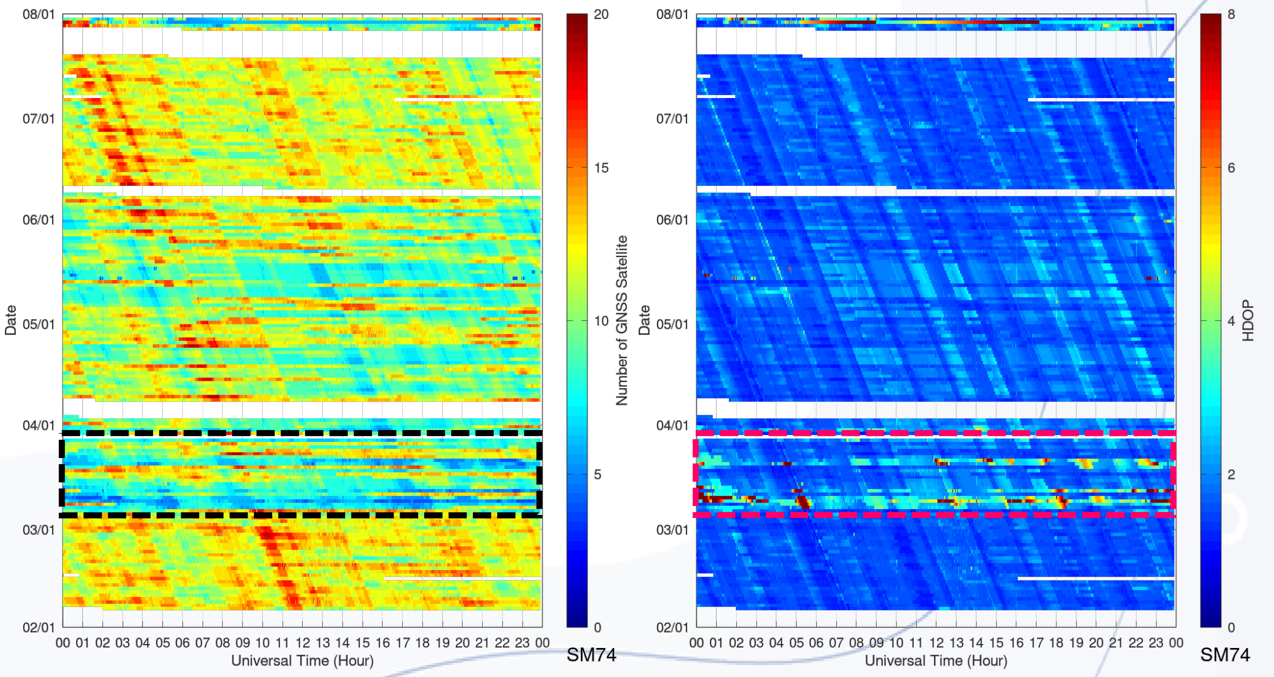




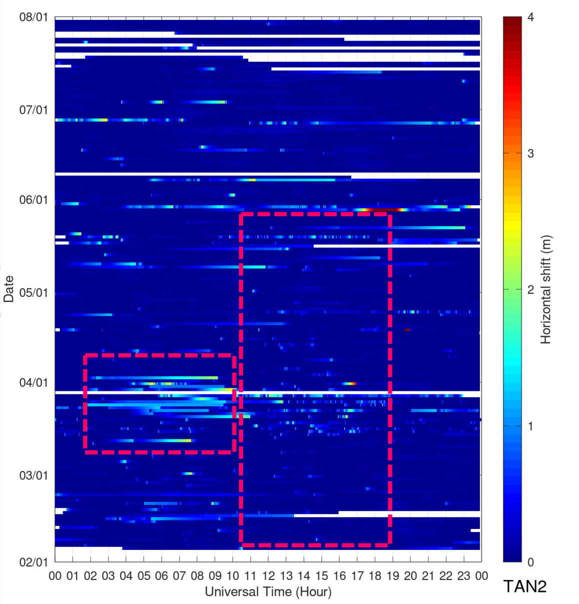
分析1：衛星使用數量與水平定位精度

- 接收站可見衛星數量會隨時間而變，理論變動範圍約在4-8顆衛星數。部分時段衛星使用數量不足10顆，有可能是特定星系無法接收、環境干擾或接收機狀態異常。
- 水平定位精度數值與衛星使用數量有顯著關聯，該指數會考慮每顆衛星的位置來估計得到的位置精度。故當數值越大時，定位誤差越大，精度就越低。

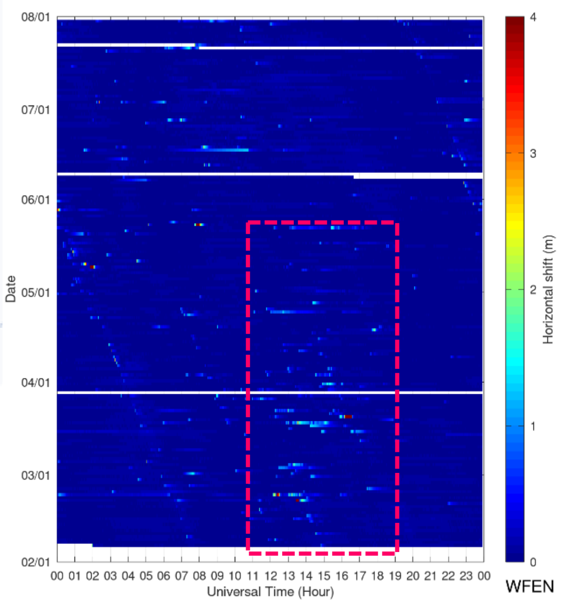




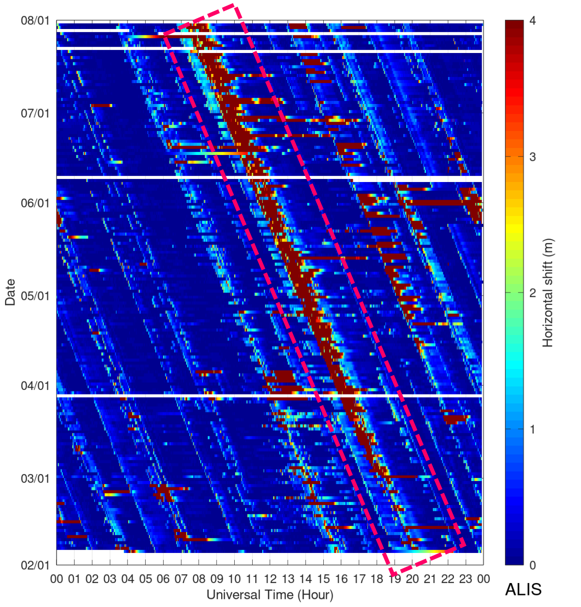
比對結果-水平定位偏差 以分析時段之經緯座標中位數為參考值，相減後計算水平偏差量(公尺)。



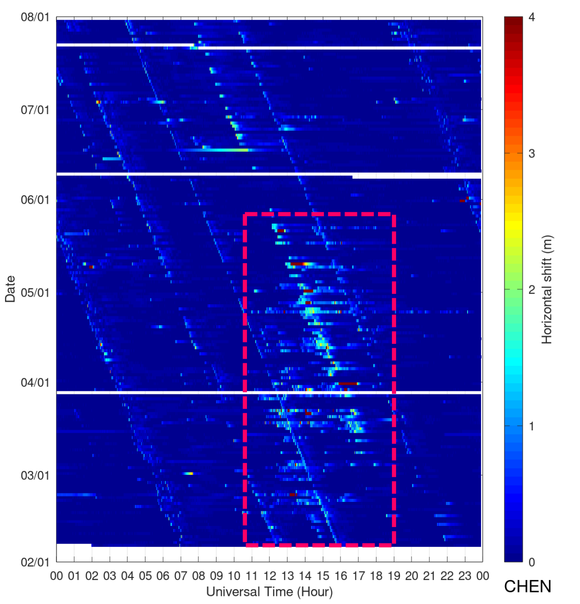
TAN2



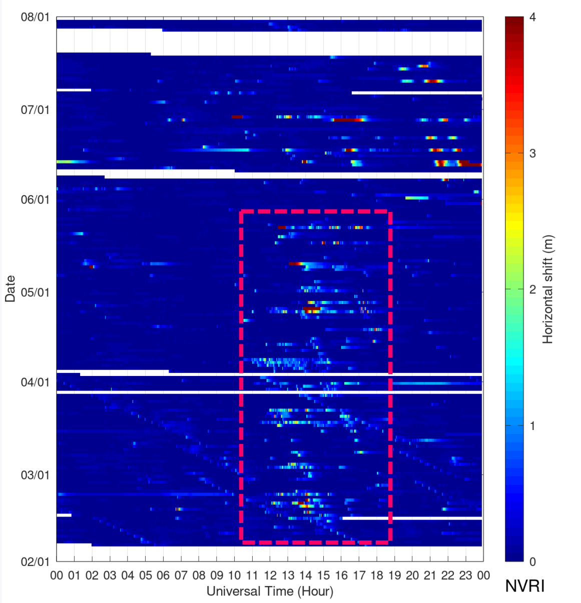
WFEN



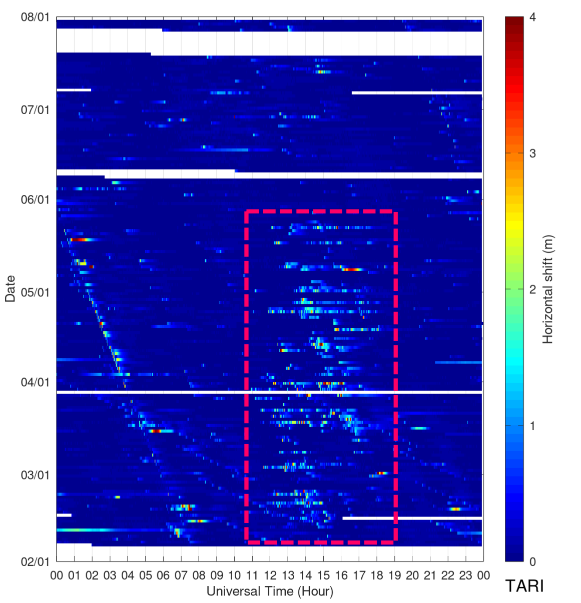
ALIS



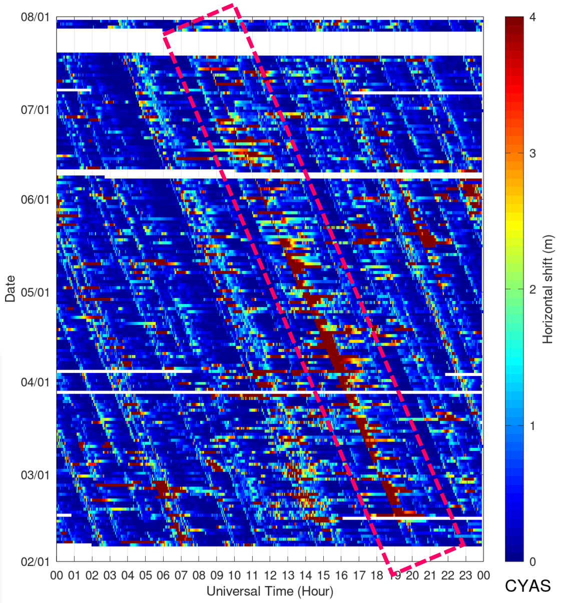
CHEN



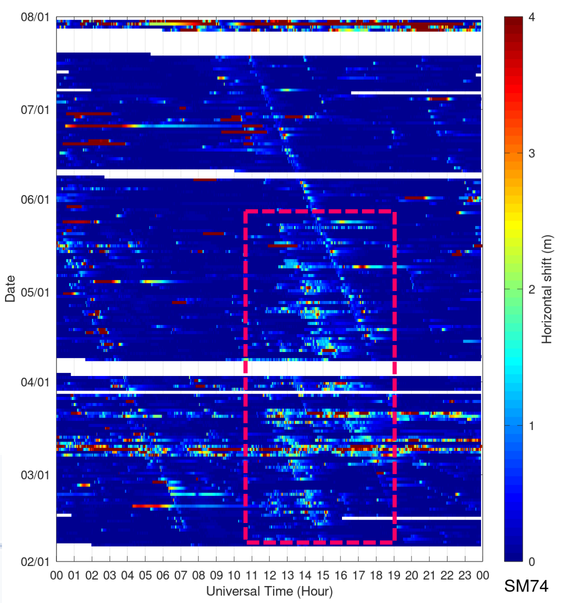
NVRI



TARI



CYAS

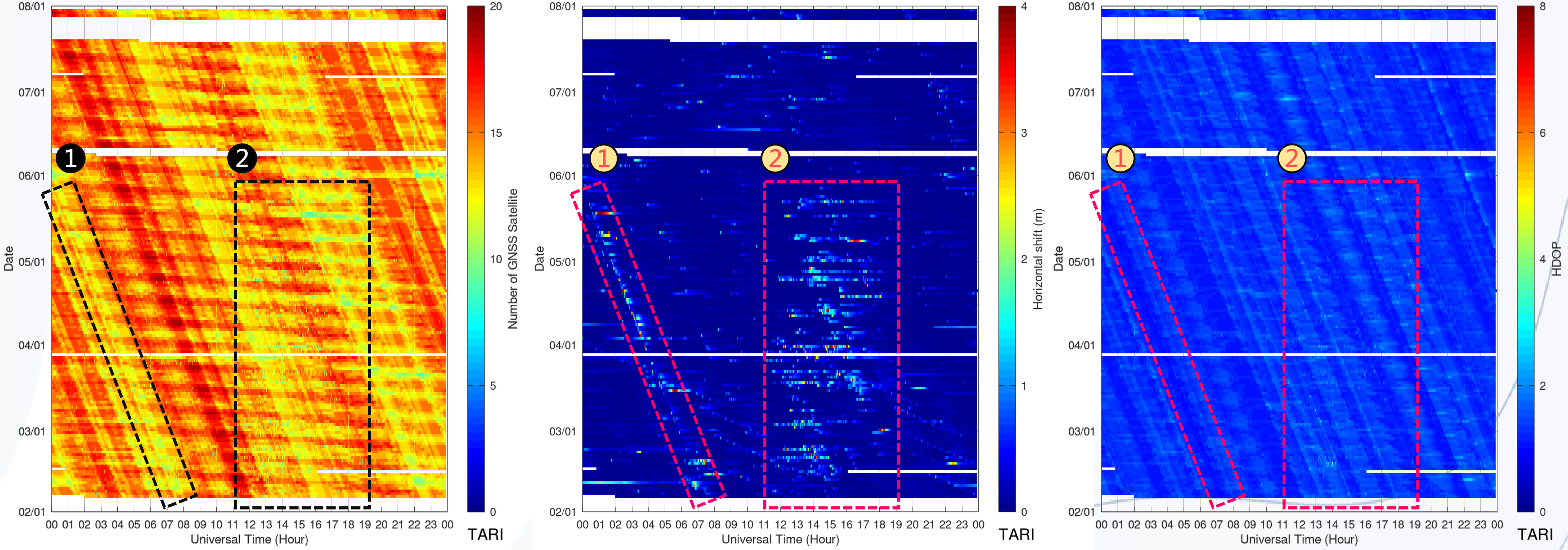


SM74

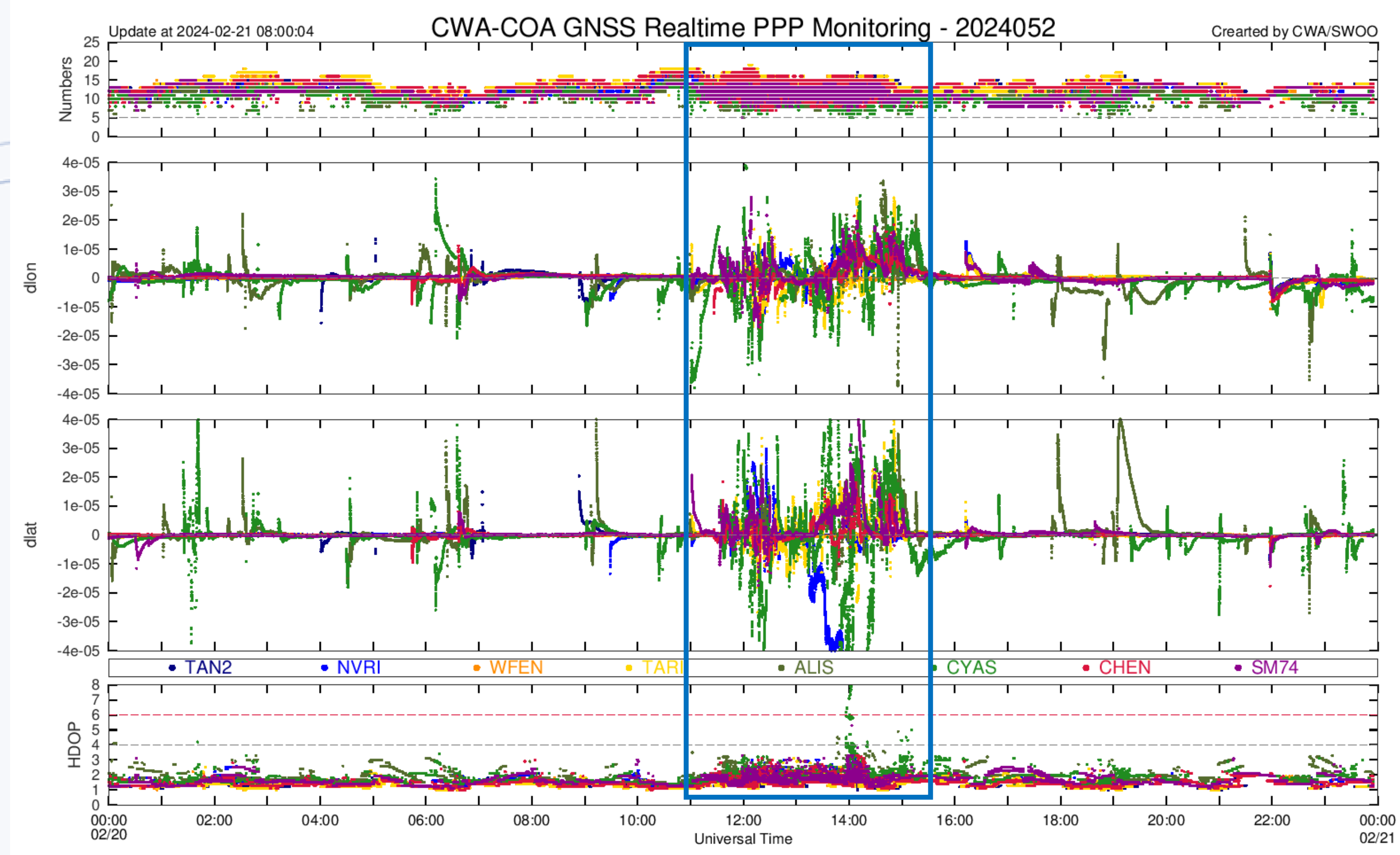
分析2：水平偏差量時段分布

① 水平偏差量分布與衛星使用數量，可能是受到衛星分布(但HDOP相對低)、或是特定方位訊號產生干擾或多重路徑效應造成解算結果出現偏差。

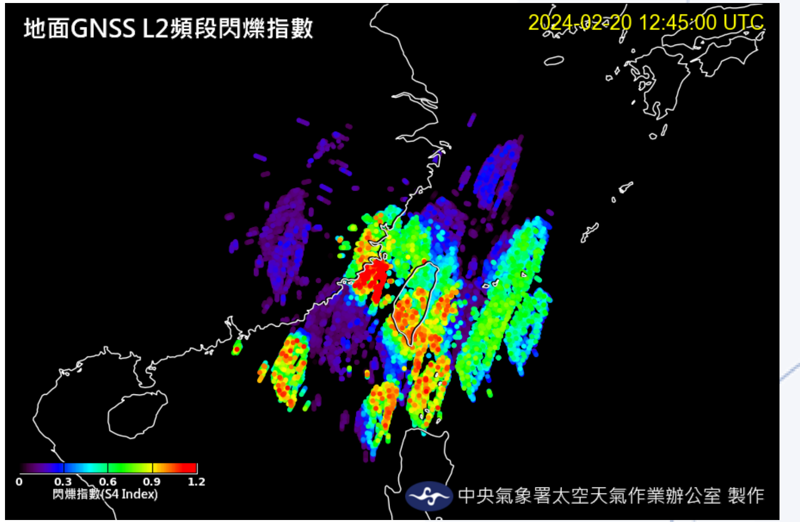
② 水平偏差量集中出現在特定時段且HDOP未出現類似分布，時段分布於12-18UT之間並僅持續至5月下旬結束，推測可能是受到電離層不規則體的影響。



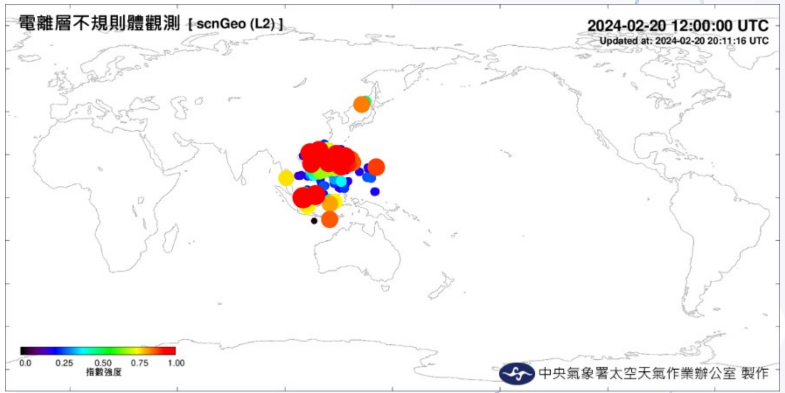
電離層不規則體(電漿泡)影響



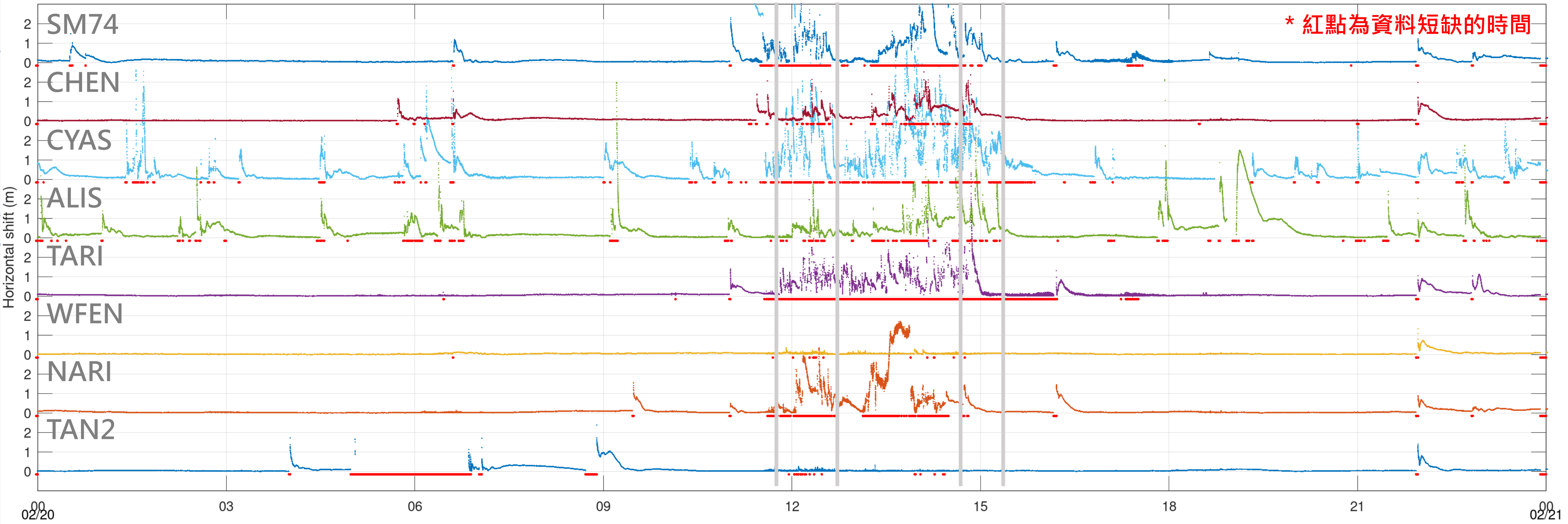
圖：地面站單點精確定位解算結果時序圖


地面GNSS L2頻段閃爍指數
2024-02-20 12:45:00 UTC
0
0.3
0.6
0.9
1.2
閃爍指數(S4 Index)
中央氣象署太空天氣作業辦公室 製作

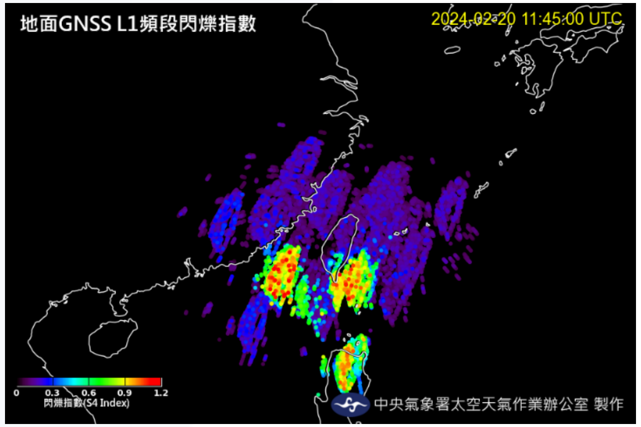
圖：地基GNSS L2頻段電離層閃爍指數(S4)觀測

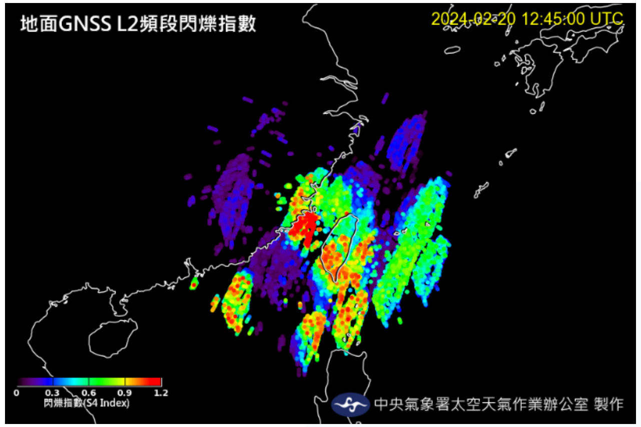

電離層不規則體觀測 [scnGeo (L2)]
2024-02-20 12:00:00 UTC
Updated at: 2024-02-20 20:11:16 UTC
0.0
0.25
0.50
0.75
1.00
指數強度
中央氣象署太空天氣作業辦公室 製作

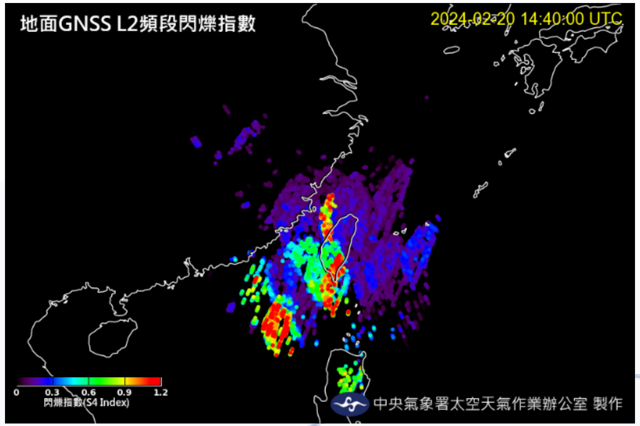
圖：福衛七號電離層不規則體觀測(scnGeo)

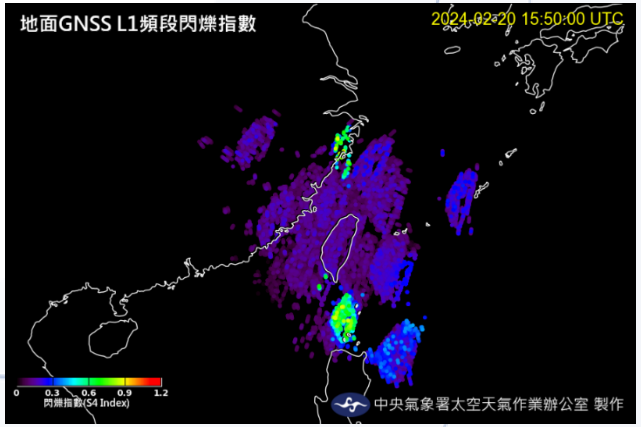

SM74
CHEN
CYAS
ALIS
TARI
WFEN
NARI
TAN2
Horizontal shift (m)
0
1
2
00
02/20
03
06
09
12
15
18
21
00
02/21

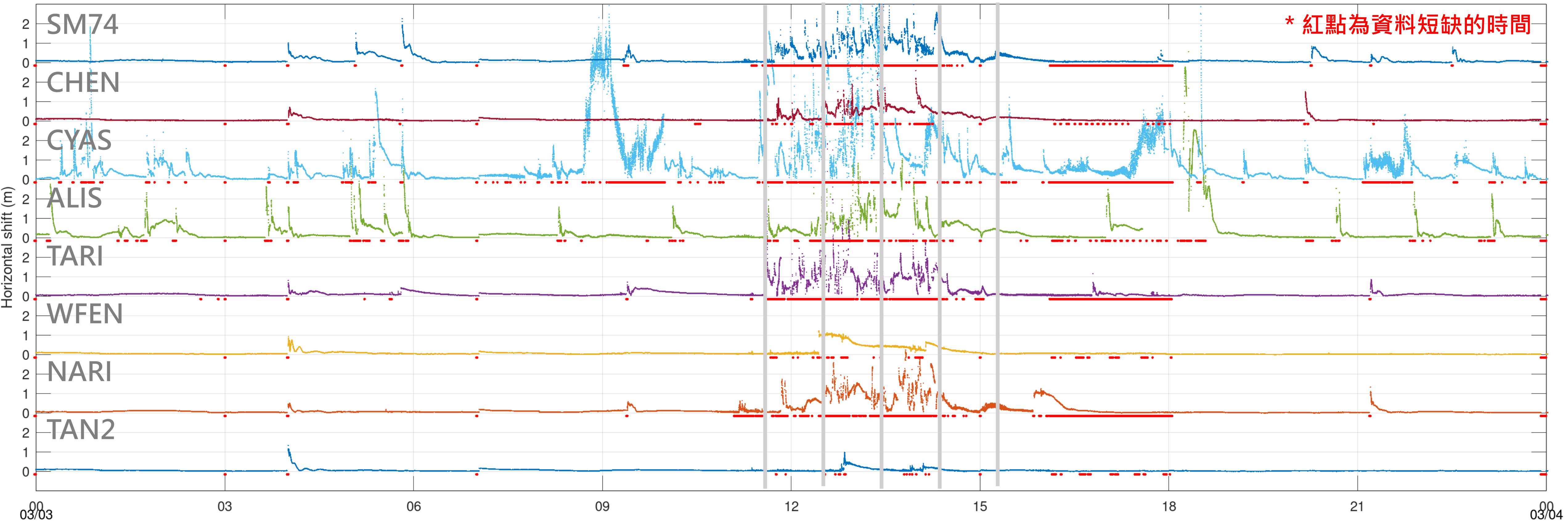
* 紅點為資料短缺的時間


地面GNSS L1頻段閃爍指數
2024-02-20 11:45:00 UTC
0
0.3
0.6
0.9
1.2
閃爍指數(S4 Index)
中央氣象署太空天氣作業辦公室 製作

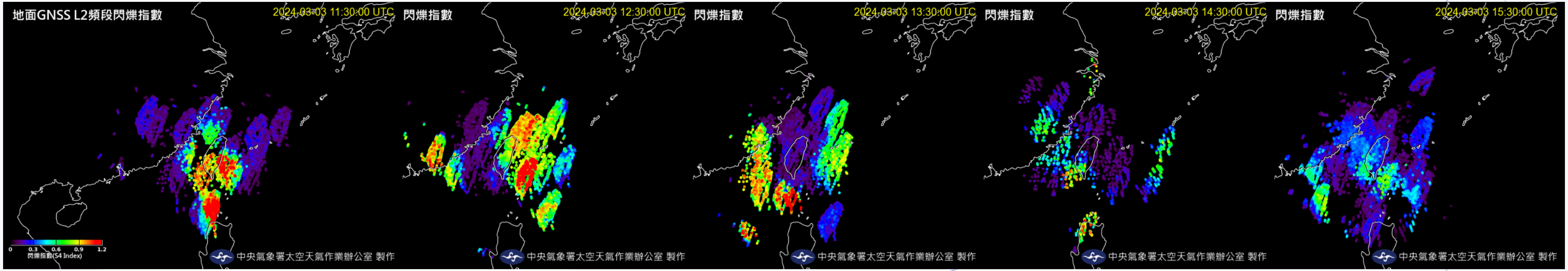

地面GNSS L2頻段閃爍指數
2024-02-20 12:45:00 UTC
0
0.3
0.6
0.9
1.2
閃爍指數(S4 Index)
中央氣象署太空天氣作業辦公室 製作


地面GNSS L2頻段閃爍指數
2024-02-20 14:40:00 UTC
0
0.3
0.6
0.9
1.2
閃爍指數(S4 Index)
中央氣象署太空天氣作業辦公室 製作


地面GNSS L1頻段閃爍指數
2024-02-20 15:50:00 UTC
0
0.3
0.6
0.9
1.2
閃爍指數(S4 Index)
中央氣象署太空天氣作業辦公室 製作



* 紅點為資料短缺的時間


0
0.3
0.6
0.9
1.2
閃爍指數(S4 Index)

地面GNSS L2頻段閃爍指數 2024-03-03 11:30:00 UTC

閃爍指數 2024-03-03 12:30:00 UTC

閃爍指數 2024-03-03 13:30:00 UTC

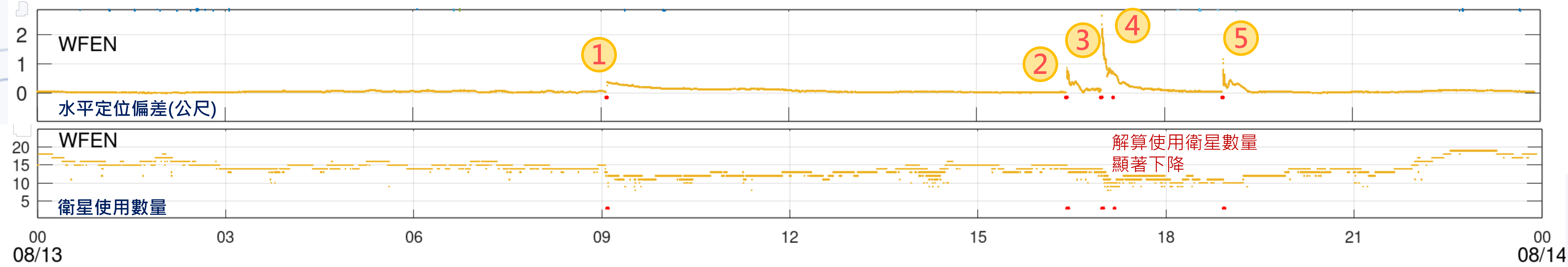
閃爍指數 2024-03-03 14:30:00 UTC

閃爍指數 2024-03-03 15:30:00 UTC

中央氣象署太空天氣作業辦公室 製作

分析3：定位數據資料短缺分析

- 為能完整分析解算解果與資料來源，因此選擇2024/08/13 (226) 的WFEN站數據進行分析



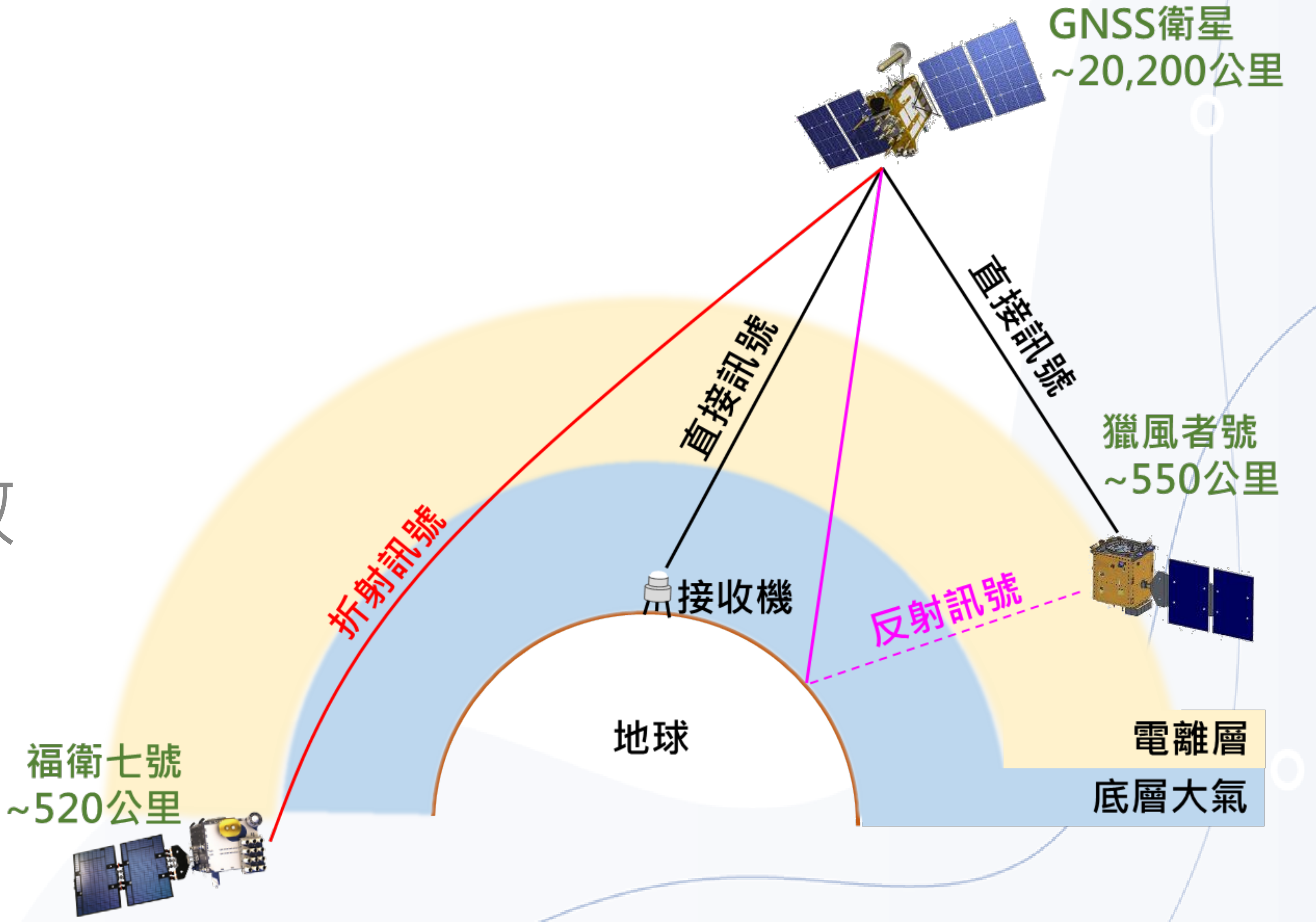
	定位時序資料(TS)	長度	NMEA	PPP(閏秒+18s)	觀測檔Ofile(Stream)	觀測檔Ofile(T02轉)	觀測檔Ofile(FTP)
1	缺 09:04:59-09:05:57	59s	同左	缺 09:05:17-09:06:15	完整資料	時間範圍內 有零星缺少資料	時間範圍內 有缺少紀錄
2	缺 16:25:22-16:26:26	65s	同左	缺 16:25:40-16:26:44	缺 16:25:40-16:26:43	16:24:58-16:26:59 另有零星缺少	缺 16:24:58-16:27:00
3	缺 16:58:58-16:59:57	60s	同左	缺 16:59:16-17:00:15	完整資料	完整資料	完整資料
4	缺 17:10:48-17:10:50	3s	同左	缺 17:11:06-17:11:08	完整資料	完整資料	完整資料
5	缺 18:55:07-18:56:06	60s	同左	缺 18:55:24-18:56:24	完整資料	完整資料	完整資料

討論與結論

- 基於GNSS各個星系的軌道特性，單一地面接收站可接收到的衛星數量會隨時間變化，平均可接收到的衛星訊號數量約為20-30顆，而**用於解算的衛星數量約在12-15顆衛星**，且多數時段因能均勻分布於天頂，因此對於水平定位精度(HDOP)的數值影響不大。
- 從水平定位偏差的時段分布，除了受到解算所使用的衛星數量影響外，也可見到受到電離層不規則所造成的影響(**特徵為偏差數值上升但HDOP無顯著變化**)，且分布時段見於春季傍晚至午夜後，亦符合台灣上空不規則體好發時段特徵。
- 水平定位偏差出現不連續的跳動情況來自於資料短缺，經過上游資料完整度的交叉比對後，可以分為**(1)沒有觀測資料可以進行計算**或**(2)觀測資料可能無法解算**出可用結果。但分析時也有發現資料連續出現短缺但定位數值沒有明顯跳動的情形，因此兩種狀態對於解算所造成的影響仍有待進一步的分析。
- 除了嘉義阿里山兩站(ALIS和CYAS)的資料較為發散可能是受到測站環境影響外，其餘**各比對區域的觀測資料特性一致**，透過BKG解算結果可見NetR9的資料相較BD990略顯穩定。
- 在進一步**釐清資料短缺**以及**BNC軟體解算的偏差量與使用者體驗的一致性**，即有望透過整合全台即時地面GNSS觀測數據，監測各地定位即時狀態並用以評估可能偏差量值。

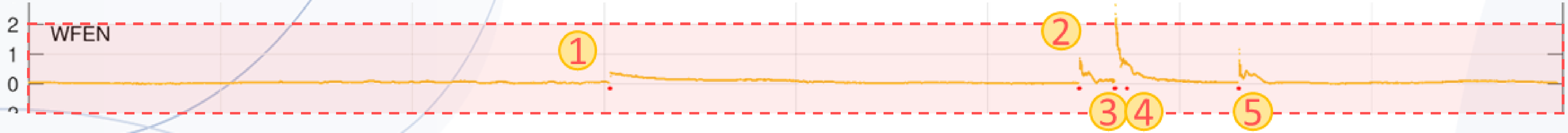
感謝聆聽

歡迎提問與指教


GNSS衛星
~20,200公里
直接訊號
直接訊號
折射訊號
反射訊號
獵風者號
~550公里
接收機
地球
電離層
底層大氣
福衛七號
~520公里

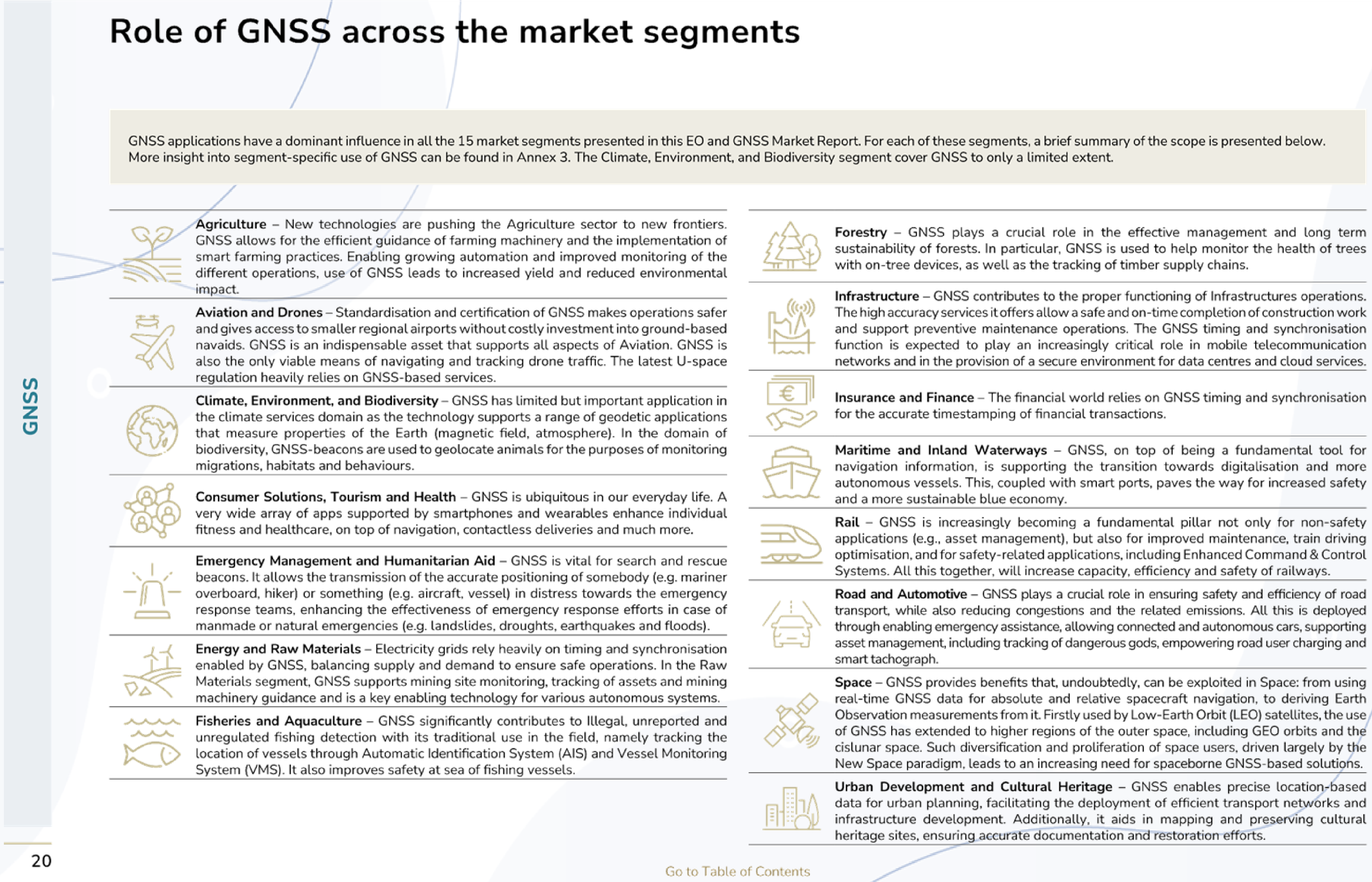
Backup Slides

數據資料短缺紀錄



	TS	NMEA	PPP(因閏秒差+18s)	Ofile(R3)	PPP_NEW	
1	缺 09:04:59-09:05:57	同左	同 09:05:17-09:06:15	時間範圍內有缺少紀錄 *1	有資料	09:15:39 09:16:18 09:38:43-09:38:49 09:38:55-09:40:10 09:40:12-09:40:13 09:40:15-09:40:19 09:40:25:09:40:26 09:40:37
2	缺 16:25:22-16:26:26	同左	同 16:25:40-16:26:44	16:24:58-16:26:59，另有缺少紀錄*2	同 16:25:40-16:26:44	
3	缺 16:58:58-16:59:57	同左	同 16:59:16-17:00:15	有資料	有資料	
4	缺 17:10:48-17:10:50	同左	同 17:11:06-17:11:08	有資料	有資料	
5	缺 18:55:07-18:56:06	同左	同 18:55:24-18:56:24	有資料	有資料	

*1				*2						
09:00:01	09:04:49	09:08:04	09:26:30	16:01:17	16:28:27	16:40:21	16:45:28	16:49:18	16:50:53	16:52:21
09:00:02	09:04:53	09:08:05	09:26:48	16:01:31	16:28:42	16:40:22	16:45:36	16:49:28	16:51:24	16:52:43
09:00:07	09:05:04	09:09:16	09:27:25	16:23:36	16:28:47	16:40:23	16:45:40	16:49:32	16:51:27	16:52:48
09:00:08	09:05:05	09:15:43	09:28:45	16:23:57	16:28:52	16:40:24	16:46:06	16:49:40	16:51:37	16:53:35
09:00:11	09:05:10	09:16:01	09:29:39	16:24:27	16:30:01	16:40:25	16:47:01	16:49:42	16:51:45	16:53:41
09:00:33	09:05:11	09:16:06	09:29:43	16:24:49	16:30:16	16:42:17	16:47:07	16:49:50	16:51:48	16:53:46
09:01:36	09:05:27	09:16:23	09:29:50	16:27:39	16:33:52	16:42:35	16:47:15	16:49:51	16:51:49	16:53:47
09:01:44	09:05:28	09:16:24	09:29:51	16:27:41	16:35:35	16:42:43	16:48:11	16:50:01	16:51:57	16:53:52
09:01:45	09:05:43	09:16:29	09:30:01	16:27:42	16:35:37	16:42:46	16:48:18	16:50:02	16:52:19	
09:01:55	09:07:12	09:16:30	09:30:28	16:27:53	16:35:42	16:43:02	16:49:04	16:50:21	16:52:12	
09:02:14	09:08:01	09:16:51		16:28:10	16:38:53	16:43:36	16:49:08	16:50:46	16:52:13	
09:03:45	09:08:02	09:26:26		16:28:19	16:40:01	16:43:37	16:49:11	16:50:47	16:52:17	



Role of GNSS across the market segments

GNSS applications have a dominant influence in all the 15 market segments presented in this EO and GNSS Market Report. For each of these segments, a brief summary of the scope is presented below. More insight into segment-specific use of GNSS can be found in Annex 3. The Climate, Environment, and Biodiversity segment cover GNSS to only a limited extent.

Agriculture – New technologies are pushing the Agriculture sector to new frontiers. GNSS allows for the efficient guidance of farming machinery and the implementation of smart farming practices. Enabling growing automation and improved monitoring of the different operations, use of GNSS leads to increased yield and reduced environmental impact.

Aviation and Drones – Standardisation and certification of GNSS makes operations safer and gives access to smaller regional airports without costly investment into ground-based navaids. GNSS is an indispensable asset that supports all aspects of Aviation. GNSS is also the only viable means of navigating and tracking drone traffic. The latest U-space regulation heavily relies on GNSS-based services.

Climate, Environment, and Biodiversity – GNSS has limited but important application in the climate services domain as the technology supports a range of geodetic applications that measure properties of the Earth (magnetic field, atmosphere). In the domain of biodiversity, GNSS-beacons are used to geolocate animals for the purposes of monitoring migrations, habitats and behaviours.

Consumer Solutions, Tourism and Health – GNSS is ubiquitous in our everyday life. A very wide array of apps supported by smartphones and wearables enhance individual fitness and healthcare, on top of navigation, contactless deliveries and much more.

Emergency Management and Humanitarian Aid – GNSS is vital for search and rescue beacons. It allows the transmission of the accurate positioning of somebody (e.g. mariner overboard, hiker) or something (e.g. aircraft, vessel) in distress towards the emergency response teams, enhancing the effectiveness of emergency response efforts in case of manmade or natural emergencies (e.g. landslides, droughts, earthquakes and floods).

Energy and Raw Materials – Electricity grids rely heavily on timing and synchronisation enabled by GNSS, balancing supply and demand to ensure safe operations. In the Raw Materials segment, GNSS supports mining site monitoring, tracking of assets and mining machinery guidance and is a key enabling technology for various autonomous systems.

Fisheries and Aquaculture – GNSS significantly contributes to Illegal, unreported and unregulated fishing detection with its traditional use in the field, namely tracking the location of vessels through Automatic Identification System (AIS) and Vessel Monitoring System (VMS). It also improves safety at sea of fishing vessels.

Forestry – GNSS plays a crucial role in the effective management and long term sustainability of forests. In particular, GNSS is used to help monitor the health of trees with on-tree devices, as well as the tracking of timber supply chains.

Infrastructure – GNSS contributes to the proper functioning of Infrastructures operations. The high accuracy services it offers allow a safe and on-time completion of construction work and support preventive maintenance operations. The GNSS timing and synchronisation function is expected to play an increasingly critical role in mobile telecommunication networks and in the provision of a secure environment for data centres and cloud services.

Insurance and Finance – The financial world relies on GNSS timing and synchronisation for the accurate timestamping of financial transactions.

Maritime and Inland Waterways – GNSS, on top of being a fundamental tool for navigation information, is supporting the transition towards digitalisation and more autonomous vessels. This, coupled with smart ports, paves the way for increased safety and a more sustainable blue economy.

Rail – GNSS is increasingly becoming a fundamental pillar not only for non-safety applications (e.g., asset management), but also for improved maintenance, train driving optimisation, and for safety-related applications, including Enhanced Command & Control Systems. All this together, will increase capacity, efficiency and safety of railways.

Road and Automotive – GNSS plays a crucial role in ensuring safety and efficiency of road transport, while also reducing congestions and the related emissions. All this is deployed through enabling emergency assistance, allowing connected and autonomous cars, supporting asset management, including tracking of dangerous gods, empowering road user charging and smart tachograph.

Space – GNSS provides benefits that, undoubtedly, can be exploited in Space: from using real-time GNSS data for absolute and relative spacecraft navigation, to deriving Earth Observation measurements from it. Firstly used by Low-Earth Orbit (LEO) satellites, the use of GNSS has extended to higher regions of the outer space, including GEO orbits and the cislunar space. Such diversification and proliferation of space users, driven largely by the New Space paradigm, leads to an increasing need for spaceborne GNSS-based solutions.

Urban Development and Cultural Heritage – GNSS enables precise location-based data for urban planning, facilitating the deployment of efficient transport networks and infrastructure development. Additionally, it aids in mapping and preserving cultural heritage sites, ensuring accurate documentation and restoration efforts.

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