

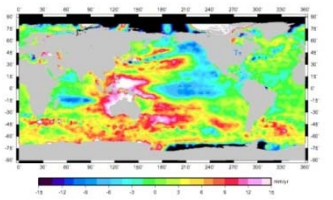
Tsunami 2011, Japan



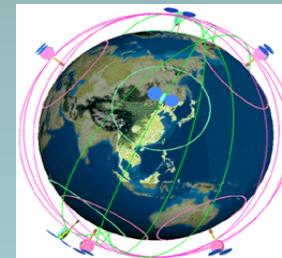
Meteotsunami, 1978, Vela Luka



Global Sea Level Trend Observed by GEOSAT, ERS-1/2 and TIP (1985-2001)



# GPS/IMU水位及波浪觀測系統



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<sup>3</sup>中央研究院地球科學研究所

103年天氣分析與預報研討會

2014 Conference on

Weather Analysis and Forecasting 2014/09/16-18



# Tide Gauge and Satellite Altimetry

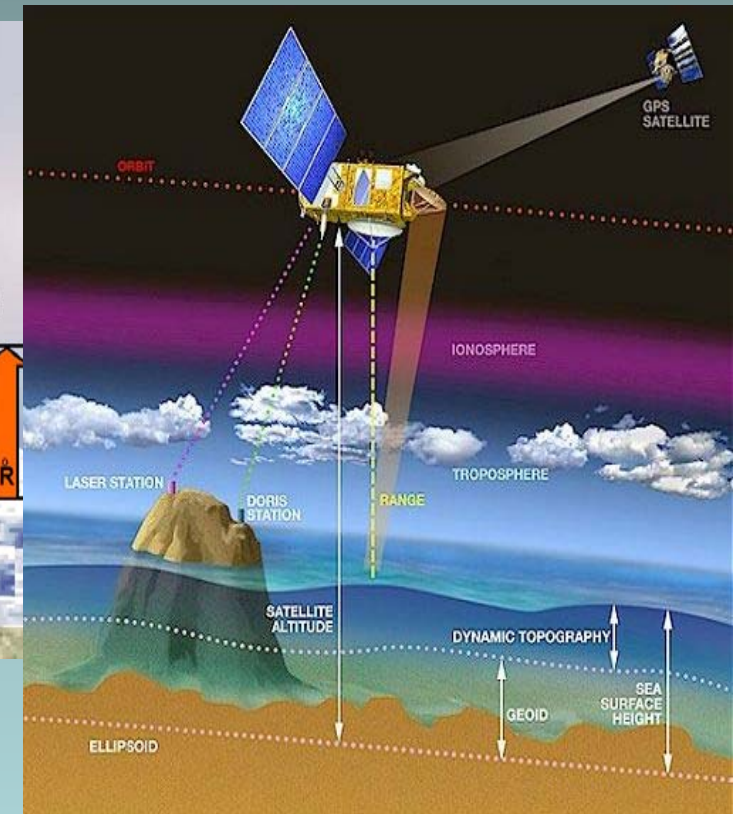
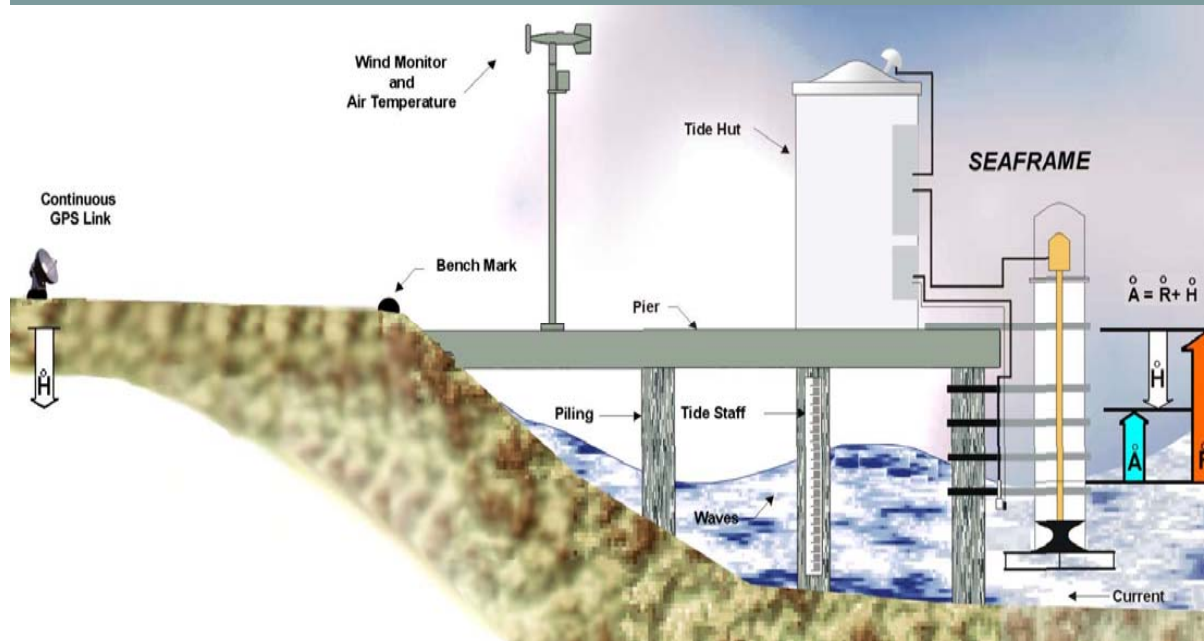
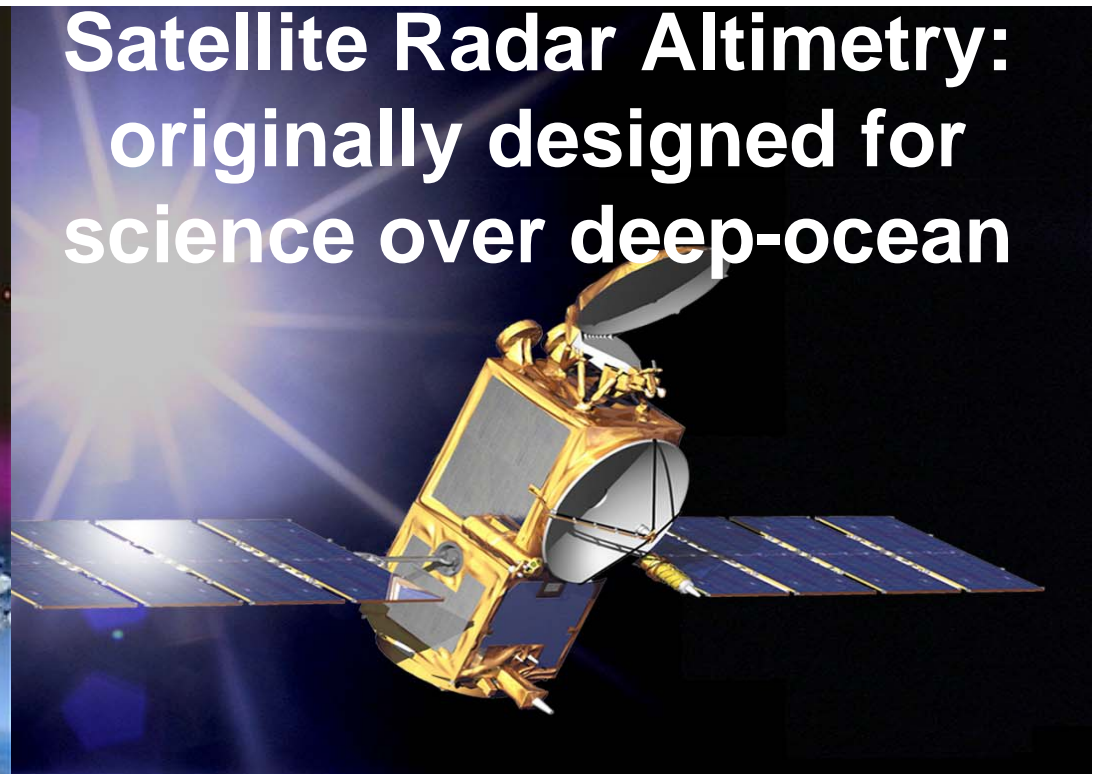
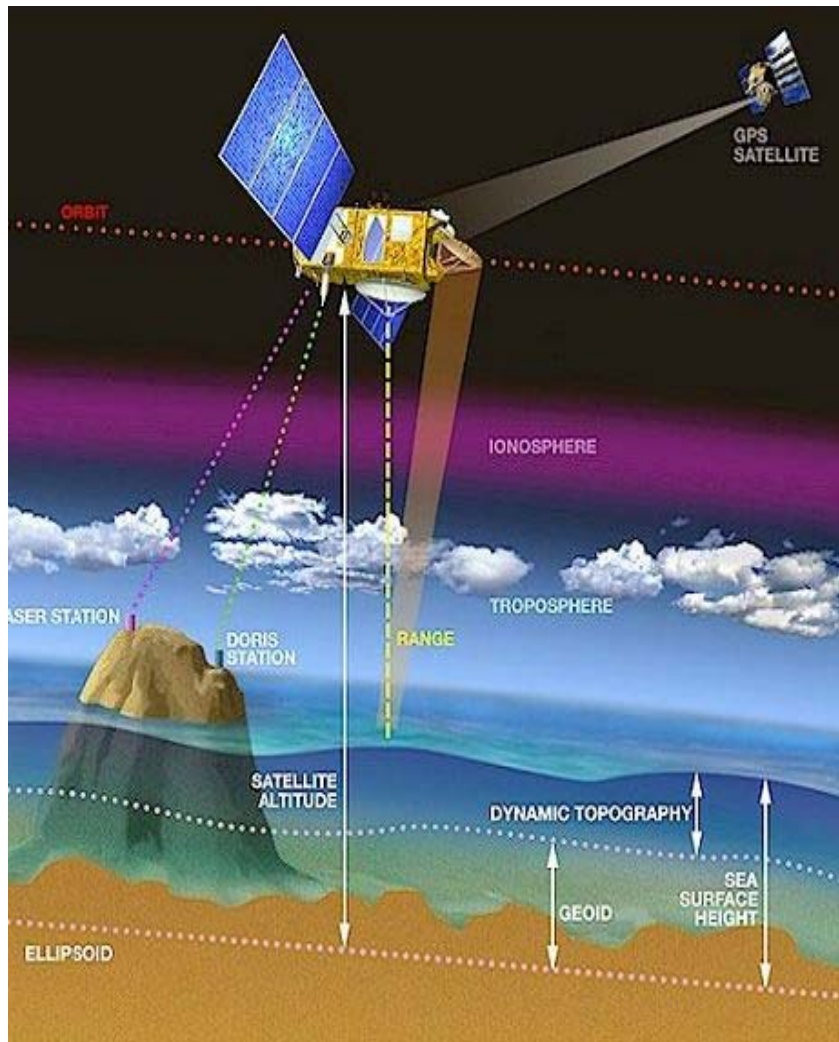


Figure Credit: John Luick, NTF

Tide gauges measures **relative sea level**, requires GPS for measuring vertical motion

**Satellite Radar Altimetry:** originally designed for science over deep-ocean

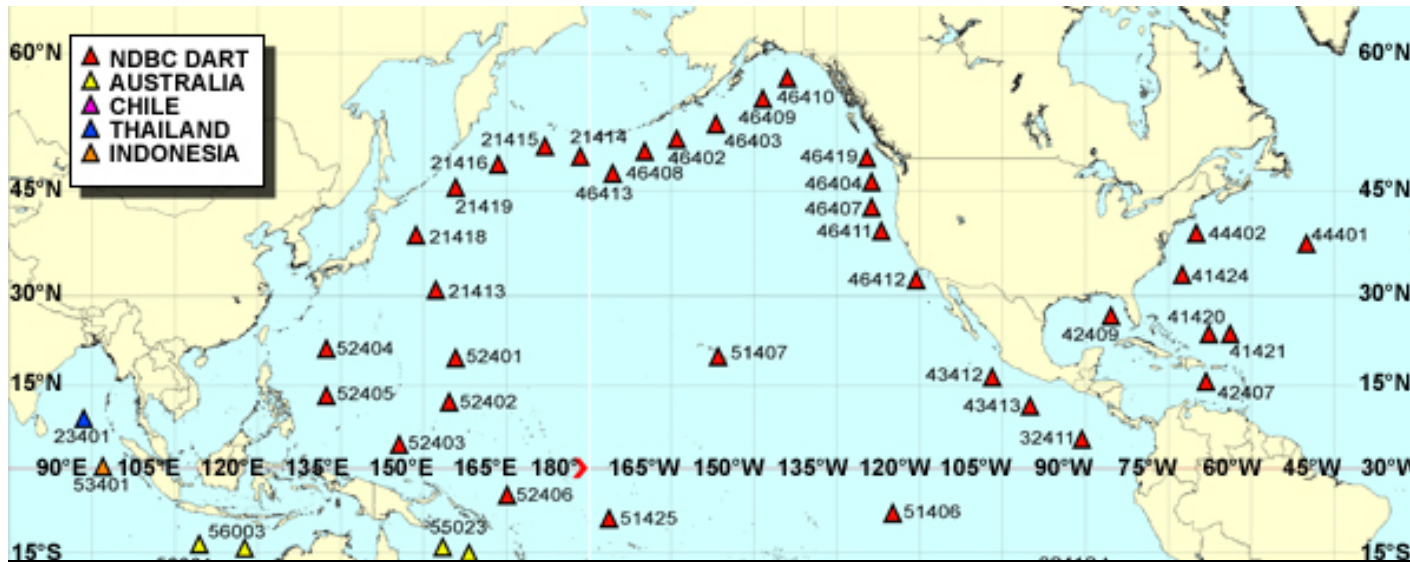
# Satellite Radar Altimetry: originally designed for science over deep-ocean



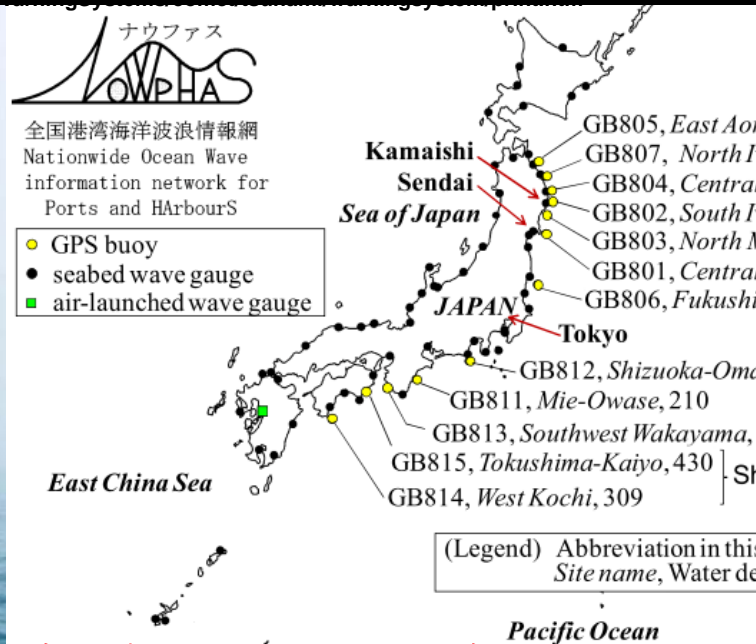
**Historic & current missions:** Seasat (1978), Geosat (1984), ERS-1/2 (1991, 1995), TOPEX/POSEIDON (1992), GFO (1998), JASON-1 (2001), Envisat (2002), JASON-2 (2009), CryoSat-2 (2009)

**Planned missions:** AltiKa (2012), JASON-3 (2013), Sentinel-3 (2013), SWOT (2020), GFO-2 (?)

- Inland hydrology
- Coastal oceanography
- Ice-sheet elevation change
- Solid Earth deformation (glacial isostatic adjustment)



## Deep-ocean Assessment and Reporting of Tsunamis (DART)

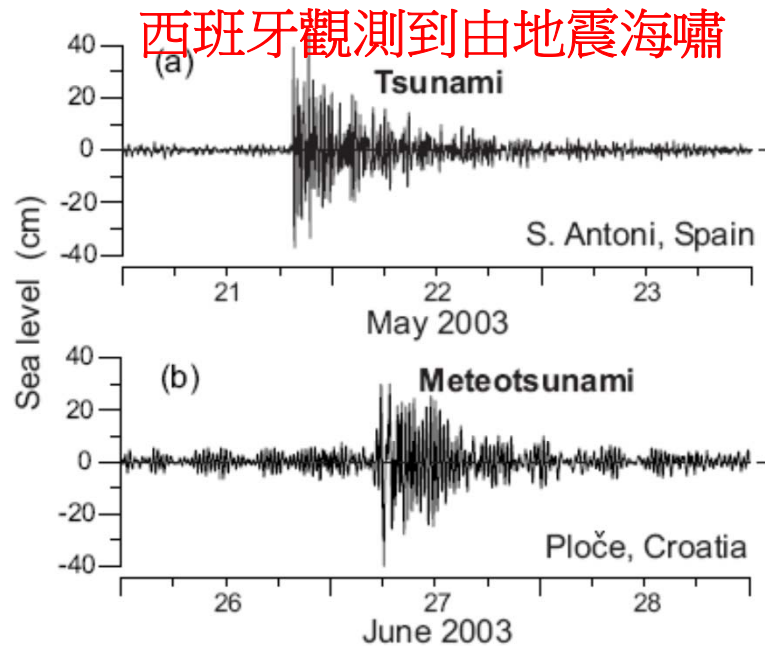


国土交通省東北地方整備局

Kawai et al., 2012

臺灣東部海域海纜觀測系統: 進行地震監測及其它海洋環境科學觀測之任務, 其中該計畫亦配置海嘯壓力計來進行即時海嘯觀測



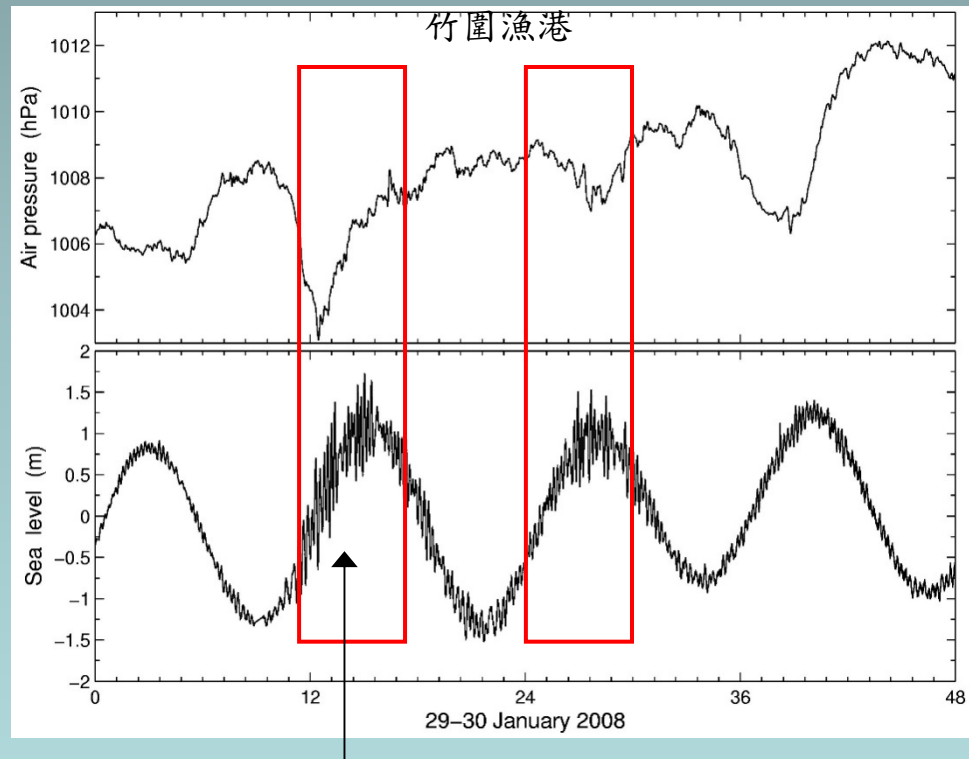


克羅地亞觀測到氣象海嘯

Fig. 1. (a) Tsunami oscillations recorded at Saint Antoni (Iuiza Island, Spain) after the Algerian earthquake of 21 May 2003; and (b) the meteotsunami recorded at Ploče Harbour (Croatia) on 27 June 2003. Both records have been high-pass filtered to eliminate oscillations with periods longer than 2 h.



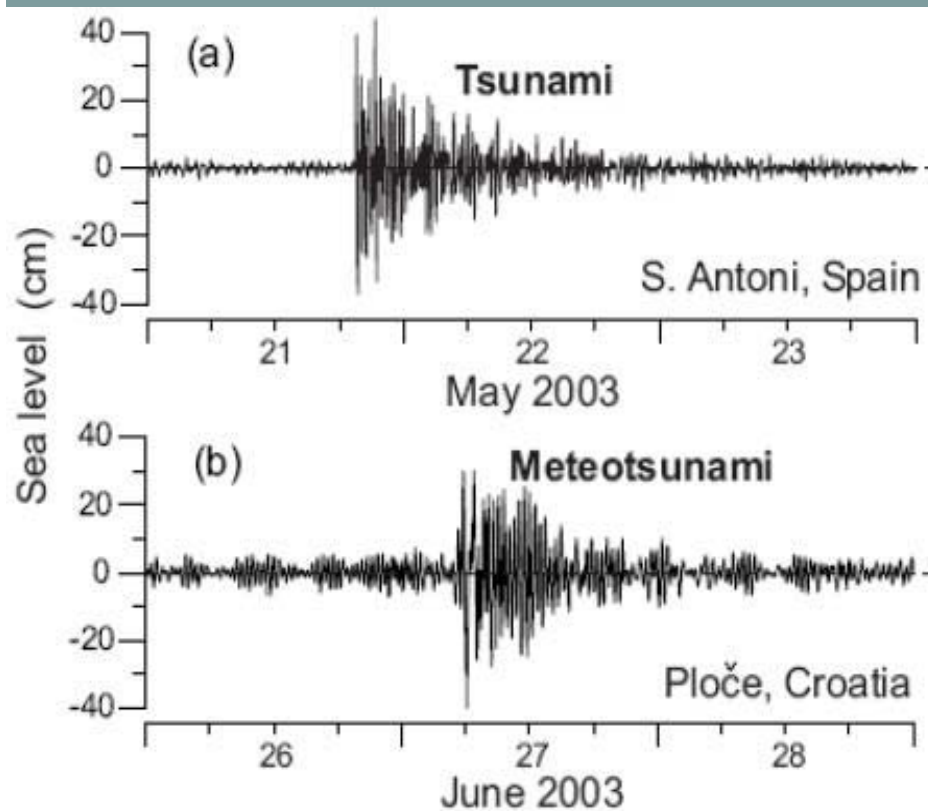
- 如壓力跳動、熱帶氣旋、鋒面通過等氣象因子變動引起海水面異常升降
- 頻率和振幅與地震海嘯類似
- 振幅受港灣共振之影響而放大



Sea level change : 1.5 m

Lin and Liang, 2013

# 氣象海嘯



[Monserrat *et al.*, 2006]

- 如壓力跳動、熱帶氣旋、鋒面通過等氣象因子變動引起海水面異常升降，  
[Defant, 1961; Hibiya and Kajiura, 1982 ;  
Rabinovich and Monserrat, 1996, 1998]
- 
- 頻率和振幅與地震海嘯類似
- 振幅受港灣共振之影響而放大

# GPS/IMU System Design

## Phase I



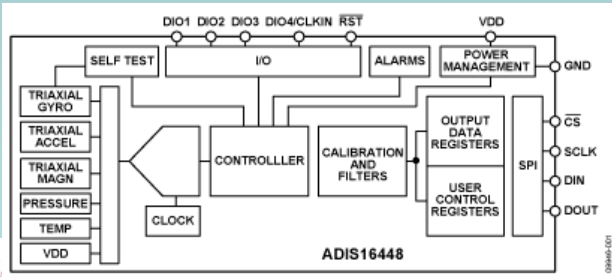
## Observation system



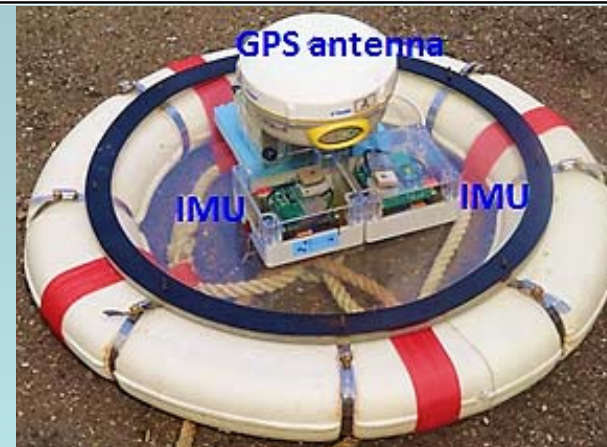
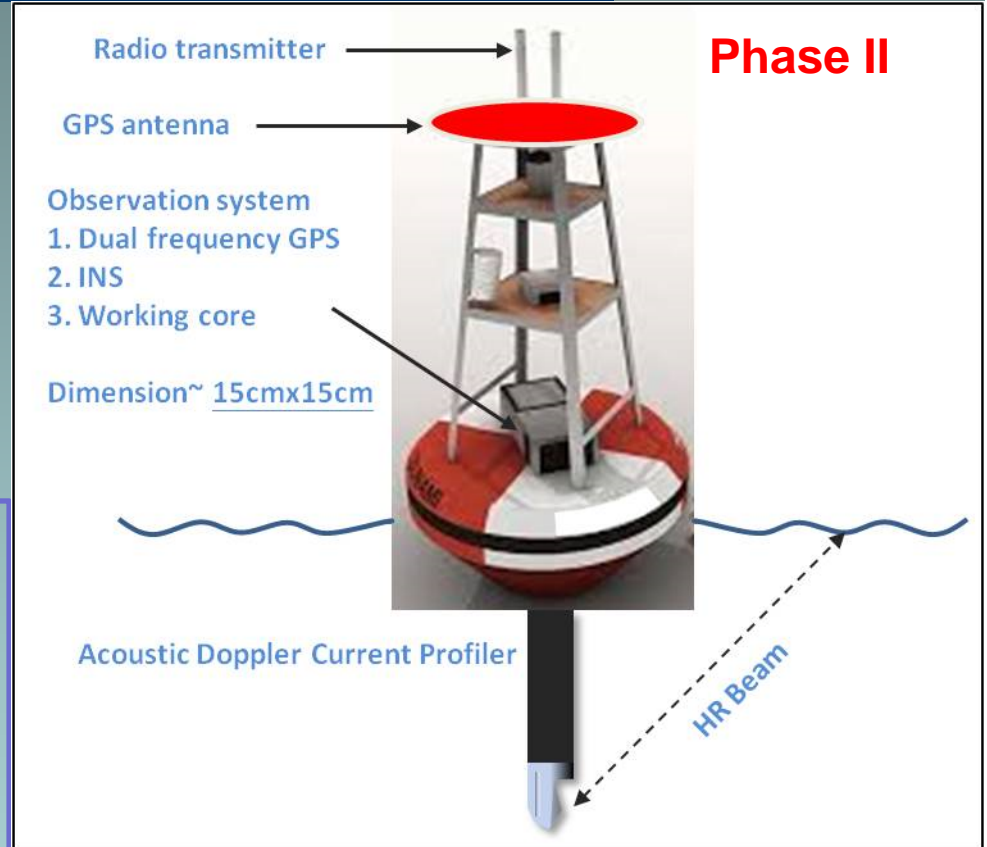
GPS Pathfinder ProXRT Receiver



IMU ADIS16488



## Phase II



# Global Navigation Satellite System

- **Definition of GNSS:** The Global Navigation Satellite System (GNSS) is a space-based radio positioning system that includes one or more satellite constellations, augmented as necessary to support the intended operation, and that provides 24-hour three-dimensional position, velocity, and time information to suitably equipped users anywhere on, or near, the surface of the earth (and sometimes off earth).

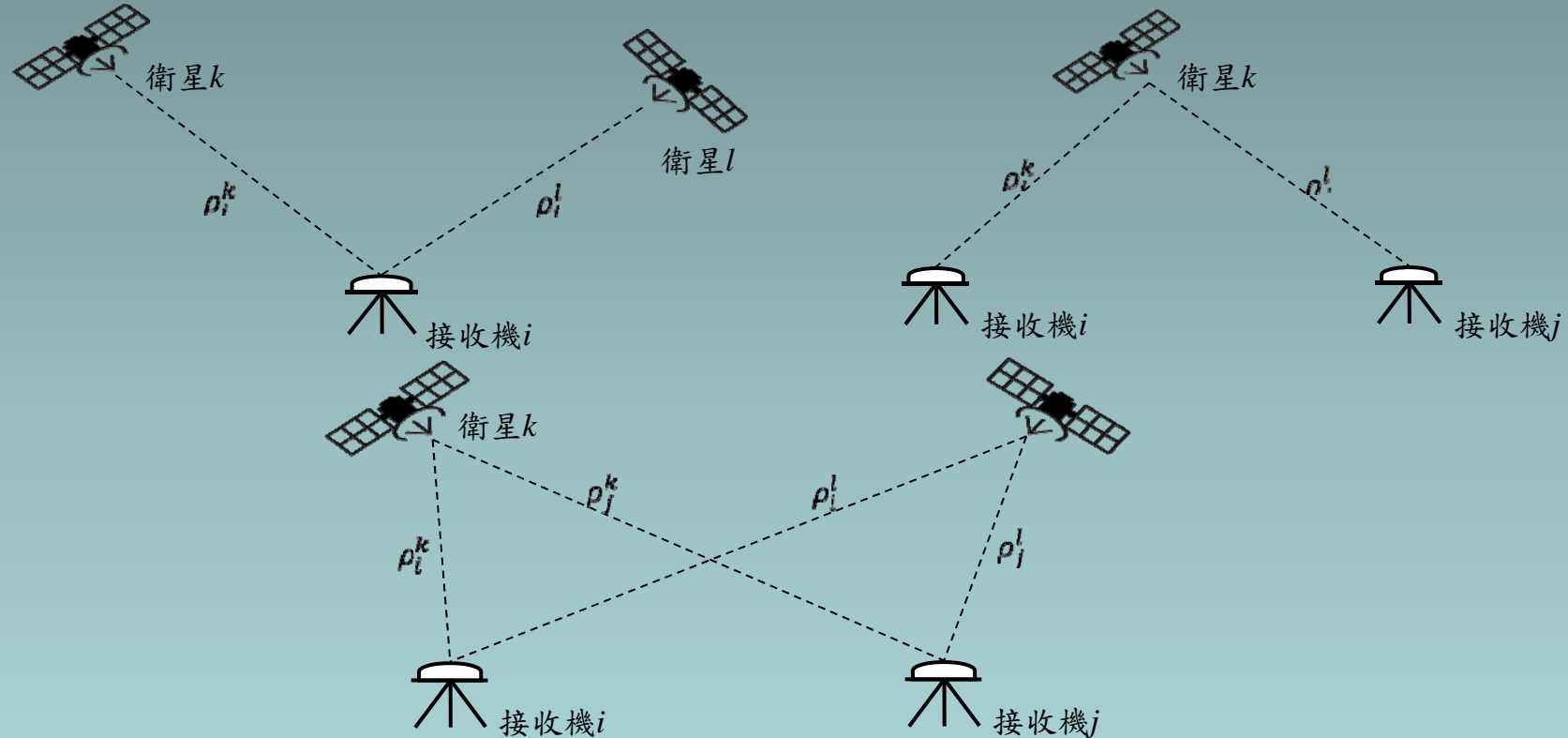
- 美國系統 : GPS
- 俄羅斯系統 : GLONASS
- 歐盟系統 : Galileo
- 大陸 : Beidou





# GPS Positioning method

## ➤ 相對差分定位—一次差、二次差

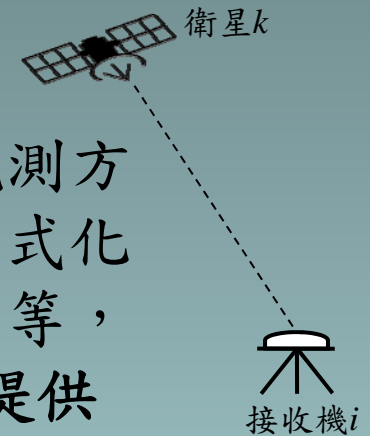


兩台以上接收儀同時接收衛星訊號，若接收儀彼此距離不遠，則可透過差分大幅降低共同之系統誤差，例如衛星時錶差、衛星軌道誤差、對流層延遲誤差及電離層延遲誤差等。

# GPS Positioning method

## ➤ 精密單點定位

利用無差分觀測量進行定位，無法像差分藉由觀測方程式相減而消去系統誤差，故必須改正其它未模式化的誤差，例如對流層延遲誤差、電離層延遲誤差等，並搭配使用 IGS(International GNSS Service)提供之精密星曆產品、衛星時錶資料。



## ➤ 相對差分定位 v. s. 精密單點定位

相對差分定位	精密單點定位
需兩台以上的接收儀，故儀器成本與人力成本較高	不需要購買多台接收儀，只需 <b>單台接收儀即可得到高精度的定位</b> 。
距離參考主站之基線不可過長，否則將影響精度。	<b>定位精度不受基線距離限制</b> ，無地區受限之疑慮，故對於遠洋地區的量測較為便利。

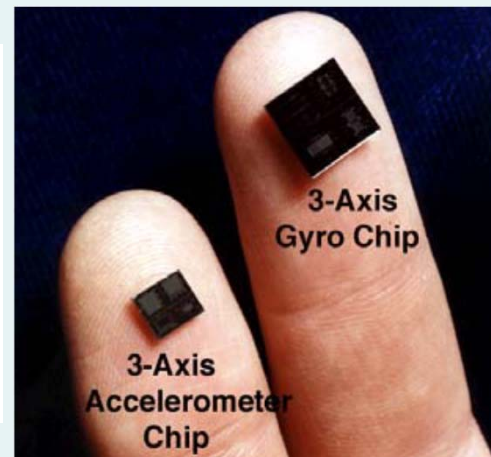
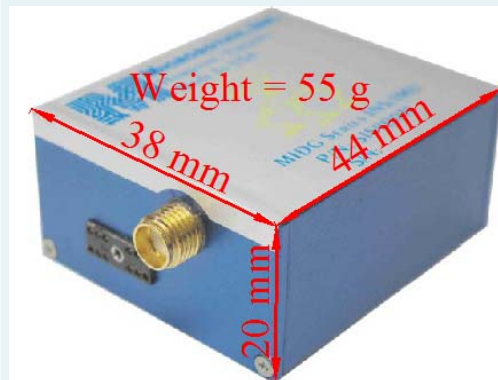
# 慣性測量單元 (Inertial measurement units, IMU)

	導航等級	戰術等級	電等級
價格	美金	美金	美金
定位精度 (無任何輔助資訊)	<		公尺/分鐘
陀螺飄移(度/小時)			3600
加速度計飄移			0.5 g
出口管制	無	無	無



(有數頁不到) (頁對可能任低) (EU(歐洲產品))

## 微機電等級



# GPS/IMU cost

## GPS/IMU 製作費用

**Inertial Measurement Unit**

**6cmx8cm Cost : 20,000 NTD**

**GPS**

**400, 000 NTD (Future 4170,000**

**GPS+IMU : 1500,000 NTD**

**CWB : Cost : 500,000~700,000 NTD**



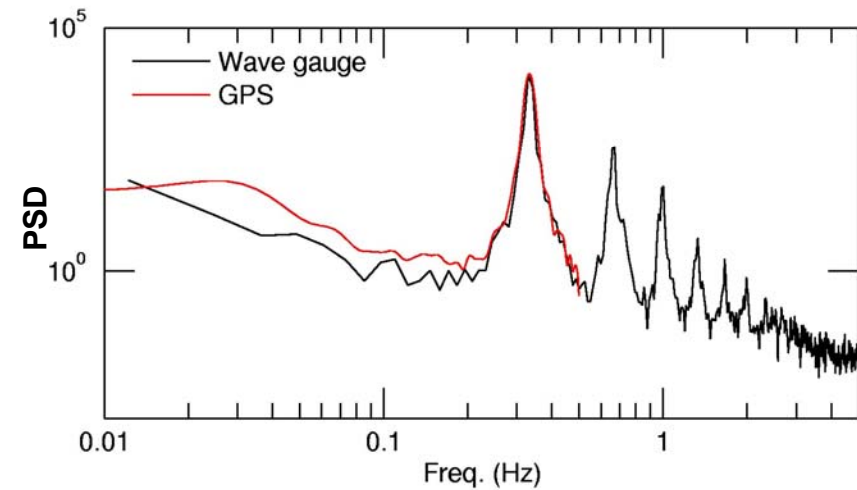
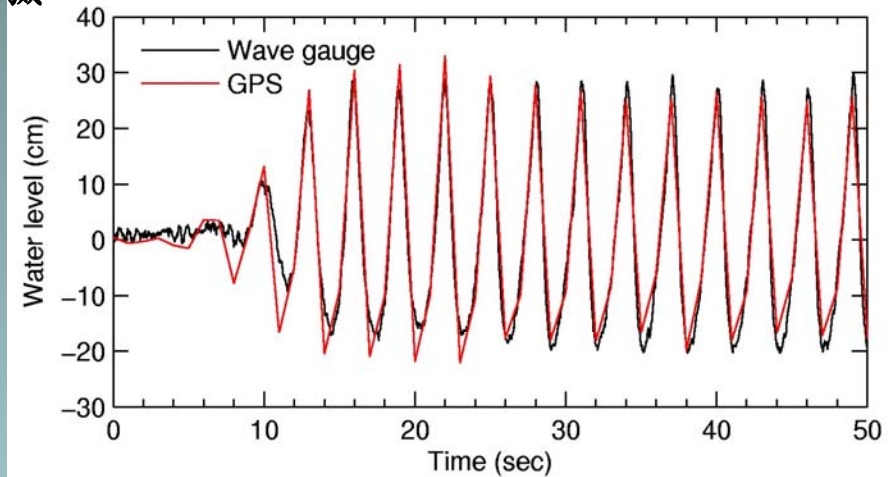
# Testing and Validation -1

總共做了20, 30, 40, 50 cm的波高共四組試驗  
每組試驗時間為5分鐘



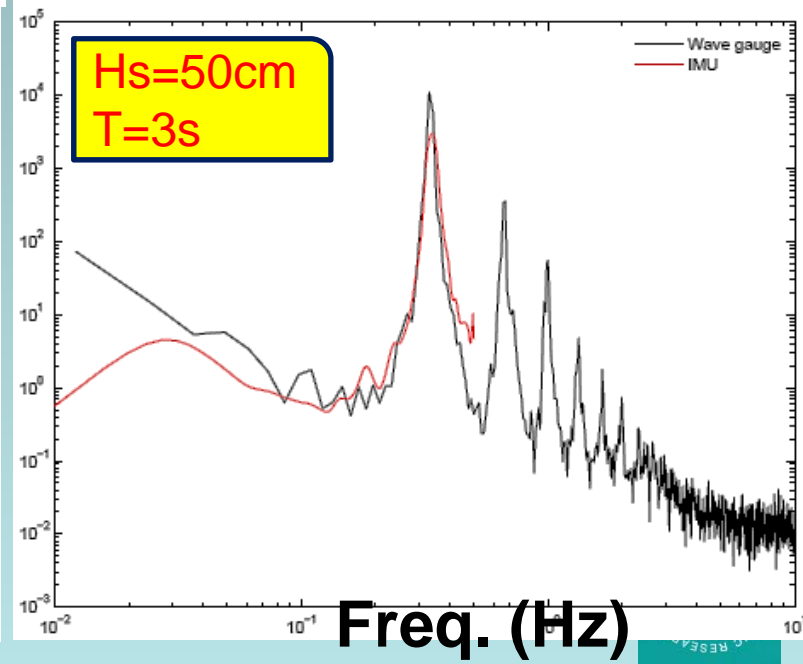
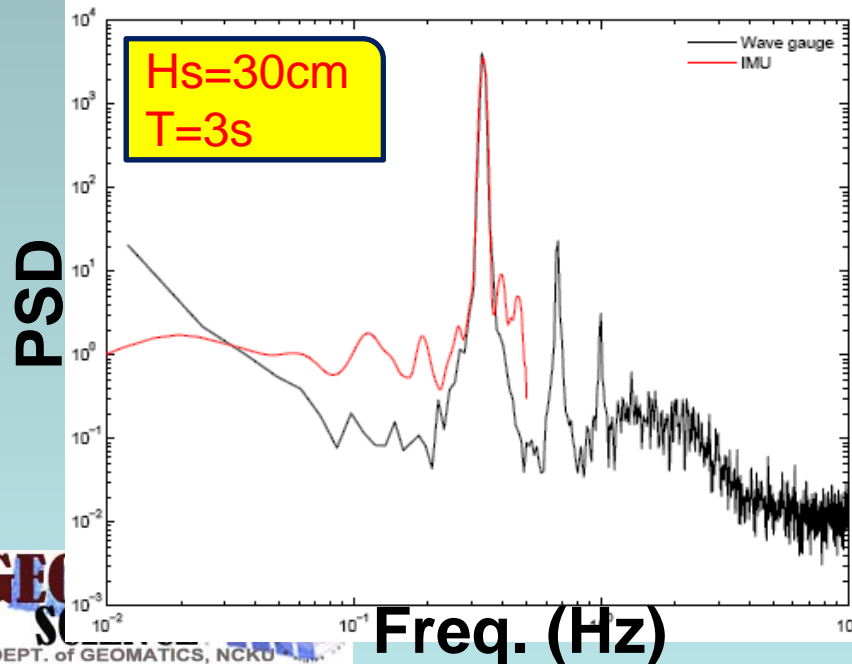
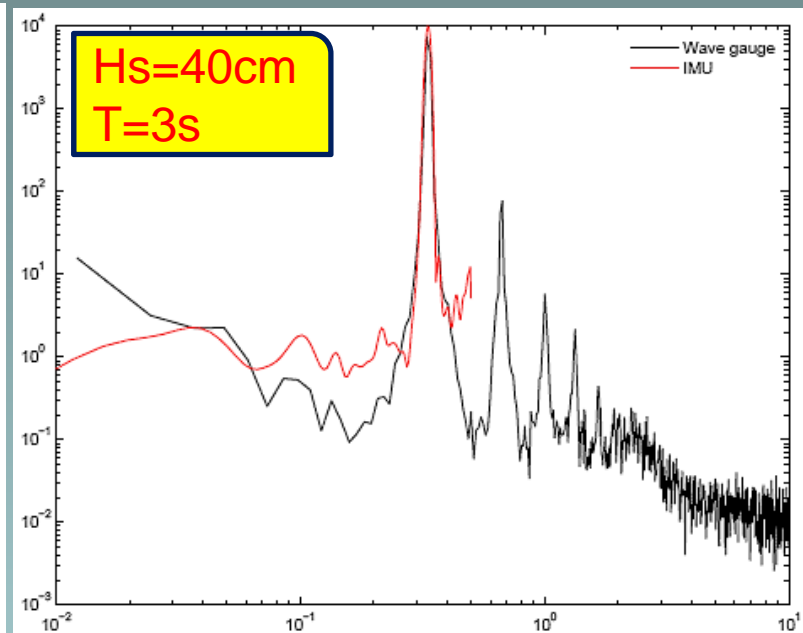
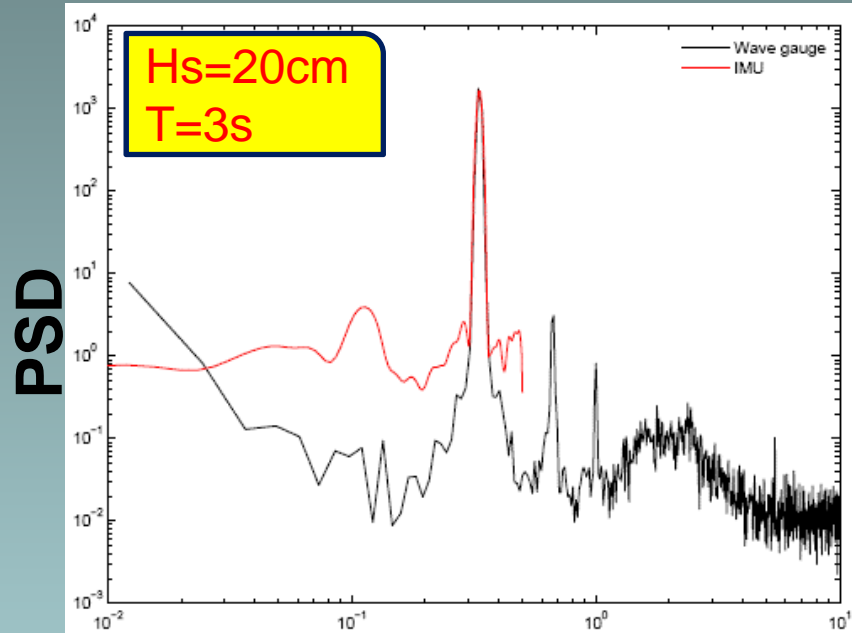
斷面試驗造浪水槽  
(numerical wave tank)

$H_s = 30 \text{ cm}$ ,  $T = 3 \text{ sec}$



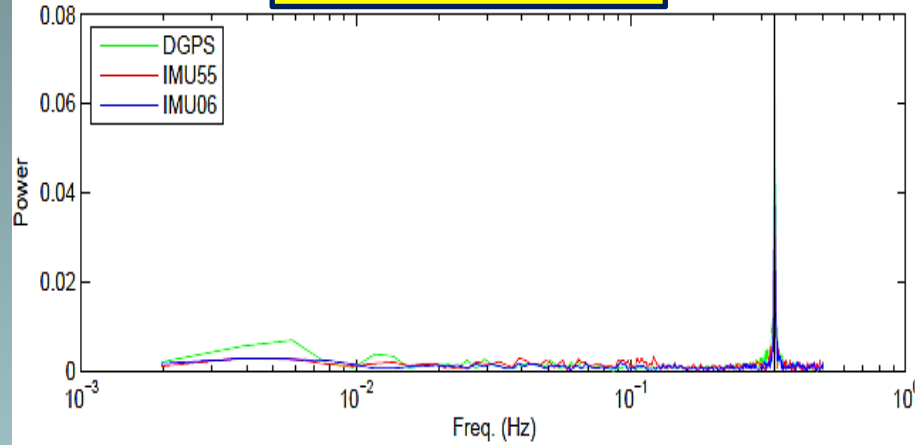
GPS/IMU Sampling rate = 1Hz  
Wave gauge Sampling rate = 25Hz

# Testing and Validation -2

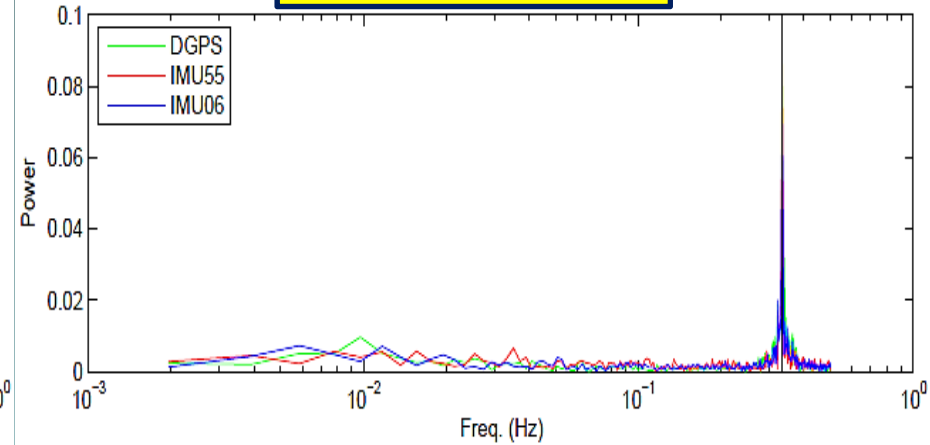


# Testing and Validation -3

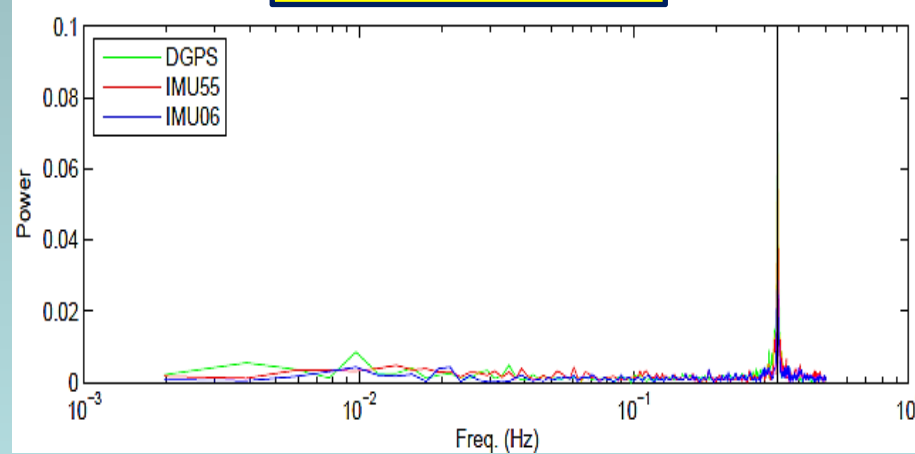
Hs=20cm T=3s



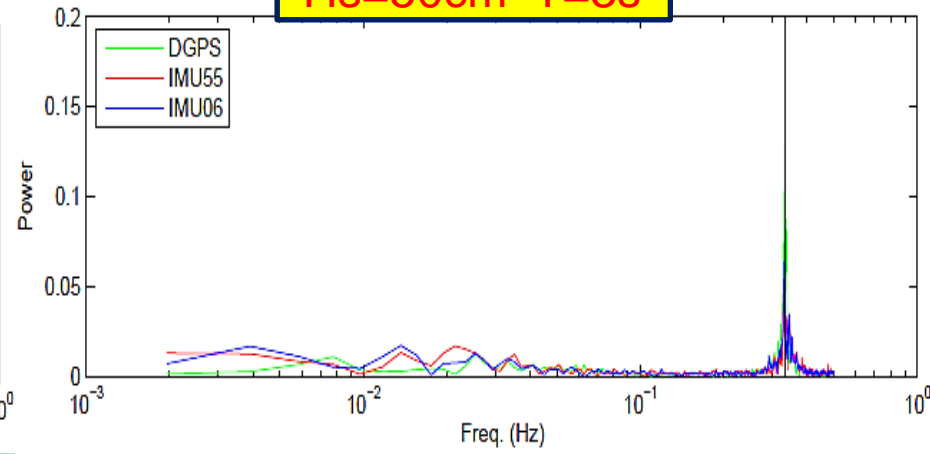
Hs=40cm T=3s



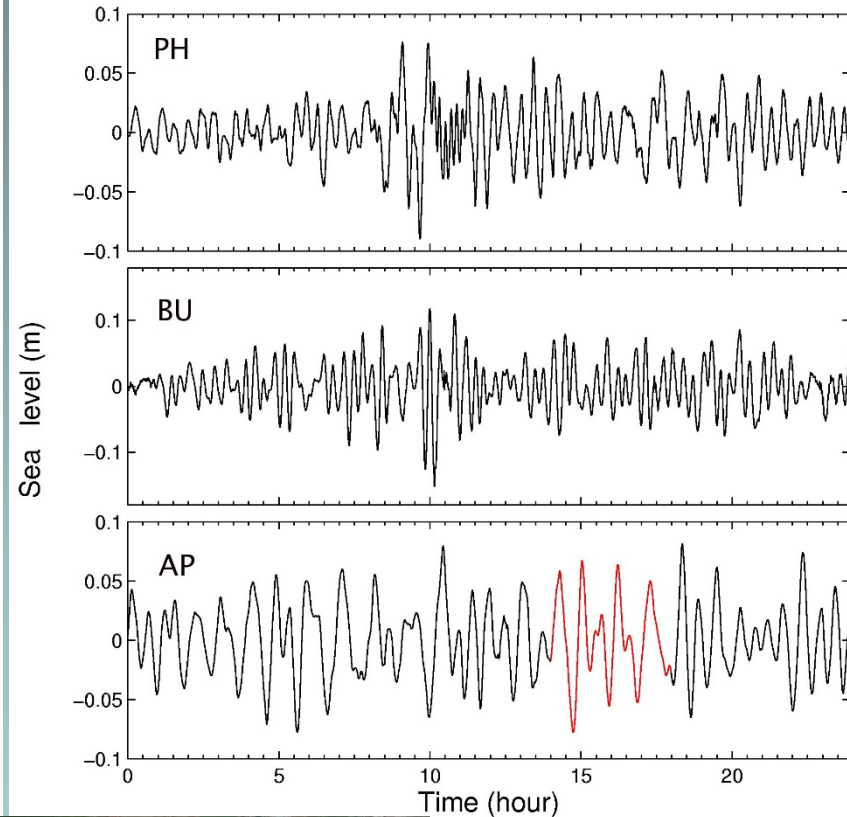
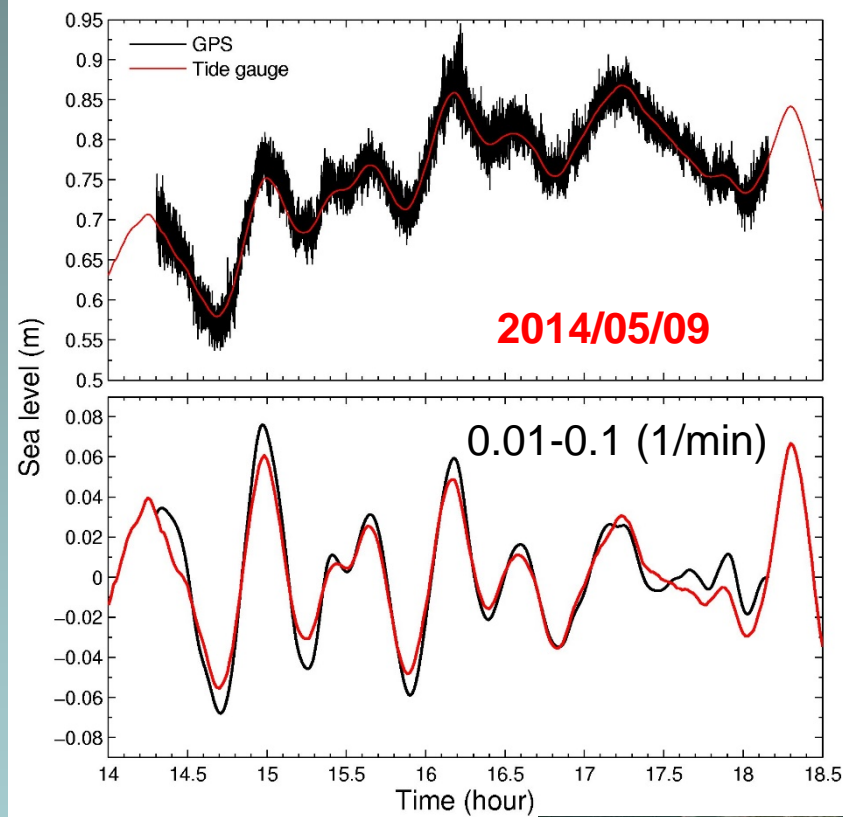
Hs=30cm T=3s



Hs=50cm T=3s



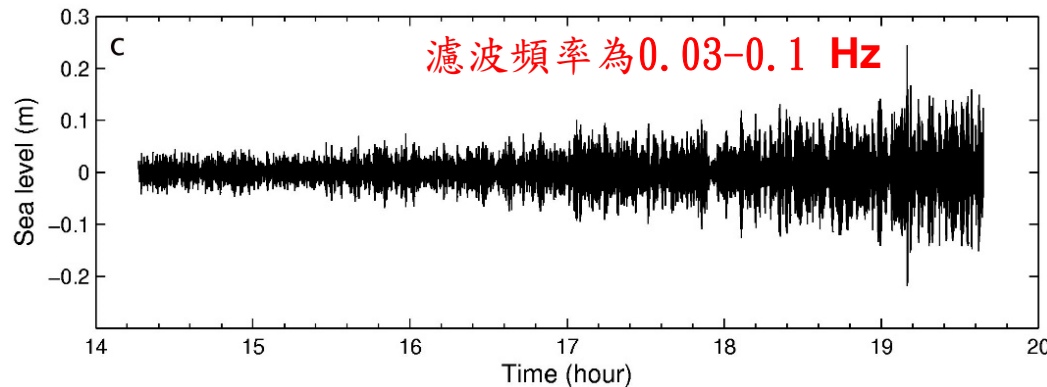
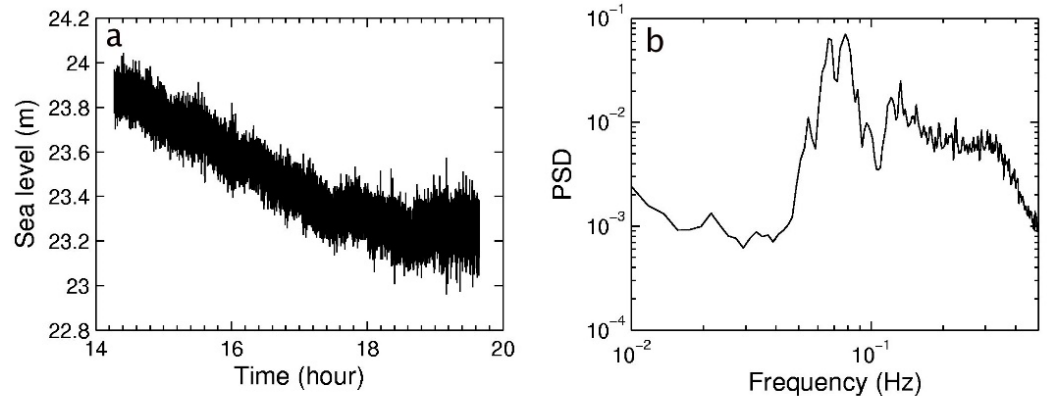
# Field Work : An-Ping Harbor (2014/05/09)





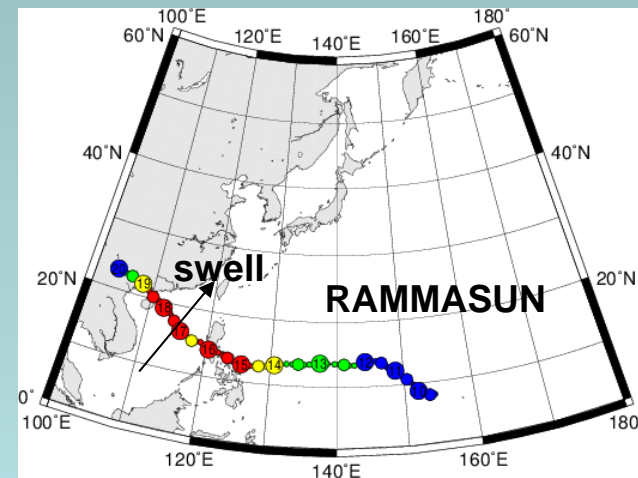
# Field Work : An-Ping Harbor(2014/07/17)

2014/07/17



Time	Hs(m)	T(s)
2014-07-17 14:00	0.77	7.8
2014-07-17 15:00	0.95	7.9
2014-07-17 16:00	0.83	7.5
2014-07-17 17:00	0.86	7.2
2014-07-17 18:00	0.96	12.9
2014-07-17 19:00	1.19	12.3
2014-07-17 20:00	1.31	12.1

安平港海域波浪觀測資料 (IHMT)



# Conclusion

- 本研究所自主研發並設計組裝之GPS/IMU系統，經由定量之測試顯示為一種有效且經濟的方案。
- 對定量波浪的測試上，GPS垂直運動之水位訊號與波高計的觀測一致；在水位振盪變化之量測精度可達公分等級，並且已成功觀測到颱風湧浪及氣象海嘯等長週期波，因此以GPS浮標取得高頻取樣空間(三軸)位置精確變動之優點，以量測風浪、流速、海嘯及其他長週期海水面變動訊號。

**Thank you**