同調性微波雷達開發 及其應用於近岸波浪場與流場監測

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近岸海洋環境監測

水動力主導下列現象：

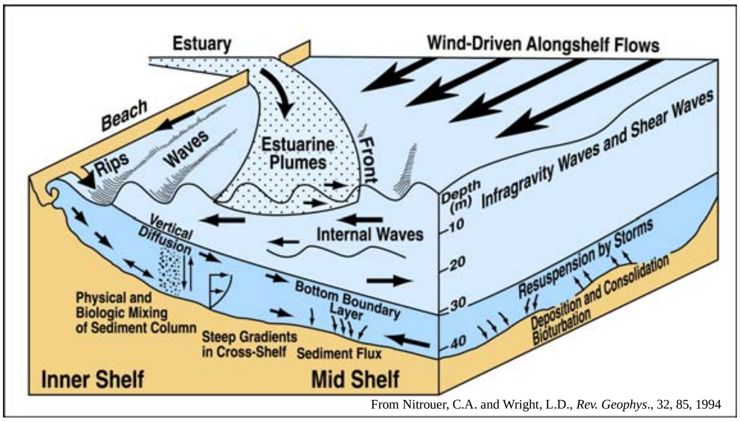
- 海岸侵蝕、波浪越堤海岸溢淹以及海域活動意外
- 向離岸水體混合作用、溢油及污染物輸送擴散、冷卻水熱擴散

近岸波場與流場呈現時空不均勻，各處流速與流向不同且皆隨時間而變：

  - 外邊界:大尺度潮汐、洋流、天氣系統
  - 內陸棚與碎波帶：崎嶇岸線遮蔽、水深地形變化，流場中產生各種尺度的渦旋、沿岸流與裂流
  - 波流的交互作用與近岸海水密度分層效應

- 傳統單點的時間序列觀測難以呈現全貌，發展時間與空間高解析精度的監測技術有助於獲得致災近岸水動力特性。

近岸波場與流場隨時空變化甚鉅，各種機制交互作用現象複雜



From Nitrouer, C.A. and Wright, L.D., *Rev. Geophys.*, 32, 85, 1994

以海岸災害監測、預警及研究需求為目的之遙測系統研發

- 研製同調性微波雷達監測系統，中央大學自行開發與執行
  1.雷達訊號處理電路、
  2.資料演算與分析方法、
  3.現場實驗與測試。
- 實現的原理(Coherent on Receive)：
  - 應用都卜勒效應，以機械式海面掃描，得到海表特徵在空間分佈與時間演變特性。
  - 觀測電磁波脈衝於海面的背向散射訊號傳遞相位，直接獲得高解析度海表水粒子速度
  - 藉此推算波浪水位、週期、方向波譜與海面流場分佈。
- 現場實驗與測試比對
  - 桃園新屋海岸中央大學臨海工作站
  - 臺中港北堤海域

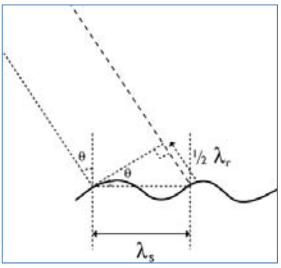
非同調性(回波強度影像) vs.同調性(都卜勒雷達)

a. Bragg Law

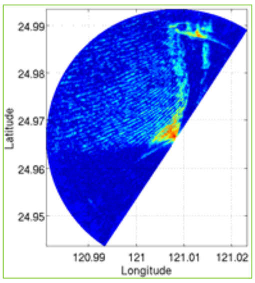
b. Barrick (1972)一階峰背向散射理論

$$\lambda_s = \frac{\lambda_r}{2\mathrm{Sin}\theta}$$

λ_r radar wave length
λ_s sea surface wavelength
θ depression angle



$$\sigma(\omega,\varphi) = 2^6 \pi \cdot k_0{}^4 \sum_{m'=\pm 1} S(-2m'\vec{k}_0) \cdot \delta(\omega - m'\omega_B)$$



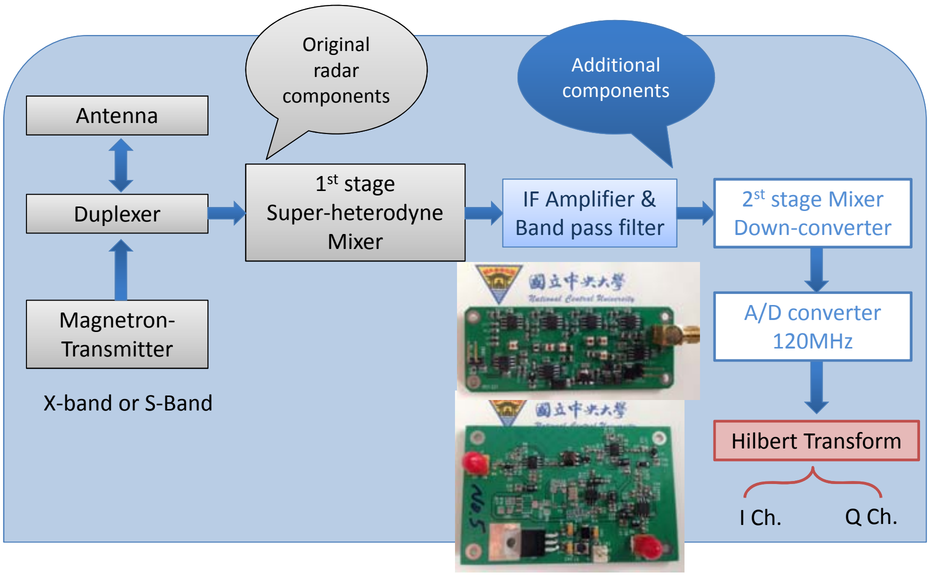
Why Coherent radar?

- 傳統影像雷達觀測波峰連線之移動速度，轉換至頻率域及波數域，套用分散關係逆推算流場
- 但是，近岸波場入射過程受折射效應影響，方向分散度變窄，且個頻率入射波向皆漸垂直海岸線，與主要海流方向垂直，故無法解析近岸流場
- 相對於傳統雷達Tracking整體波浪的時頻特性，Coherent radar觀測的是水粒子運動速度，不受近岸淺水限制

Land-based radars for detecting surface wave and current

	HF Radar	Microwave Nautical Radar
	• Frequency band: 5~25 MHz • Range：~200 km • Electronically scanning using MUSIC or Digital Beam Forming algorithm • FMCW	• Frequencies for civil use: 9.4 GHz or 3 GHz • Range：~3 km • Mechanical scanning by rotation of antenna • Pulse wave
Non-coherent: Image process based Echo intensity (amplitude of radar backscatter signal)		WaMos-Like system • Using empirical formula and MTFs to determine the wave heights and wave spectra. • Using wave dispersion to infer the surface current.
Coherent: Doppler theory based Using Phases of backscatter signal to estimate the motion of sea surface	Modulated CW • Codar SeaSonde (Compact antenna) • ISR HF radar • WERA (Antenna array) • OSMA-071 (Antenna array)	Fully-Coherent Radar, COH-radar Pulse signal from Solid state EM generator Coherent-on-Receive Radar, COR-radar Pulse signal using Magnetron

Structure of Coherent on Receive Radar modified from commercial nautical radar



Original radar components

Additional components

Antenna

Duplexer

Magnetron-Transmitter

X-band or S-Band

1st stage Super-heterodyne Mixer

IF Amplifier & Band pass filter

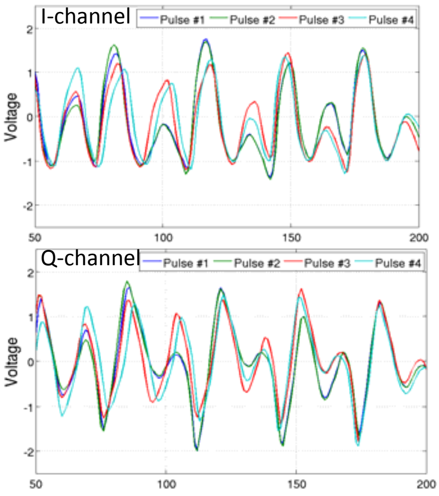
2st stage Mixer Down-converter

A/D converter 120MHz

Hilbert Transform

I Ch.

Q Ch.



1. Calculate the Quadratic signal and the corresponding phase by applying the Hilbert Transform to the I signal.
2. Alignment of the waveforms between the 1st pulse envelop and the succeeding pulse envelop using the cross spectral analysis of the 1st and 2nd I and Q channel.
3. Assume the transmitted signals in the 1st pulse and 2nd pulse have the same frequency; calculate the phase difference of the echo between pulses at every radial grid.
4. Transfer the phase difference to radial velocity using Doppler Theory.

Phase angle： $\phi = a\tan(I/Q)$

Radial velocity： $V_r = \frac{d\phi}{dt} \times \frac{\lambda}{-4\pi}$

λ=0.03 for X-band
dt=1/2000

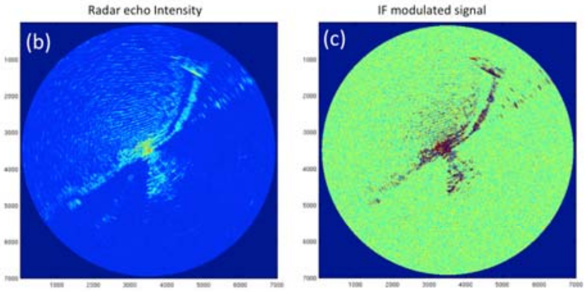
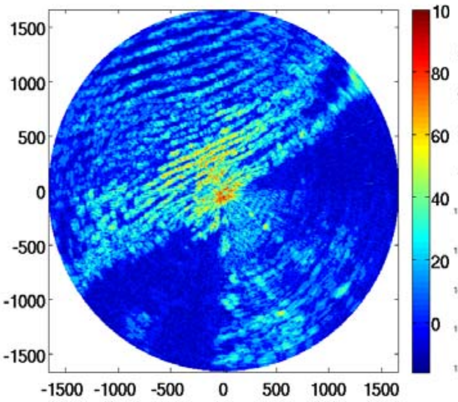


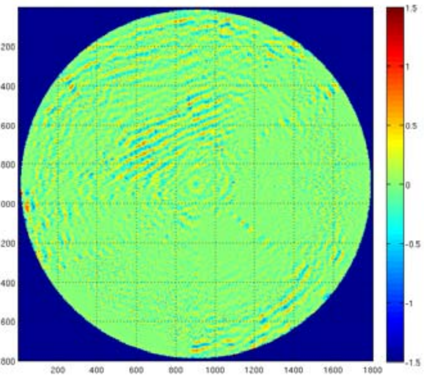
Figure 1. (a) The location of the microwave radars at NCU coastal observatory. North to the radar are Yung-An fishery harbor and sandy beach where can be identified in radar PPI images in (b) and (c). (b) The traditional marine radar PPI image illustrates the backscatter intensity, from which the pattern of surface wave is obvious. (c) Similar to panel (b), the color demonstrates the IF modulated signal, instead of the amplitude of echo strength.

如何用都卜勒雷達觀測瘋狗浪？

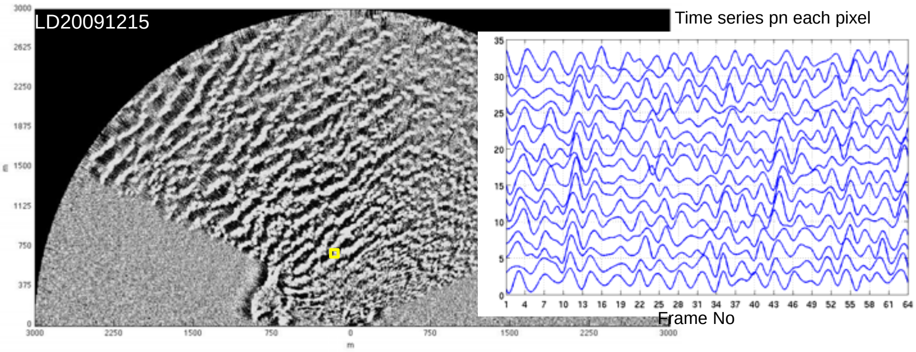
都卜勒微波雷達應用在監測波浪是一種嶄新的技術：利用都卜勒原理偵測近海海面上廣大區域每一點上水體的運動特性，從而分析得每一列波浪的波高、週期與方向，非常適合用於近岸海象的監測，最為環島海象監測網的一環。

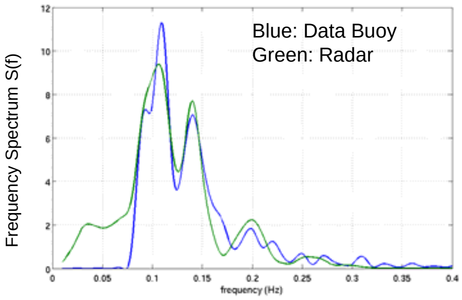


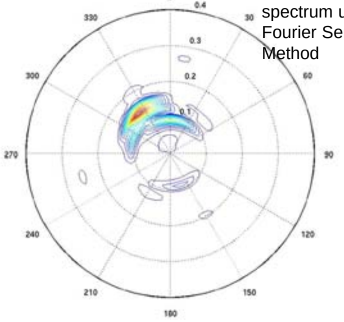
海面波浪雷達影像



經由都卜勒頻率分析後所得到海表面水粒子運動速度，藉以推算波浪波高、週期、波向等



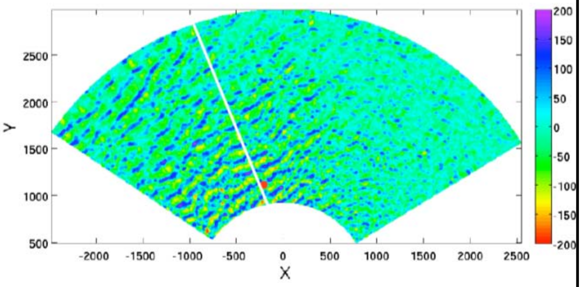




Directional spectrum using Fourier Series Method

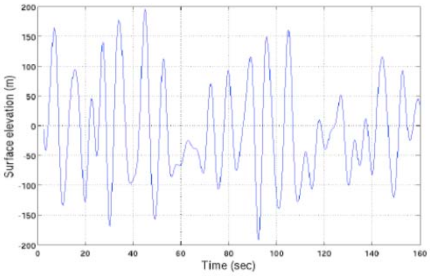
瘋狗浪監測於研究

- 都卜勒微波雷達可觀測高解析精度波浪場於時間及空間域的演變，是研究瘋狗浪特性的有力研究工具。



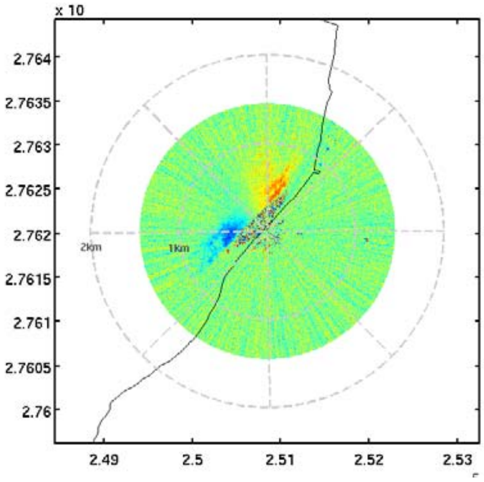
海水面水位分佈

瘋狗浪對於海域活動帶來安全威脅



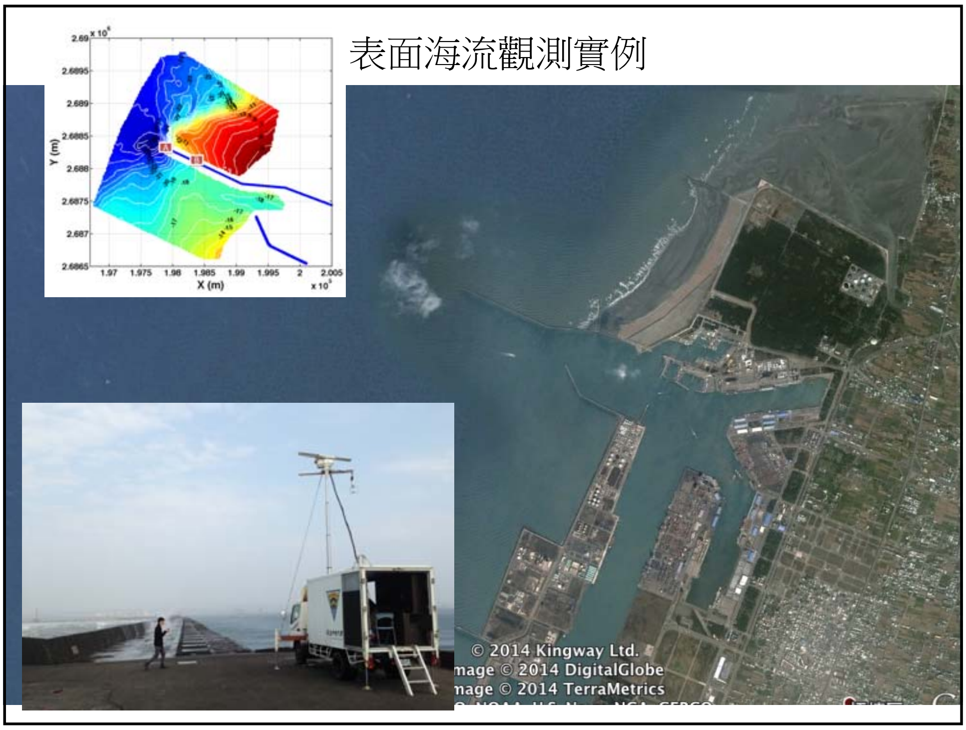
水位變動隨時間變化，掌握瘋狗浪發生特性

近岸流的監測

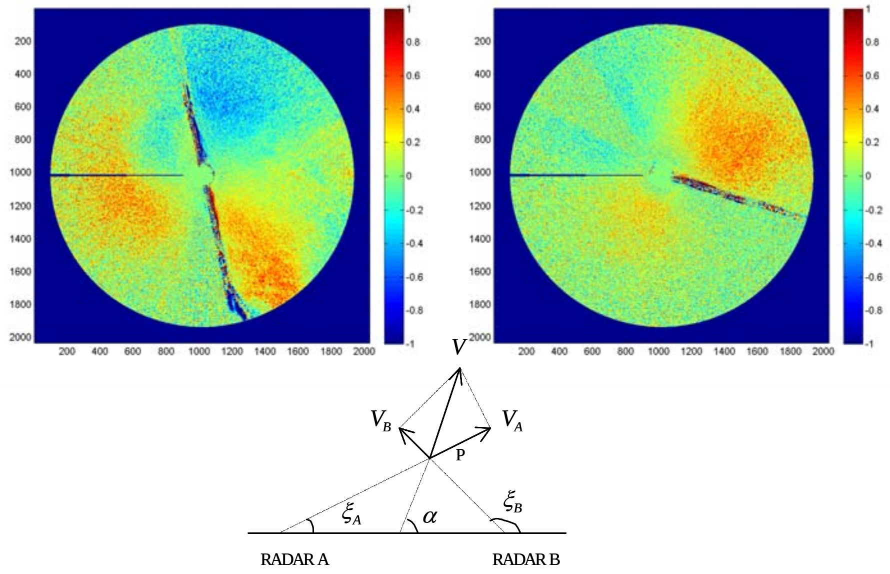


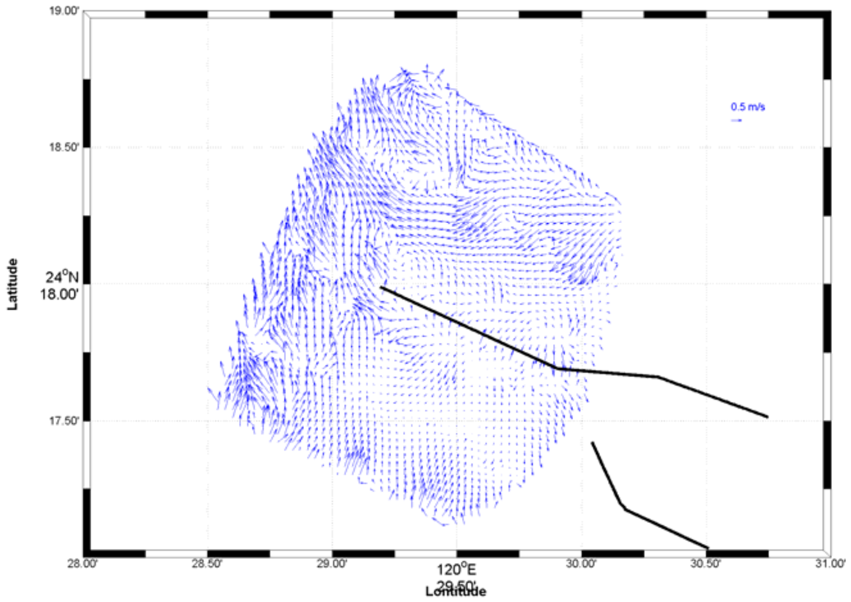
都卜勒徑向流速場

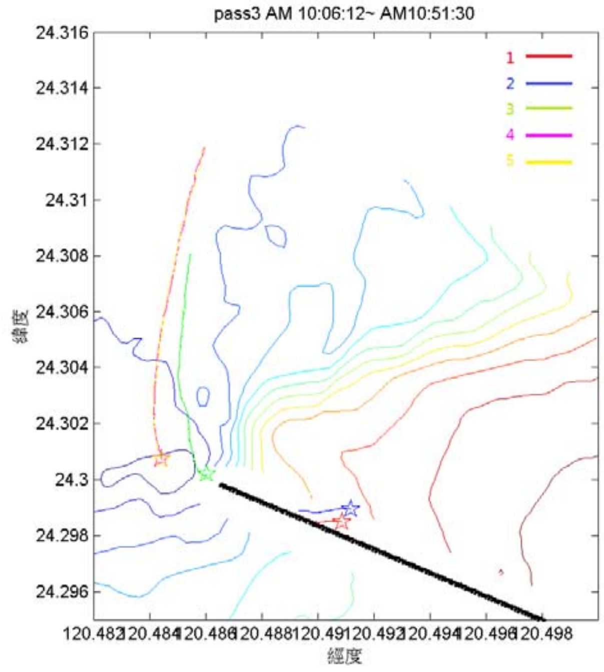
表面海流觀測實例

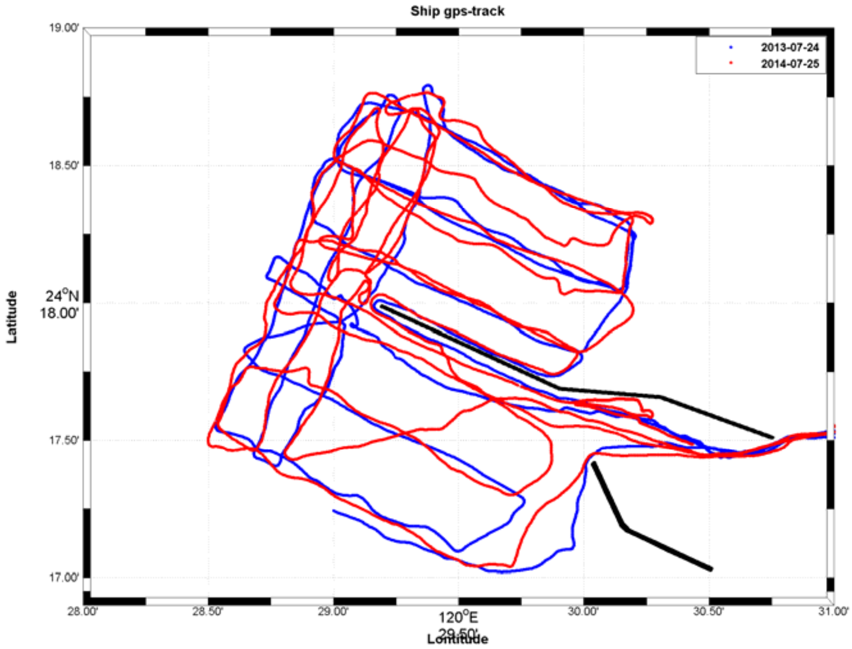


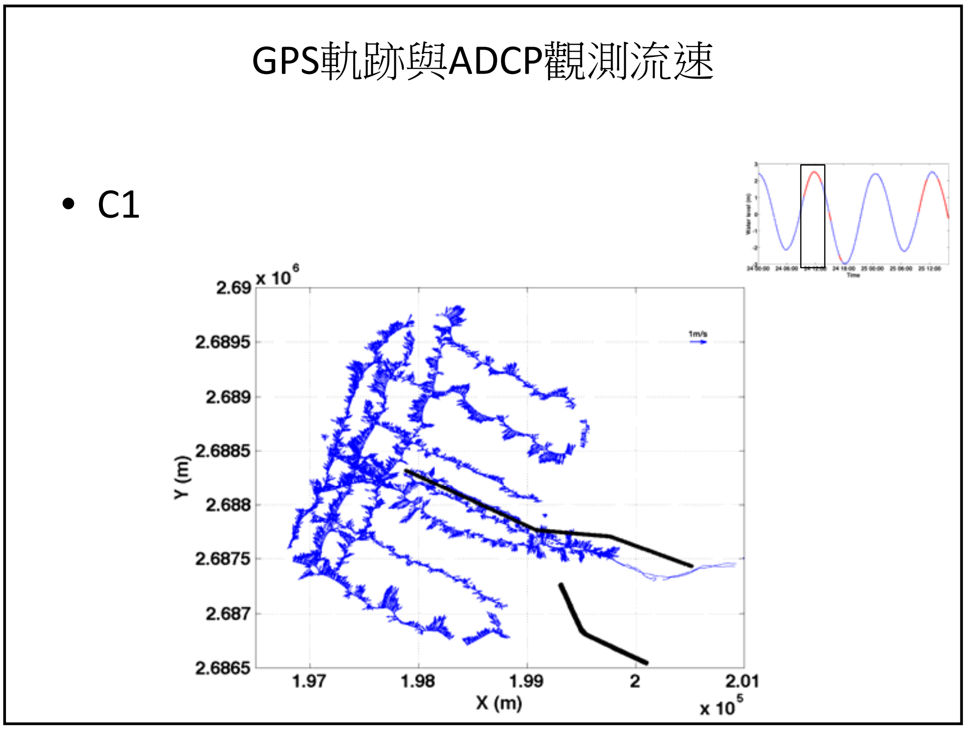
雙站徑向表面海流速度場分布
Vector map derived from radials of two stations





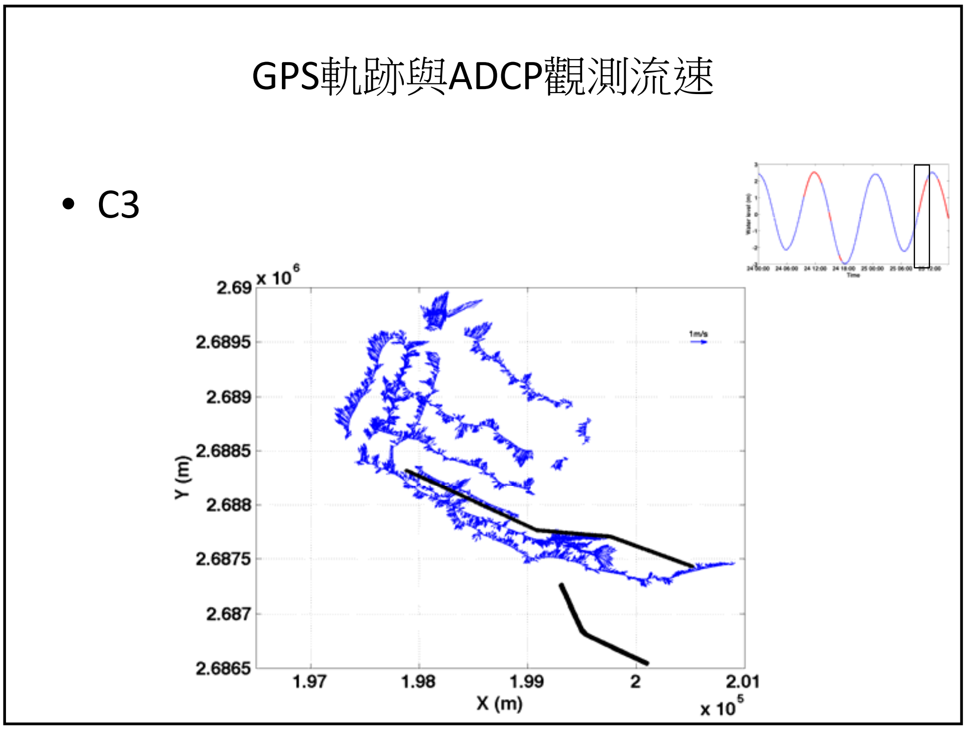

pass3 AM 10:06:12~ AM10:51:30
緯度
24.316
24.314
24.312
24.31
24.308
24.306
24.304
24.302
24.3
24.298
24.296
1
2
3
4
5
120.482
120.484
120.486
120.488
120.49
120.492
120.494
120.496
120.498
經度


Ship gps-track
2013-07-24
2014-07-25
Latitude
19.00'
18.50'
24°N
18.00'
17.50'
17.00'
28.00'
28.50'
29.00'
120°E
29.50'
30.00'
30.50'
31.00'
Lontitude



GPS軌跡與ADCP觀測流速

- C1

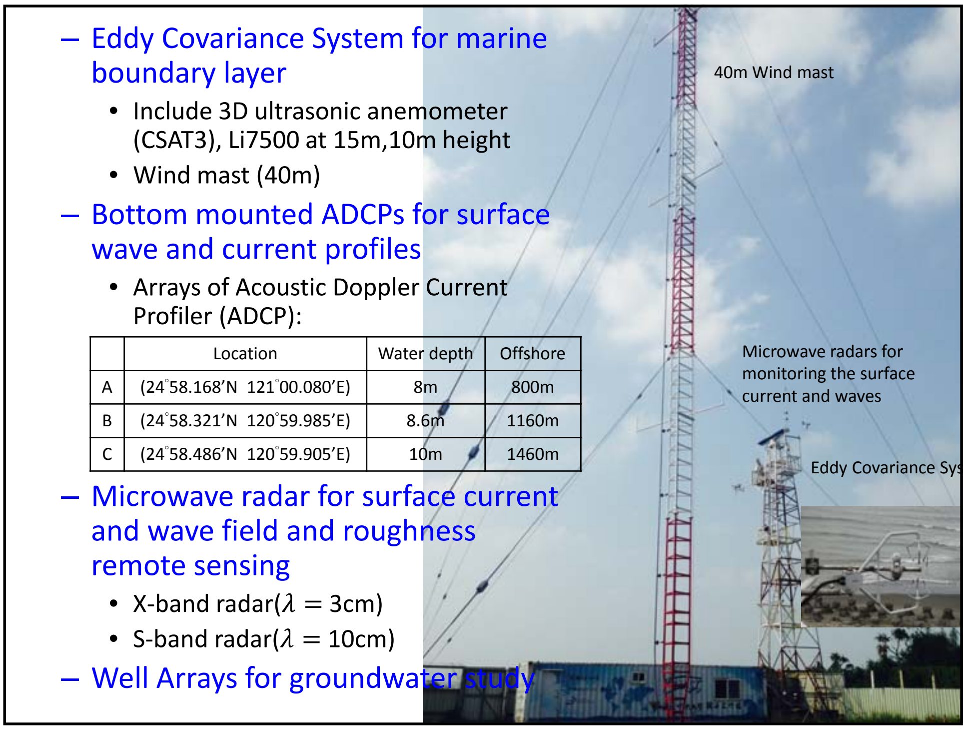


GPS軌跡與ADCP觀測流速

- C3

驗證測試場地：
中央大學臨海工作站

- *Since 2010*



- Eddy Covariance System for marine boundary layer
  - Include 3D ultrasonic anemometer (CSAT3), Li7500 at 15m,10m height
  - Wind mast (40m)
- Bottom mounted ADCPs for surface wave and current profiles
  - Arrays of Acoustic Doppler Current Profiler (ADCP):

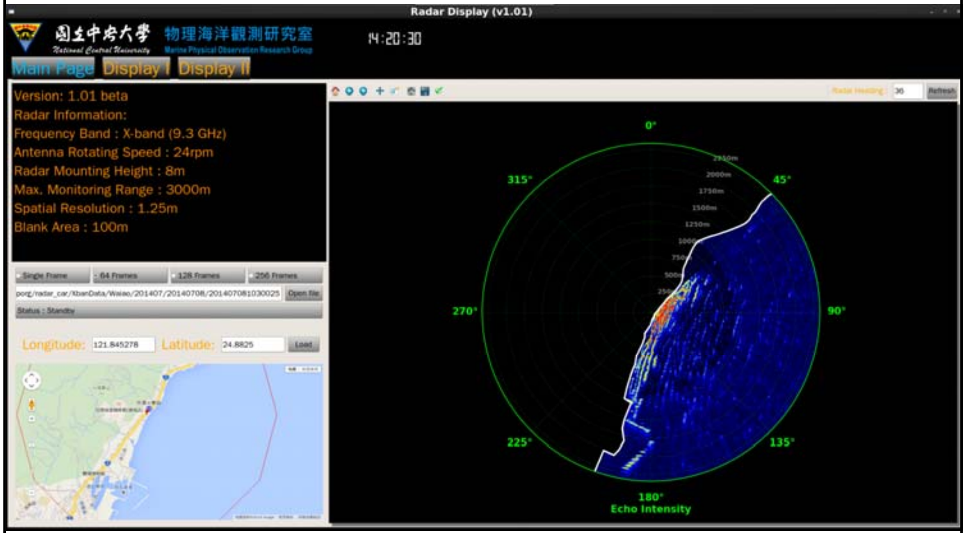
	Location	Water depth	Offshore
A	(24°58.168′N 121°00.080′E)	8m	800m
B	(24°58.321′N 120°59.985′E)	8.6m	1160m
C	(24°58.486′N 120°59.905′E)	10m	1460m

- Microwave radar for surface current and wave field and roughness remote sensing
  - X-band radar($\lambda = 3$cm)
  - S-band radar($\lambda = 10$cm)
- Well Arrays for groundwater study

40m Wind mast

Microwave radars for monitoring the surface current and waves

Eddy Covariance Sys



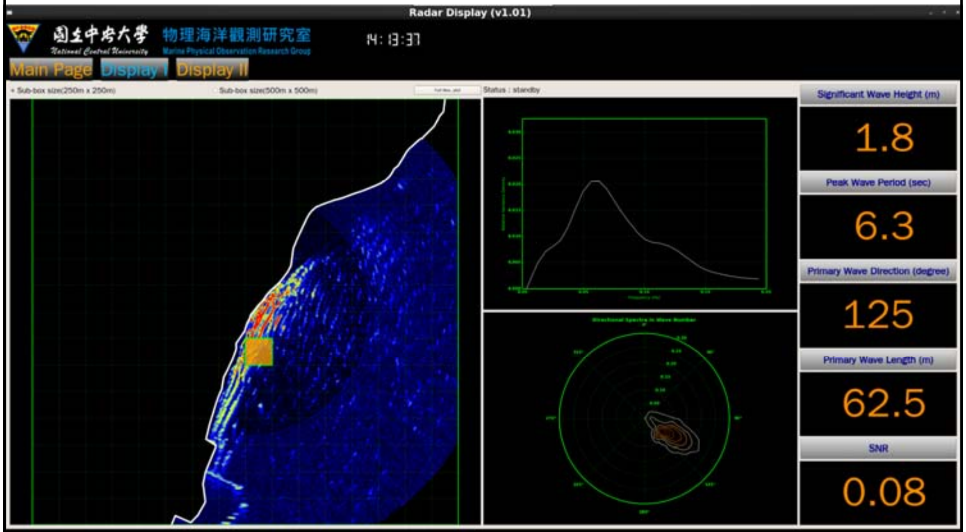
Version: 1.01 beta
Radar Information:
Frequency Band : X-band (9.3 GHz)
Antenna Rotating Speed : 24rpm
Radar Mounting Height : 8m
Max. Monitoring Range : 3000m
Spatial Resolution : 1.25m
Blank Area : 100m

porg/radar_car/XbanData/Waiao/201407/20140708/201407081030025

Status : Standby

Longitude: 121.845278 Latitude: 24.8825

Radar Heading: 30



Status : standby

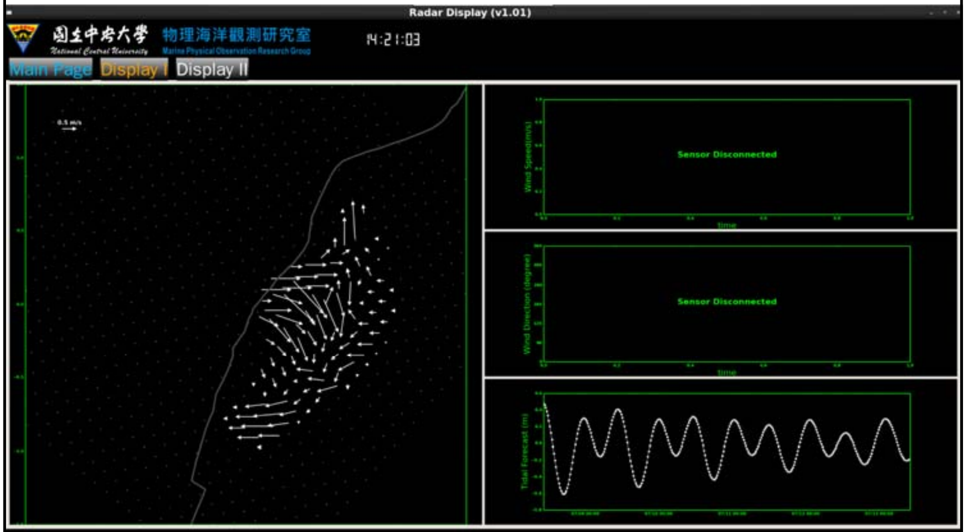
Significant Wave Height (m): 1.8

Peak Wave Period (sec): 6.3

Primary Wave Direction (degree): 125

Primary Wave Length (m): 62.5

SNR: 0.08



Sensor Disconnected

Sensor Disconnected

Summary

岸基同調性微波雷達特色：

- 空間上高解析度，時間上密集不中斷的監測，可完整掌握近海水動力極端事件過程
- 較雷達回波強度特徵分析方法更能有效獲得近岸流流場
- 1.關鍵雷達整合技術，2.資料演算分析方法，3.現場實驗比對驗證，完全由中央大學自主開發研製，因此監測系統：
  - 可根據需求調整，限制少
  - 持續進步，追求觀測數據之品質
  - 不同波段(S band與X band)可適用不同天氣條件與需求