高頻測流雷達(CODAR)的原理、計算與軍事上的運用
－高頻測流雷達實測資料與數值模擬結果之比較－
The theory and calculation of CODAR and its military applications
-Comparison of CODAR observations with model results-

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提　要

一、高頻雷達偵測海流是一種最新的技術，所偵測知海流，是全面性的。美國海軍於1990年開始，投入大量人力、物力進行研究其軍事用途。美國海岸巡防對與國土安全於2003完成美國東西岸的測流雷達的設置。

二、本文作者對最新「高頻沿岸測流雷達」實測資料進行學理推導、資料分析，並利用三維「海洋數值模型」結果對「高頻沿岸測流雷達」實測資料進行驗證。本文作者是全球第一人使用海洋數值模擬結果校正「高頻偵流雷達」資料。

三、本文研究動機為運用海洋數值模型，並將模型結果與普勒測流儀所測得之資料進行比對，並利用校正好的模型結果去比對雷達測出來海水表面水流，詳細驗正高頻測流雷達的準確性，以便作為日後國軍用途考量。本文證明高頻測流雷達實測資料相當準確，而且運用起來，方便且可信度高。

四、作者建議如果在臺灣沿岸佈設5-6個座長距離高頻測流雷達，不僅能提供即時航行服務（表面水流），同時空難與海難時，也可以預知海流方向，提供有用搜救資訊。對國軍而言，可即時掌握海戰場環境狀況，對「戰場環境即時預報系統」的預測準確性，亦有大助益。同時建議我國向美購買反潛機P3-C時，應該要求加裝與美軍相同設備──高頻測流雷達。

關鍵詞：高頻測流雷達、海洋數值模型、戰場環境預報系統、反潛機P3-C

Abstract

1.HF current radar, a new technology and sensor of mapping sea surface currents, providing two dimensional measurements with a long time period. In 1992, the US Navy starts to study coastal current radars with a large amount of people and budgets for military applications. Since

2003, the US Coast Guard and the US Department of Homeland Security have completed the installation of coastal current radars in the both sides of US coastlines.

2.The author of this paper examines the calculation and theory of 'High Frequency coastal current radar', and also uses a three-dimensional ocean model to verify HF radar-measured observations (CODAR). The author is the first person to do the comparison of model results with observations in the world.

3.In this study, the Princeton Ocean Model (POM) is used and validated by ADCP measurements, and the validated model is used to verify the HF radar-measured surface currents. Our purpose of this study is to verify the accuracy of HF radar-measured current velocity. This study shows that CODAR observations are quite accurate which are convenient and quite reliable.

4.The author suggests that 5-6 HF coastal current radars are recommended to place along the coastline around Taiwan Island, providing instant services of navigation and rescue information. Of course, it also provide great in-situ observations for numerical model validations, which increase the accuracy of 'NOWCAST model for marine battlespace environment'. At the mean time, with army sale with the US, we should ask for installation of airborne HF current radars onboard.

Key words: HF coastal current radar, CODAR, numerical ocean model, POM, P3-C

壹、前　　言

1970年，美海軍研究兩棲登作戰日誌，發現沿岸海流影響兩棲登陸作戰深遠，遂委託美國海洋大氣總署(NOAA)與史丹福大學(Stanford University)，研究發展以雷達來偵測海流的技術。當時效果不佳，誤差太大，加上冷戰時期，美海軍作戰地點在大洋，也就作罷，相關研究資料與技術於1985年解密[註一]。1990年，冷戰結束後，美國海軍的戰場已由大洋大兵力對決的作戰方式轉換為濱海作戰，對沿岸海洋資料的需求，更為迫切[註二]，加上美國發動波斯灣戰爭，美國海軍遂於1990年首度廣邀學者專家，進行大規模一連串海軍與作戰環境研討會[註三]，更確定雷達測流的需求。然而，原史丹福大學計畫主持人與研究人員Lipa和Barrick於1985年自組公司[註四]，從事高頻雷達研究與出售，經過多年實驗與改進，可信度已大幅的提高，且最遠可偵測250公里以內的海面水流與波浪。美國海軍遂於1992年開始，以CODAR Ocean Sensors公司研究為基礎，投入大量人力、物力，加入高頻流速偵測雷達軍事用途的研究行列。

[註一] High Frequency Radars for Coastal Oceanography, 1998. Oceanography Vol 10, No 2.

[註二] Strategic Plan of US Dept of Defense in technology (May 1997): We will enhance our operating forces'ability to operate safely and dominate the battlespace through superior understanding and exploitation of the natural environment. http://www.dod.mil/

[註三] 1990在美國加州海軍研究院召開四天「戰術海洋學」，約400軍官與學者參加，等級「機密」。1991在美國維州召開四天「沿岸海洋學」，等級「機密」。1993在美國加州召開「沿岸海洋學與濱海作戰」，等級「機密」。1995在美國內華達州召開「戰術氣象與海洋學與攻擊作戰」，等級「機密」。2000召開「海洋學與佈雷作戰」，等級「機密」。部分會議記錄於2003年解密。http://www.nap.edu/

[註四] http://www.codaros.com/

1.Introduction

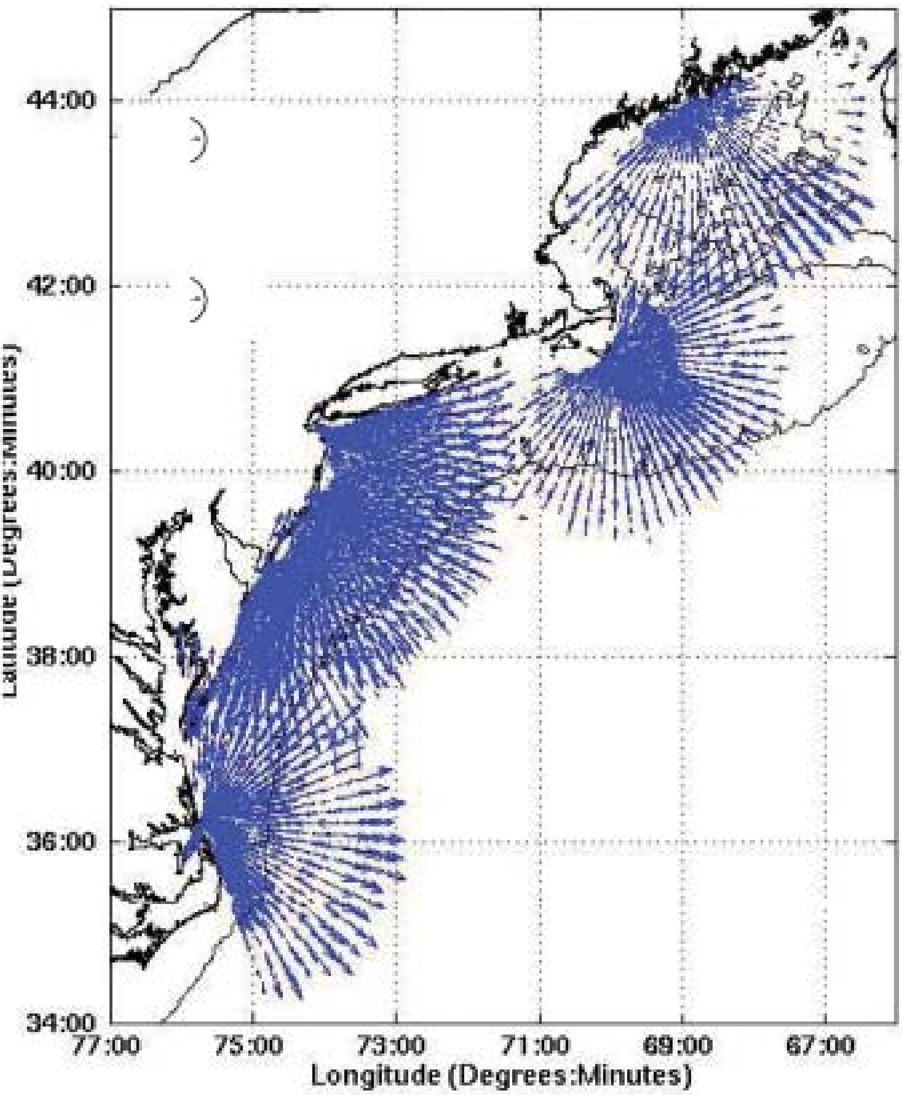
In 1970, the US Marine Corps studied the war diary of amphibious operations, and they found that the coastal currents crucially affected the battle results. At that time, they asked helps from National Oceanic and Atmospheric Administration (NOAA) and Stanford University to study a coastal current radar which can map surface currents. After all, they found the coastal current radar is less accurate. In addition, the US Navy (USN) set its maritime strategy of seeking primary campaign in the open ocean with union of Soviet republics (USSR) at the Cold War. Eventually, they decided to forgive this project. The research papers and skills were declassified in 1985. In 1990, after the Cold War, the USN has replaced its maritime strategy of seeking primary campaign in the open ocean with conducting operations in the littoral waters. At the meanwhile, the US started a war in the Persian Gulf, which cause USN need to know more environmental information of littoral zone. The USN held a series of symposium of coastal environments and invited professors and scholars to discuss USN needs in the littoral zone. After a series of symposium, the USN confirmed the need of coastal current radars for littoral warfare. However, the original researcher (Lipa and Barrack) of NOAA and Stanford University continued their study and opened a company (CODAR Ocean Sensors) in 1985. After long term research, their products (coastal current radars) have an effective range of 250 km with a high accuracy. In 1992, the USN, based on studies of CODAR Ocean Sensors, starts to study coastal current radars with large amount of people and budgets for military applications.

雷達偵測海流或波浪的技術，是一種新的海流與波浪觀測儀器（圖一），這種不直接接觸海水的波浪觀測儀器，採主動式發射並接收電達脈波，藉以分析海面波場特性，既不受雲雨、水氣干擾，又可不分晝夜進行全天候波浪觀測的功能特徵，是海洋潮流觀

圖一　沿岸高頻測流雷達

資料來源：本圖摘自CODAR Ocean Sensors(2003)。

圖二　美國東岸高頻岸制雷達佈放位置



資料來源：美國海岸巡防隊與國土安全部2003施政報告書。

HF current radar, a new technology and sensor of mapping sea surface currents and waves, is the remote senor which does not need to touch the sea water can radiates electromagnetic pulses outward and receives the back signals and calculates the surface current velocity. This sensor is not affected with any weather conditions - clouds, rains and water vapors, which is the evolution of current sensor in oceanography. With remote sensing, the surface currents can be measured for long time intervals, continuation and larger spatial area, providing two dimensional measurements. This sensor can provide essential contribution on rescue and marine engineering. Since 2003, the US Coast Guard and the US Department of Homeland Security have completed the installation of coastal current radars in the both sides of US coastlines.

測儀器上的一大變革與進展。遙測觀念與技術的引進波場觀測，除可獲取長時間、連續性的海流與波浪統計資料外，更可快速取得廣域性的波場資訊，兼具時間與空間性二維度波浪資料的應用，可提升其在沿岸救難、工程及軍事等多方面的實質貢獻與效益。美國海岸巡防隊(US coast Guard)與國土安全部(US department of Homeland Security)自2003年起，已陸續完成美國東、西岸的測流雷達的設置（圖二）[註五]。

問題是，高頻雷達偵測海流速度的準確率有多少？這方圓數百浬的海水表面水流都是正確嗎？儀器製造商說有80-90%的準確率[註六]，但依需時間與地點而不同。自1995至今2006年，英國、法國與美國軍方與學界上百篇論文從各方面探討用雷達來偵測海流的準確性。無論他們結果如何，他們把雷達來偵測的整個海面海流速度與單一或數個的測

註五 http://www.oeatech.com/pages/surveillance
註六 http://www.codaros.com/

流儀(Acoustic Doppler Current Profilers, ADCP)[註七]來進行比較（表一），其準確性(γ^2)從0.39至0.77[註八]。筆者認爲，這是非常不適當的。本文研究目的是確定高頻測流雷達的準確性，以便做爲日後國軍用途考量。筆者運用並改良普林斯頓海洋數值模型(Princeton Ocean Model, POM)，並將模型結果與都普勒測流儀(ADCP)所測得之資料進行比對[註九]，並利用校正好的模型結果去比對高頻雷達所測出來海水表面水流，詳細驗正高頻測流雷達的準確性[註十]。

The question is how accurate the High Frequency (HF) radar -measured current velocities are? Are the surface currents in the large area all correct? HF radar manufacturer declares there are 80-90% accuracy of HF radar-measured current velocities, depending on time and locations. Since 1995 until now (2006), there are hundreds papers published by British, France and US military and civilian academic communities discuss the accuracy of HF coastal current radars. No matter what their results are, they did point-com-

表一　高頻測流雷達所測之海流速度與單一的測流儀(ADCP)比較表

γ^2爲準確性（相似率）；$\Delta\theta$爲流向誤差；Δv爲流速誤差

1	2	3	4	5	6	7	8	9	10	11	12	13	14
											$V_{HF} = V_{a}m + b$		
HF site	Mooring	Start date	End date	Data points (hourly)	Bearing (°)	Range (km)	r^2	$\Delta\theta$ (°)	ΔV_{rms} (cm s^{-1})	Bias (cm s^{-1})	m	b	Sector width (km)
FBK	ABOF	1 Feb 1999	14 Nov 1999	125	299	36.7	0.59	16	11	−2	0.63	4.3	3.2
FBK	SAOF	1 Feb 1999	15 Nov 1999	5227	258	32.6	0.59	−8	11	−1	0.76	0.3	2.8
FBK	SAMI	1 Feb 1999	15 Nov 1999	3500	244	16.7	0.70	−4	9	−2	0.75	0.1	1.5
FBK	SAIN	1 Feb 1999	14 Nov 1999	2044	216	8.3	0.57	−11	11	−1	0.51	−2.3	0.7
FBK	AROF	1 Feb 1999	3 Oct 1999	4746	195	44.2	0.59	0	13	−1	0.78	−0.8	3.7
FBK	ARMI	1 Feb 1999	3 Nov 1999	2862	190	39.4	0.68	0	11	−3	0.76	0.6	3.4
ARG	SAIN	1 Nov 1998	14 Nov 1999	457	355	25.8	0.52	10	14	6	0.31	0.5	2.3
ARG	SAMI	1 Nov 1998	15 Nov 1999	1488	334	28.0	0.39	17	16	1	0.51	0.6	2.4
ARG	SAOF	1 Nov 1998	15 Nov 1999	901	311	39.2	0.46	19	15	2	0.71	−2.4	3.4
ARG	AROF	1 Nov 1998	3 Oct 1999	3218	220	13.4	0.60	0	12	1	0.73	−3.1	1.2
ARG	ARMI	1 Nov 1998	3 Nov 1999	2127	215	7.7	0.59	0	11	−1	0.64	−2.1	0.7
ARG	SMIN	1 Nov 1998	7 Mar 1999	913	137	26.7	0.62	−7	19	−4	0.44	8.4	2.3
PTC	ARMI	1 Jun 1998	28 Jan 1999	2521	291	22.2	0.74	9	10	2	0.79	−3.7	1.9
PTC	AROF*	1 Aug 1997	3 Oct 1999	6636	279	25.2	0.58	6	14	2	0.76	−4.5	2.2
PTC	AROF	1 Jun 1998	28 Jan 1999	3717	279	25.2	0.71	1	10	3	0.84	−4.3	2.2
PTC	SMOF	1 Jun 1998	28 Jan 1999	3009	177	33.0	0.63	−12	9	−2	0.76	−2.5	2.9
PTC	SMIN	27 Jun 1998	28 Jan 1999	2904	160	5.7	0.77	−16	7	1	0.85	−1.2	0.5
RFG	ADCP	20 May 1998	12 Oct 1999	10 186	147	28.0	0.50	1	12	4	0.74	−1.9	2.4
COP	ADCP	20 May 1998	12 Oct 1999	6659	189	17.7	0.60	−1	11	−3	0.88	3.5	1.5

資料來源：取自Emery, B.M., L. Washburn, and Harlan (2004) Evaluating radial current measurements from CODAR high-frequency radar with moored current meters. J. Atm. Oceanic Tech.

[註七] 音響式都卜勒流剖儀(ADCP)顧名思義，利用都卜勒偏移(Doppler shift)來測量流速的儀器。而都卜勒偏移乃是指因發射訊號的波源和接收訊號的收受者之間的相對運動，導致所量的訊號頻率偏移。它的測流原理是假設水層中有許多隨流移動的微小粒子，當觀測者利用音響式都卜勒流剖儀發射出聲波時，由於觀測者與微小粒子間存在著相對速度，故聲波在碰到粒子而反射時，聲波的頻率(或相位)會產生都卜勒位移，於是當音響式都卜勒流剖儀收到反射回來的聲波時，計算其與原發射出去聲波之頻率差，即可反算出微小粒子與音響式都卜勒流剖儀之間的相對運動速度大小與方向。此觀測原理與警用測速雷達原理是一樣的。

[註八] Emery, B.M., L. Washburn, and Harlan (2004) Evaluating radial current measurements from CODAR high-frequency radar with moored current meters. J. Atm. Oceanic Tech.

[註九] 目前，全世界海洋界都認可單一、定點都普勒測流儀(ADCP)的測量資料最準確。

[註十] Mau, J.-C.; D-P Wang, D. S. Ullman and D. L. Codiga. 2007. Comparison of observed (HF radar, ADCP) and model barotropic tidal currents in the New York Bight and Block Island Sound. Estuarine, Coastal and Shelf Science 72 (2007) 129-137.

parisons of HF radar-measured current with single or multi-ADCP measurements, which accuracy falls between the γ^2 value of 0.39-0.77 (Table 1). I strongly question about these methodology and comparisons. In this study, the Princeton Ocean Model (POM) is used and validated by ADCP measurements, and the validated model is used to verify the HF radar-measured surface currents. Our purpose of this study is to verify the accuracy of HF radar-measured current velocity.

貳、高頻測流雷達原理與速度計算

雷達原理，相信讀者有一定的基本認識。高頻測流雷達頻率是屬3至30MHz範圍內，相對波長爲100至10公尺。雷達遙測海流理論最早大概可追溯至Crombie(1955)有關海面反射雷達散射訊號的研究[註十]，他發現靠近海邊所記錄的HF訊號會與所發射的雷達波有微小的都卜勒頻移(Doppler Shift)，並且認爲這是由於海上的波浪對於雷達波產生布拉格散射(Bragg scattering)效應所致。之後，Barrick對雷達測波的一系列研究[註十一]，確定反射波譜中第一階波能強度可以決定群波之波長及波向，其一、二階散射

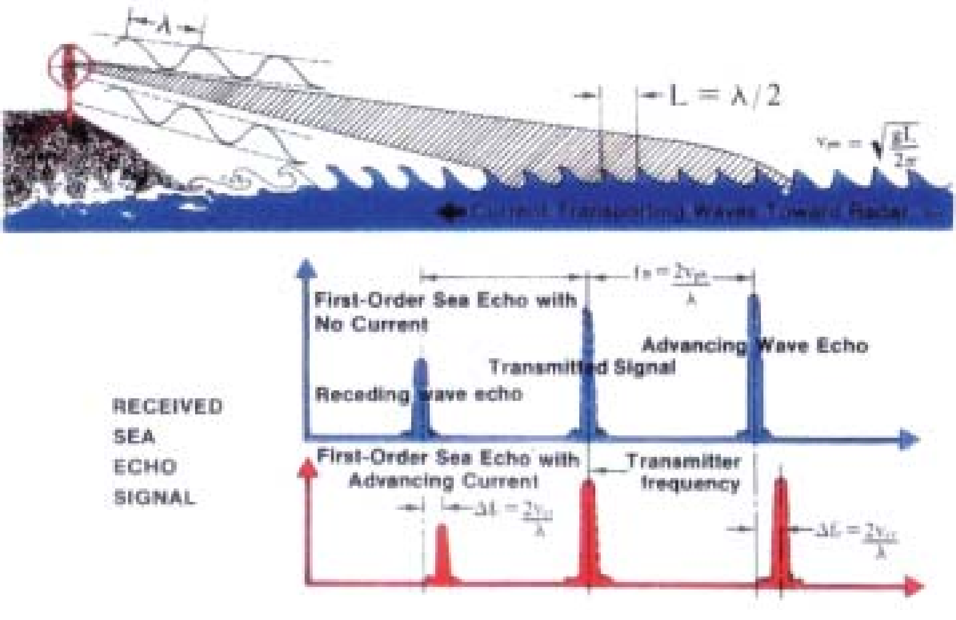
理論也驗證以高頻雷達應用於海洋實驗的正確性。所謂的布拉格散射，如圖三所示，當海面上的運動波浪波長恰好爲雷達波長的二分之一時，則會產生強烈的反射雷達波。波長一旦確定，利用深水波相速度公式便可得出波速。典型的反射波譜如圖三下圖所示，反射波譜主要是由海面上的運動波浪所提供，其中包括了第一階的能量峰值以及次階的峰值。Crombie (1971)提出藉由計算前後兩次的反射波譜都卜勒頻移量，便可以推算出徑向上的流速[註十二]。

2.The theory of HF coastal current radar and its velocity calculation

The basic principal of radar theory must be familiar with readers. The HF band of the elec-

圖三　高頻雷達測流原理示意圖

上圖爲海流與波浪相互作用時所產生的物理機制；中圖爲在無海流作用下，已知波浪消散關係式下的布拉格散測與波浪共振的頻譜圖；下圖爲有海流作用下的都卜勒位移頻譜圖



資料來源：本圖摘自CODAR Ocean Sensors(2003)。

[註十] Crombie D. D. (1955), Doppler Spectrum of Sea Echo at-13.56Mc/s', Nature 175, 681-682.

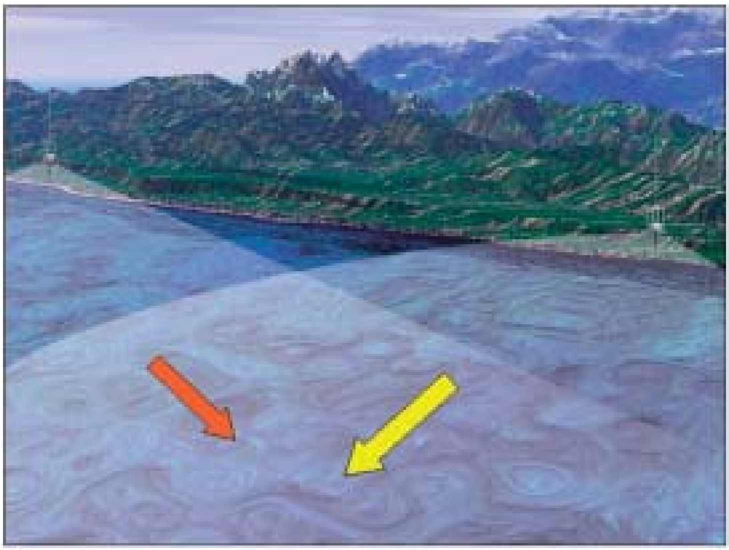
[註十一] Barrick D. E. (1971), Dependence of Scend-order Sidebands in HF Sea Echo upon Sea State, IEEE G-Ap International Symposium Digest, Sept.

[註十二] Crombie, D.D. (1971), Backscatter of HF radio waves from the sea, Electromagnetic Probing in Geophysics, J.R. Wait, ed., Golem Press: Boulder, CO., pp. 131-162.

tromagnetic spectrum, with frequencies of 3 to 30 MHz corresponding to wavelengths of 100 to 10m, is within the radio bands. Crombie (1955) found that some HF signals recorded near the ocean had a Doppler shift of less than a hertz above and below the transmitted signal and concluded the shift was due to "Bragg scattering" of the signal by ocean waves. Bragg scattering occurs when the transmitted energy (HF radar waves in our case) is reflected by ocean waves that are traveling radially towards or away from the radar and whose wavelength is half as long as the transmitted signal. These reflections result in strong peaks in the backscatter spectrum (Figure below). HF radars use the scattering of the first order Bragg peaks to estimate ocean currents by comparing the scattering to the expected Doppler shift due to the Bragg waves (additional shift is then attributed to currents). Once the CODAR system measures the backscattered signal, the current speed can be extracted by determining the Doppler Shift of the waves. Because the waves are moving, the frequency of the signal returned is not quite the same frequency as the signal transmitted. Waves moving toward the receiver increase the return frequency, while waves moving away decrease the return frequency.

雷達遙測理論的發表以及軟硬體的配合之下，1980年代兩種不同設計概念的岸基海象遙測系統被發明出來。一是美國系統，以兩組全指向性天線相互搭配，將雷達測掃面交疊覆蓋，以求取海面流場的CODAR(Coastal Ocean Dynamics Application Radar)[註十四]，如圖四所示；另一是歐洲系列，將天線以相位陣列方式排列，沿海岸可達數十至上百公尺之WERA (WavE RAdar)系統[註十五]，如圖五所示。目前高頻測流雷達的市場，以美系CODAR爲主體，而本文亦介紹美系CODAR。

圖四　兩臺雷達共同涵蓋區域示意圖



資料來源：本圖摘自CODAR Ocean Sensors(2003)。

圖五　相位陣列方式排列雷達

資料來源：本圖摘自http://ifmaxp1.ifm.uni-hamburg.de/WERA_Guide/

[註十四] http://www.codaros.com/
[註十五] http://ifmaxp1.ifm.uni-hamburg.de/WERA_Guide/

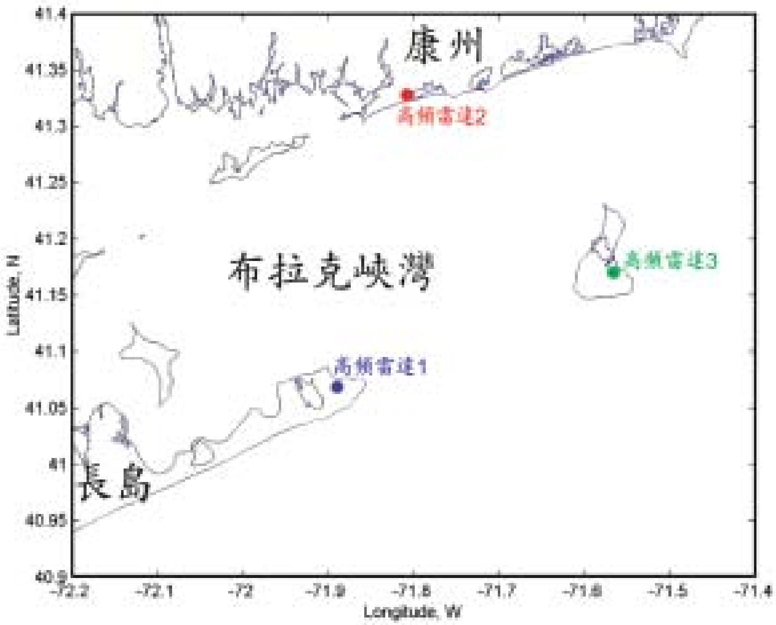
With the theory and improvement of the HF coastal current radar, there are two kinds of HF current-measured radars are developed. As figure 4 shown, one is the US system called CODAR (Coastal Ocean Dynamics Application Radar), which is omni-directional. The mapping area must be covered by two radars in order to produce surface current velocities. The other one is European system, shown as figure 5. HF antennas show a matrix array, extending several tens meters to a hundred meter long, called WERA (WavE RAdar). Currently, CODAR are more popular than WERA in oceanography community, and we also would like to introduce the US system-CODAR.

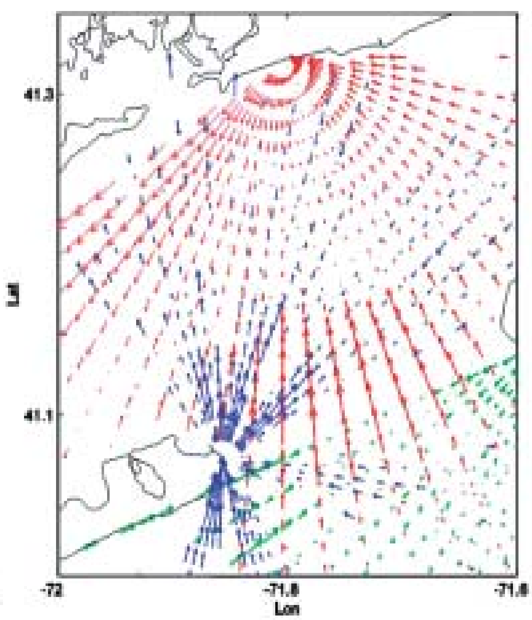
高頻測流雷達所測得海水表面水流並非傳統直角座標系的速度表示方式U（東西方向速度分量）與V（南北方向速度分量），而是放射性方向速度(radial velocities)。圖六一一是美國康乃狄克州布拉克峽灣(Block Island Sound, CT)三具所屬海岸巡防隊與美國海軍的高頻測流雷達站[註十六]。藍、紅及綠色點表是雷達站。此雷達有效距離爲30km，屬岸置短程雷達。圖六一二表示高頻測流雷達即時(snoptshot)放射性方向速度。紅色放射性箭頭是雷達站㈠所偵測的放射性方向海水表面流速；藍色放射性箭頭是雷達站㈡所偵測的放射性方向海水表面流速。

HF radar-measured currents are radial velocities, instead of traditional recognized velocities-Cartesian coordinate system (rectangular coordinate system in a plane) U (east-west component) and V (north-south component). Figure 6-1 show three CODAR sites supported by US Navy and US Coast Guard, which present as blue, red and green sites. The radar is a land-base, short

圖六一一　美國康乃狄克州布拉克峽灣(Block Island Sound, CT)三具所屬美國海岸巡防隊與美國海軍的高頻測流雷達站

圖六一二　表示高頻測流雷達即時(snoptshot)放射性方向速度





資料來源：作者自繪。

[註十六] http://www.nopp.uconn.edu/CODAR/index.html range radar, which effective range is about 30km. Figure 6-2 show a snopshot of surface radial velocities measured by CODAR. Red arrows show the radial surface velocities measured at CODAR site 3 (Misquamicut, CT), and blue arrows show the surface radial velocities measured at CODAR site 1 (Montauk Point, Long Island)

放射性方向速度可以用下列兩種方式（平均數與流線方程式），解算成傳統直角座標系的速度。圖七一一是顯示如何解算放射性速度至傳統直角座標系的速度表示方式U（東西方向分量）與V（南北方向分量）。圖七一二是顯示解算結果；

The radial velocity can be processed with the following two methods (ensemble means and stream function) to convert into Cartesian coordinate system (rectangular coordinate system in a plane) U (east-west velocity component) and V (north-south velocity component). Figure 7-1 shows how to convert radial velocity into traditional velocity U and V components. Figure 7-2 shows the results of after calculation.

平均數公式(Ensemble mean)如下；

The formula of ensemble mean shows as follows;

For a given radial velocity r_1

$$a_1u+b_1v=r_1$$

Where a_1 and b_1 are geometric parameters.

When, there are n radials within a footprint

$$\begin{pmatrix} a_1 & b_1 \\ \vdots & \vdots \\ a_n & b_n \end{pmatrix}\begin{bmatrix} u \\ v \end{bmatrix}=\begin{bmatrix} r_1 \\ \vdots \\ r_n \end{bmatrix}$$

流線方程式(Stream function)解算方式如下；

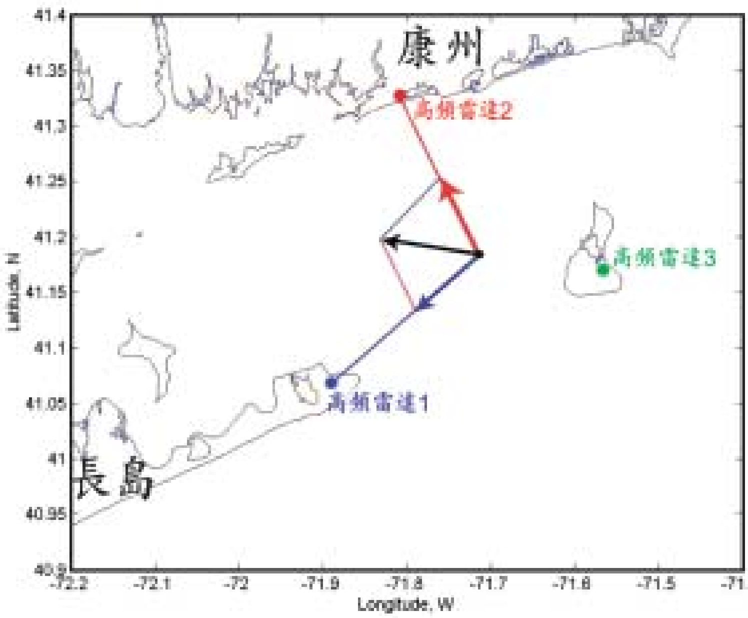
Stream function also is shown as follows;

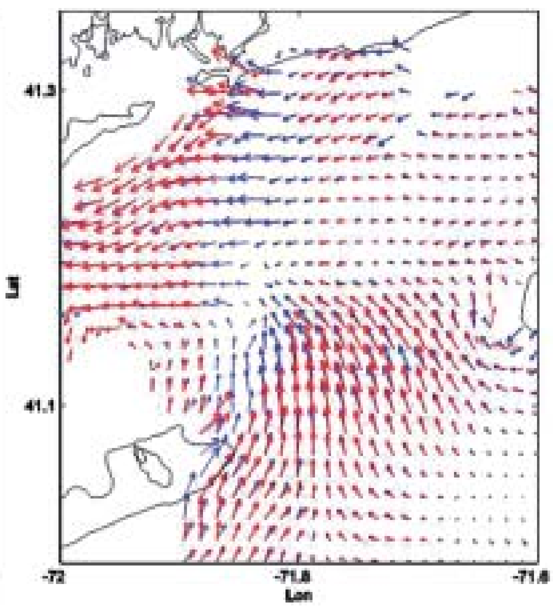
The stream function can be expressed in polynomials

$$\psi = A_1x+A_2y+A_3xy+\frac{1}{2}(A_4x^2+A_5y^2)$$
$$\mu = -(A_2+A_3x+A_5y)$$
$$\nu = A_1+A_3y+A_4x$$

圖七一一　是顯示如何解算放射性速度至傳統直角座標系的速度

圖七一二　紅色速度向量是以平均數公式(Ensemble Mean)；藍色速度向量是以流線方程式(Stream Function)來解算





資料來源：作者自繪。

Substitute into radial velocity

$$\begin{bmatrix} b_k\text{-}a_k & b_k y_k\text{-}a_k x_k & b_k x_k\text{-}a_k y_k \end{bmatrix} \begin{bmatrix} A_k \\ \mathrm{M} \\ A_5 \end{bmatrix} = \begin{bmatrix} r_k \\ \mathrm{M} \\ r_5 \end{bmatrix}$$

透過此兩種方法其中一種，整個海平面的海流速度可立即被解算出來，予以有效運用。

After processing with either method shown above, the surface current velocities of Cartesian coordinate system in the whole domain are calculated.

參、高頻測流雷達(CODAR)、都普勒測流儀(ADCP)實測資料與數值模擬之比較

一、研究背景與動機

近岸水流受多重外力影響，包括潮汐、季節風、淡水流入量、沿岸流與海底地形等。流入沿岸的淡水與海水混合後，流場呈多樣化，若以傳統都普勒剖流儀ADCP進行探測，難以獲得全面性資料。布拉克島峽灣(Block Island Sound, BIS)唯一連接長島峽灣的布拉克島峽灣是一個地形複雜、水深較淺、水流複雜的一個緩衝海域（圖八）。平時，海象就多變，更遑論春、夏多雨季節；秋、冬颶風季節的影響。自2000年6月至今，康乃迪克州立大學(University of Connecticut)與羅德島大學(University of Rhode Island)獲得美國海軍與海岸巡防隊的支持，在布拉克島峽灣附近沿岸設立三座新式岸置測流雷達(CODAR)及十餘座傳統都普勒剖流儀ADCP，全面性進行探測布拉克島峽灣流場狀況（圖九）。

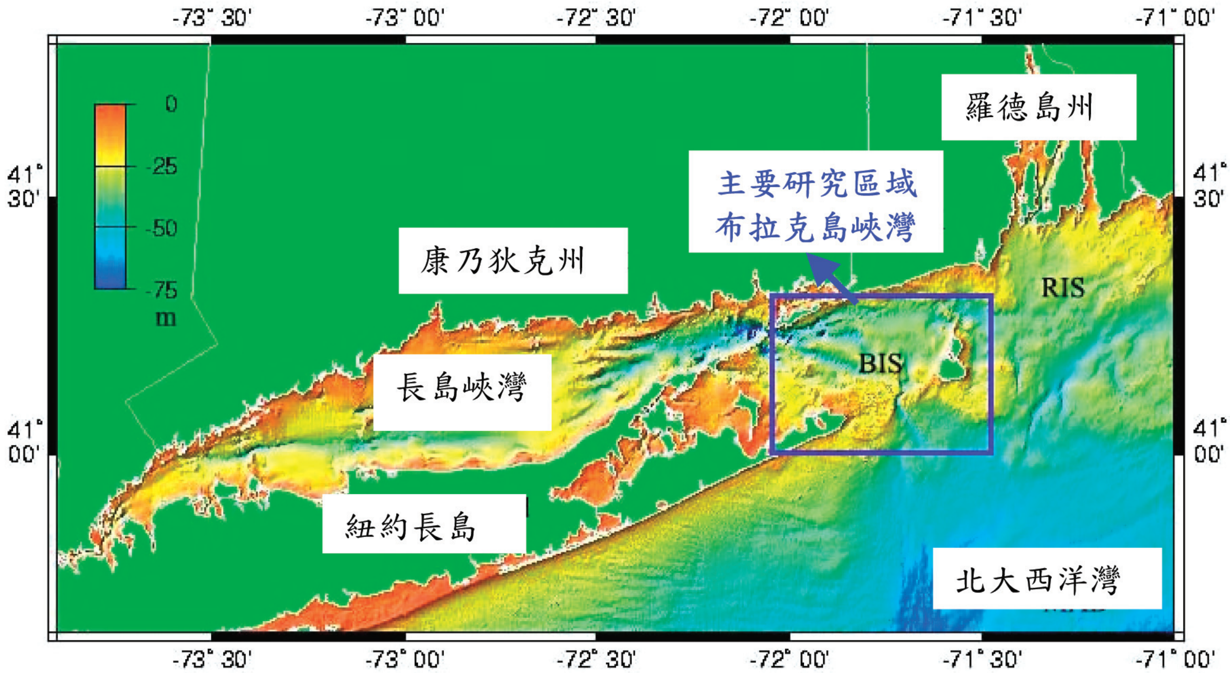
3.Comparison of CODAR with ADCP and model results

(1)Background and motivation

Coastal currents are influenced by multiply

圖八　布拉克島峽灣是美國最重要峽灣之一，因為它是長島峽灣(Long Island Sound)唯一進出北大西洋的通道

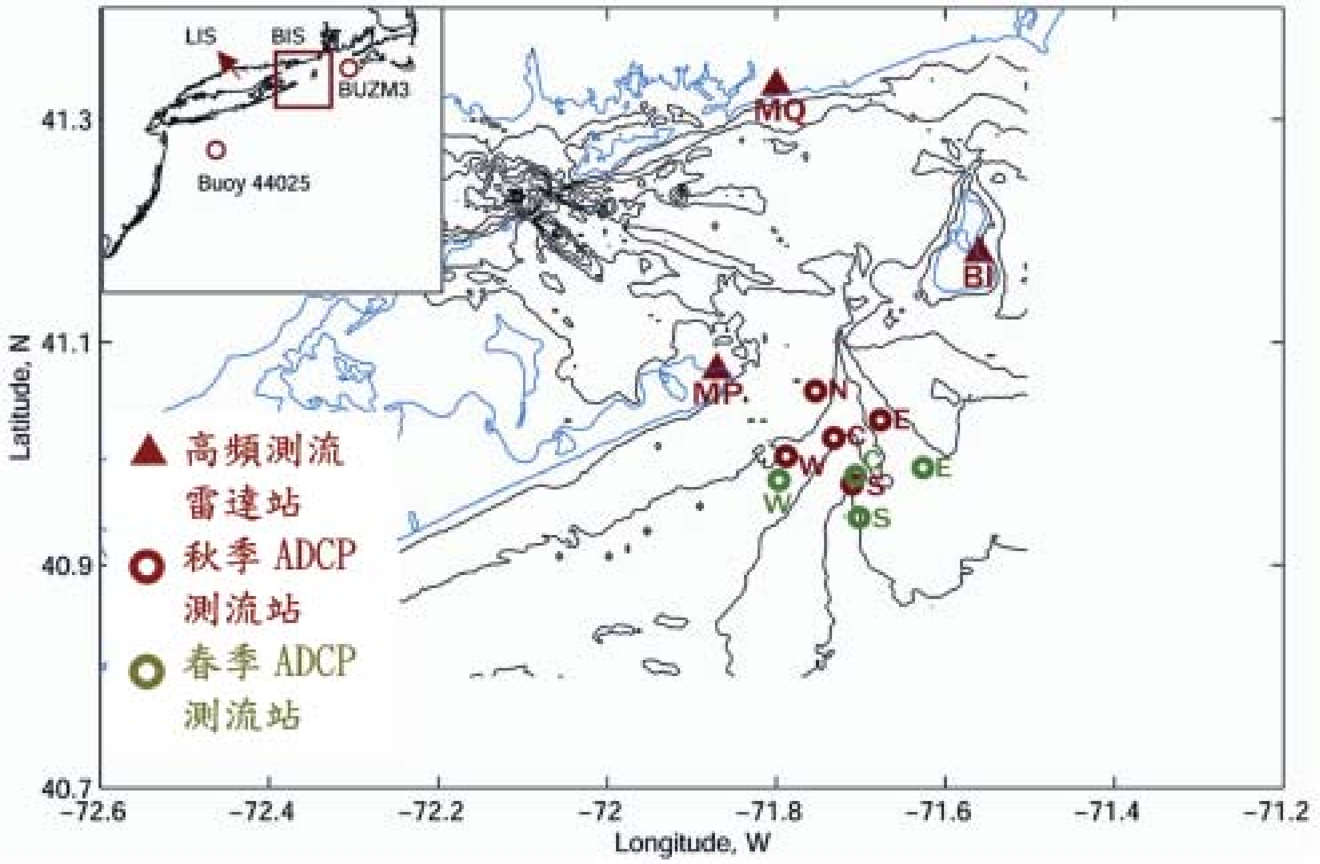
藍色長方型是本研究主要研究區域-布拉克島峽灣。圖中綠色部份表示陸地；其餘部份表示海底深度。



資料來源：作者自繪。

圖九　主要研究區域—布拉克島峽灣

紅色三角形表示高頻測流雷達站；紅色圓形表示夏天四個錨定都普勒剖流儀ADCP；綠色圓形表示冬天五個錨定都普勒剖流儀ADCP。藍色線表示海岸線；黑色線表示海底地形等深線。右上角方塊表示主研究區域地理位置；LIS表示長島峽灣，BIS表示布拉克島峽灣，Buoy44025及BUZM3表示錨碇測風儀。



資料來源：作者自繪。

forces, such as tides, seasonal winds, buoyant waters, coastal upstream currents and real bathymetry. Coastal currents joined with buoyant water and upstream currents show the complicated features on the velocity fields. Traditional current sensors such as ADCP can not provide the current velcoties in the whole domain. The Block Island Sound (BIS) is the connection between Long Island Sound (LIS) and the Middle Atlantic Bight (The MAB), where are the waters showing complicated bathymetry and velocity fields. At the sunny, no-wind days, the surface velocity fields are changeable, still more in the rainy seasons of springs and summers and hurricane season of falls and winters. Since June of the year of 2000, University of Connecticut and University of Rhode Island have been supported by the US navy and the US Coast Guard and install three CODAR sites to study the complicated velocity fields in the surface velocity fields of Block Island Sound.

本研究用一整年的高頻雷達觀測資料（2001年），配合實測傳統都普勒剖流儀ADCP資料，來研究康乃迪克河(The Connecticut River)之淡水在布拉克島峽灣的海水表面潮流變化，同時將運用普林斯頓海洋數值模型(POM)進行模擬，徹底驗證高頻雷達偵側資料之的準確性。而這是全海洋界，首次進行如此驗證研究。

One-year long CODAR observations are

used to study velocity fields in the area among buoyant waters from The Connecticut River and coastal salty waters. ADCP observations also are used to compare with CODAR observations. POM is used to simulate the in-situ case in order to verify the accuracy of CODAR observations. This is the first time to verify the accuracy with model results and ADCP observations at same time in the oceanography community.

二、實測資料（比對之用）

㈠高頻雷達在布拉克島峽灣觀測之表面水流資料（2001年，範圍約40公里×40公里，資料密度約0.8-1.5公里）[註七]。第一個雷達站爲Montauk Point(MP)；第二個雷達站爲Block Island (BI)；第三個雷達站爲Misquamicut(MQ)（圖九）。

㈡九個錨定都普勒剖流儀ADCP 垂直觀測資料（4個都普勒剖流儀ADCP在2001年夏天，5個都普勒剖流儀ADCP在2001年冬天）（圖九）[註八]。

㈢北大西洋灣內潮汐（潮流與水位高）與及海水溫鹽歷史資料(1970-2000)（圖十）[註九]。

(2)Data description (for comparison)

A.CODAR observations covering the whole area of Block Island Sound are used to study surface velocity field. (Time spans the whole year of 2001, and the domain covers 40km×40km with resolutions of 0.8-1.5km).The CODAR at Montauk Point(MP) is named as the first radar, The CODAR at Montauk Point(MP) is named as the first radar, at Block Island(BI) named as the second radar and at Misquamicut (MQ) named as the third radar. The CODAR sites are shown in figure 8.

(2)Nine mooring locations of ADCP are used (four ADCP profiles for summer, 2001 and five ADCP profiles for winter, 2001). ADCP sites are shown in Figure 9.

(3)Tidal currents and heights and historical climatology in the North of the MAB are used in the years of 1970-2000.

三、模擬區域介紹

電腦模擬區域如圖十所示。色線表示等深線，紅點爲海流實測點。模擬區域右起北大西洋灣(The Middle Atlantic Bight, MAB)是從美國東北部麻州鱈魚角(Cape Cod, MA)算起，南至紐澤西州大西洋城(Atlantic City, NJ)。灣內近岸地形平坦，水深向外逐漸增加，年平均流速約5-10cm/s(0.2節)(Beardsley et al., 1985)，流速呈季節與周期變化（約8-10天）。夏天變化較小，流速穩定，約20cm/s（0.4節）。冬天變化劇烈，流速約20-50cm/s（0.4-1.0節）。美國東岸多條河流淡水流入此灣（北大西洋灣）。康乃迪克河(The Connecticut River)以年平均 888m3/s之淡水，經由長島峽灣、布拉克島峽灣流入北大西洋灣，流入之淡水(buoyant waters)造成沿岸海水，終年南流(southward)。大陸斜坡外(continental slope)，有著名的灣流(Gulf Stream)，其形成原因與特性與臺灣東岸之黑潮(Kuroshio Current)相似，以每秒40-120cm/s速度向北流動。

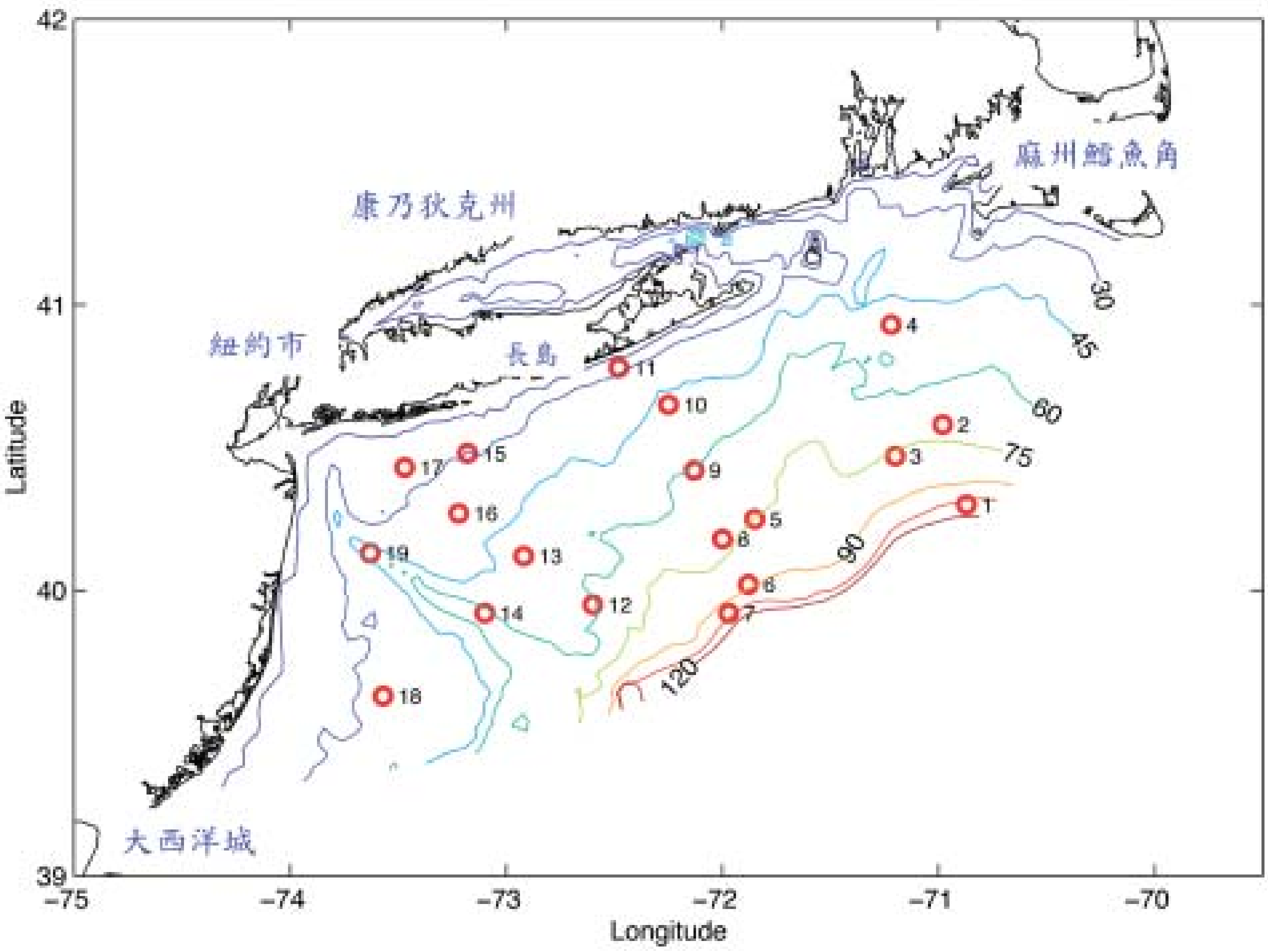
[註七] Ullman, D.S. and D.L. Codiga. 2004. Seasonal variation of a coastal jet in the Long Island Sound outflow region based on HF radar and Doppler current observations. J. Geophys. Res. 109, C07S06, doi:10.1029/2002JC001660.

[註八] Codiga , D. L. and A. E. Houk. 2002. Current profile time series from the FRONT moored array, Technique Report, Dep. of Mar. Sci., UCONN., Groton, 19pp.

[註九] Moody, J. A., B. Butman, R. C. Beardsley, W. S. Brown, P. Daifuku, J. D. Irish, D. A. Mayer, H. O. Mofield, B. Petrie, S. Ramp, P. Smith, and W. R. Wright. 1984, Atlas of tidal elevation and current observations on the northeast American continental shelf and Slope. U.S. Geological Survey Bulletin 1611, 122pp.

圖十　電腦模擬區域

色線表示水下等深線（15-120公尺）。紅點爲表面海流實測點。模擬區域右起北大西洋灣 (The Middle Atlantic Bight, MAB)是從美國東北部麻州鱈魚角(Cape Cod, MA)算起，南至紐澤西州大西洋城 (Atlantic City, NJ)。灣內近岸地形平坦，水深向外逐漸增加，水深最深設定爲120m。



資料來源：作者自繪。

(3)Introduction to model domain

Figure 10 shows model domain. Color lines show bottom bathymetry, and red dots are current mooring sites. The model domain, beginning at Cape Cod and extending southwest to Cape Hatteras. The shelf topography in the domain is relatively smooth, and the water depth increases nearly linearly from shore to shelf break except near submarine canyons. The annual mean flow is southwestward of 5 to 10cm/s and generally increases offshore (Beardsley et al., 1985). In the inner shelf, the mean flow shows subtidal and seasonal variations. In winter, storms can produce alongshore currents of 20 to 50cm/s in inner and mid shelf. In summer, alongshore currents are weaker of about 20cm/s and are less variable. The Connecticult river move into North MAB with buoyant waters of 888m3/s via LIS and BIS, which cause the coastal currents southward all year long. Outside of continental shelf, there is the Gulf Stream which is same driving mechanism as Kuroshio current in the east of the Pacific Ocean. The Gulf stream moves southward with speeds of 40-120cm/s.

本研究使用普林斯頓海洋數值模式(POM)。本數值模式主要依據Blumberg and

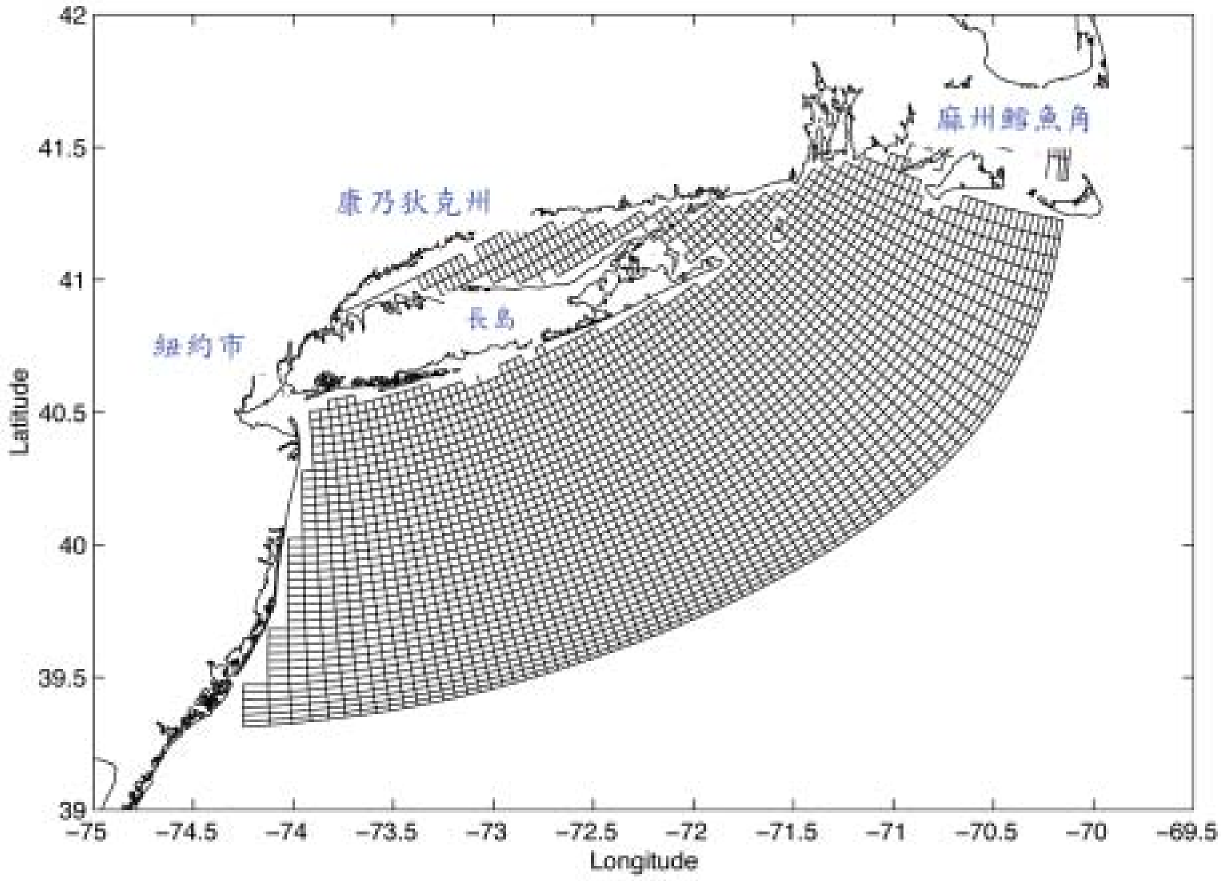
Mellor (1987)所建立[註亍]，而相關模式設定(model configurations)、開邊界條件(Open Boundary conditions)、初始值(initial conditions)之設定，請參閱Mau(2007)[註二]。本文現階段只討論潮汐（潮流與潮高），故省略表面風力(wind stress)、熱通量(surface heat flux)、南向沿岸流(southward continental currents)、沿岸河口流入之淡水(buoyant waters)，以及灣流(Gulf Stream)的影響。相關這些變量與參數的運用，請參閱Mau(2007)[註三]。

模式驅動力(model driving forces)爲半日潮(M2)與全日潮(S2)的潮高與潮流。設定網格解析度(grid resolution)爲1km～3km，水平(X,Y)方向計有151和241格，橫寬約爲200km、縱長爲400km（圖十一）。垂直共計16層。模式輸出包括速度(u, v, w)、水位和溫、鹽度(T, S)等24種海洋參數。

The numerical model used in this study is the Princeton Ocean Model (POM) which is published by Blumberg and Mellor (1987). The mod-

圖十一　電腦模擬網格圖（每3格取1格）

設定網格解析度(grid resolution)爲1km～3km，水平(X,Y)方向計有151和241格，橫寬約爲200km、縱長爲400km。垂直共計16層。



資料來源：作者自繪。

[註亍] Blumberg, A., and G. Mellor, 1987: A description of a three dimensional coastal ocean circulation model. Three-Dimensional Coastal Ocean Models, N. S. Heaps, Amer. Geophys. Union, 1-16.

[註二] Mau, J.-C.; D-P Wang, D. S. Ullman and D. L. Codiga. 2007.Comparison of observed (HF radar, ADCP) and model barotropic tidal currents in the New York Bight and Block Island Sound. Estuarine, Coastal and Shelf Science 72 (2007) 129-137.

[註三] 同註二。

el solves the three-dimensional primitive equations on an Arakawa C grid. The numerical scheme conserves linear and quadratic quantities like mass and energy. The model uses sigma coordinate system in the vertical and orthogonal curvilinear coordinate system in the horizontal. The model topography is sub-sampled from the 3 arc-second gridded East Coast bathymetry. The model has a total of 151×241×16 grid points (Fig. 11). Horizontal resolution varies from less than 1 km near the coast to about 3km at the open boundary. The grid resolves the complicated coastline and bathymetric feature. In the vertical, the water column is divided into 16 equally spaced levels. The more information and setup for model are shown in Mau (2007). Model results include 24 oceanic parameters, including velocities (u, v, w), sea level, temperature, salinity.

四、數值模擬結果比較

普林斯頓海洋數值模式設定好邊界與初始條件，並以半日潮(M2)與全日潮(S2)的潮高與潮流爲驅動力，開始進行計算與預測（模擬）。模式計算3整年，並以每小時輸出。本研究以最後一年的資料進行研究。圖十二爲數值模擬結果比較程序圖。資料先由大範圍區域（紐約灣）開始進行比對，進而比對小範圍區域（布拉克島峽灣）。從表面水流開始進行資料比對，進而比對深水水流(under currents)資料。此種方式不僅可驗證高頻測流雷達實測資料的準確性，同時也可驗證數值模擬結果的準確性。

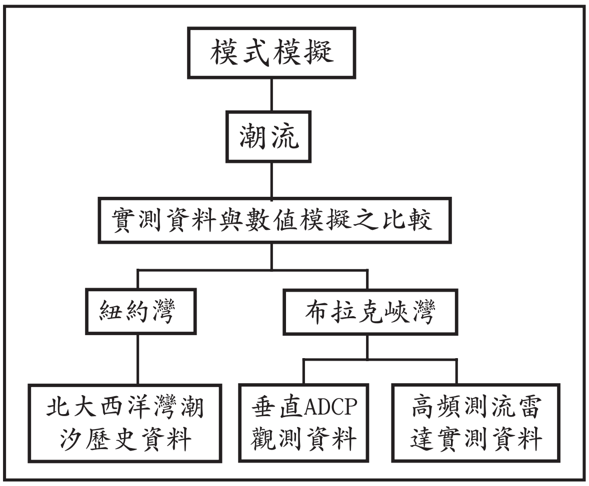
(4)Comparison

POM under well setups and initial condition, has been run for 3 years with driving forcing of tidal transports (currents and heights) at the open boundary. Model output format is set as hourly outputs and the model results of the whole third year are chose to study. Figure 12 show the roadmap to compare model results with ADCP observations. The validation area starts from larger areas (The New York Bight) to smaller area (Block Island Sound). The current validation starts from the surface to the bottom. This method not only can verify the accuracy of CODAR, but also verify the model results.

比對時，本文將著重於全日潮(S2)與半日潮(M2)的潮流橢圓(tidal current ellipses)比對[註三]。因爲此區潮流速度相當大，在大陸陸坡及大陸棚區，潮流速度可達50cm/s，在峽灣內可達100cm/s。

Comparisons are emphasized on the tidal ellipses of principal solar semidiurnal constituent (S2) and lunar semidiurnal constituent (M2). According to the tidal studies in this area, tidal currents are strong. In the continental shelf and slope, the speed of tidal currents can reach 50cm/s

圖十二　數值模擬結果與實測資料(CODAR與ADCP)比較程序圖

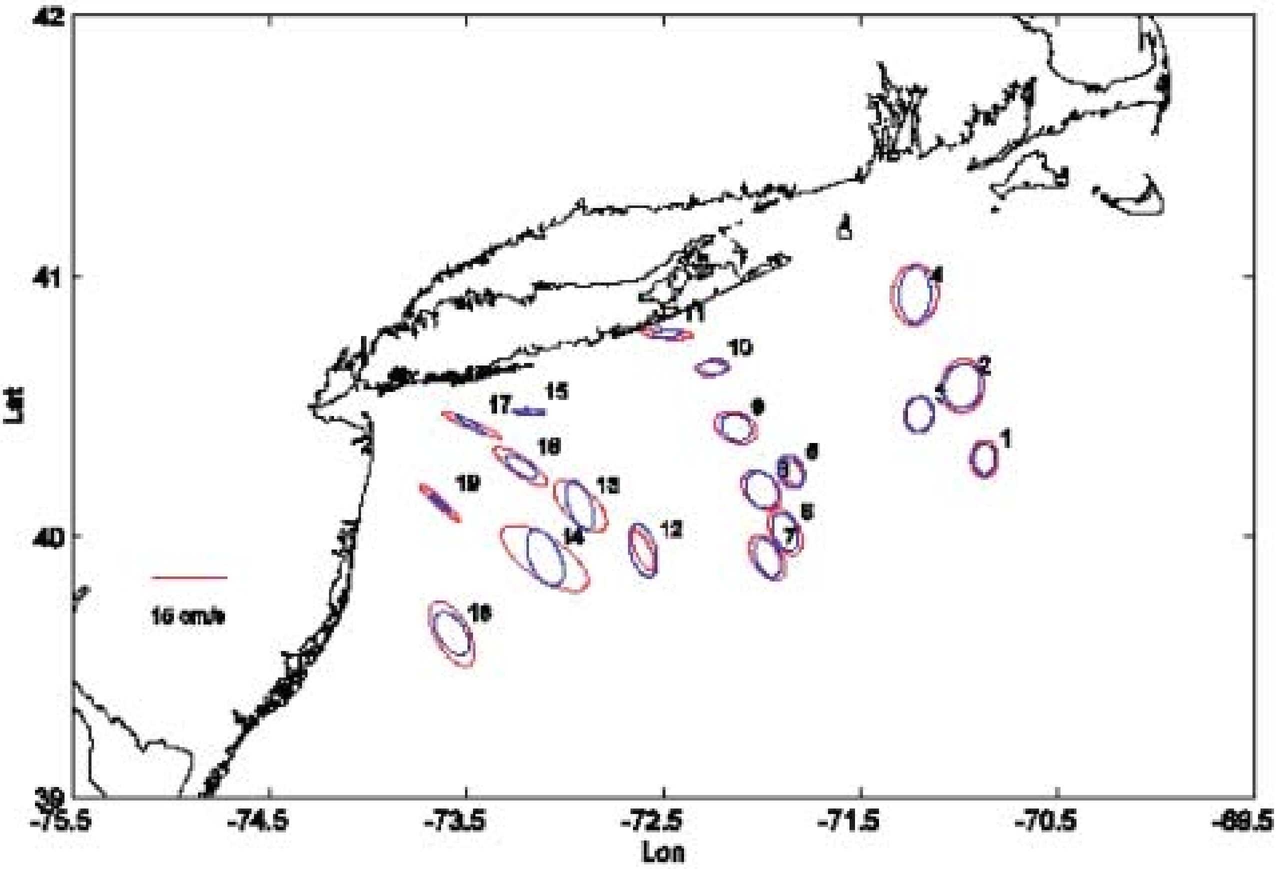


資料來源：作者自繪。

[註三] 潮流橢圓(Tidal ellipse)爲在一完整潮流循環中，潮流之調和分量(components)或其分量之「路徑圖」(Hodograph)正好是橢圓形，而利用這橢圓形，我們可以清楚知道潮流大小與方向。

圖十三　數值模擬結果與實測資料(ADCP)在紐約灣(New York Bight)針對表面潮流(tidal currents)進行比較

紅色爲ADCP實測資料；藍色爲模式計算結果。



資料來源：作者自繪。

and 100cm/s in the Sound.

㈠紐約灣(New York Bight)數值模擬結果與ADCP實測資料（1970-2000年所量測之潮流流速）比較

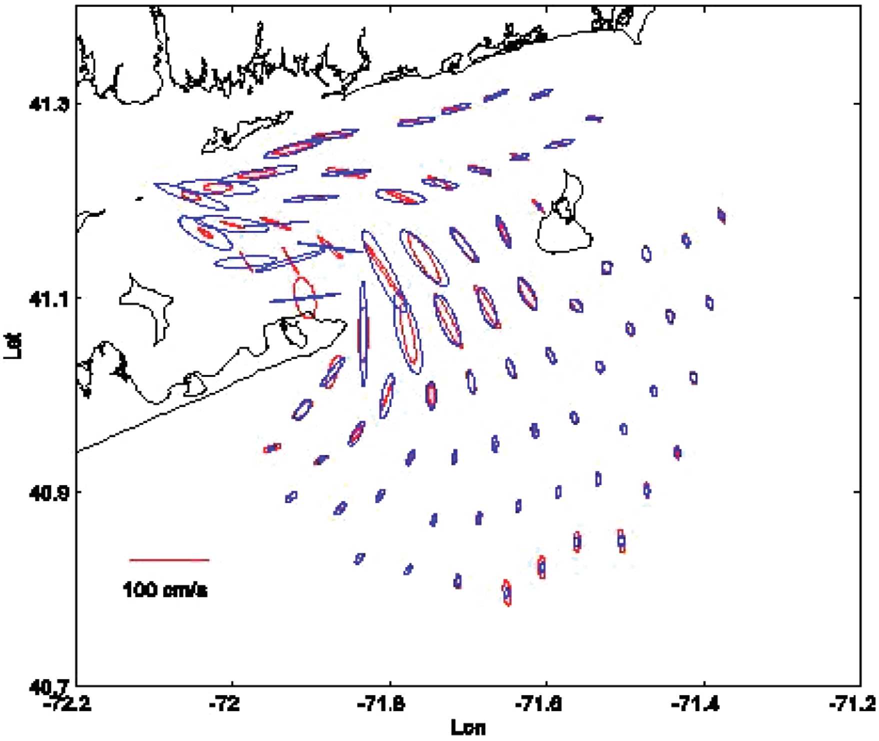
所有潮汐橢圓都是反時鐘轉，而且都是垂直於當地地形。東站(1-4)與中站(5-11)潮汐橢圓相當吻合（圖十三），平均前十一站，潮汐橢圓長軸誤差約爲1.7cm/s，潮汐橢圓短軸誤差約爲1cm/s，方向誤差約5.2°。在紐約灣的西站(12-19)，模式與實測資料的比對結果（潮汐橢圓），誤差相當大。平均後八站，潮汐橢圓長軸誤差約爲4.3cm/s，潮汐橢圓短軸誤差約爲0.9cm/s，方向誤差約15°。先前Oey et al.(1995)在模擬紐約市周圍海域風暴潮(Storm Surge)，引用Mayer et al. (1979)實測資料時，也發生相同狀況（誤差過大），而且我們發現Mayer et al. (1979)使用的測流儀器是公認誤差最高的一種(Anderaa current meters)。

A.Comparison of Model results with ADCP measurements in the New York Bight

The tidal ellipses are all traced out clockwise in time and are generally oriented approximately perpendicular to the local isobaths. The near-surface model and observed tidal current ellipses are in good agreement for the east (1-4) and middle (5-11) sites (Fig. 13). Averaged over these 11 stations, the amplitude misfits are 1.7 cm/s for semi-major axis and 1 cm/s for semi-minor axis, and the orientation misfit is 5.2°.

圖十四　數值模擬結果與實測資料(CODAR)在布拉克峽灣針對表面潮流(tidal currents)進行比較

紅色為CODAR實測資料；藍色為模式計算結果。



資料來源：作者自繪。

In the New York Apex, the model - data discrepancy is relatively large. Averaged over the 8 sites (12-19), the amplitude misfits are 4.3cm/s for semi-major axis and 0.9cm/s for semi-minor axis, and the orientation misfit is 15°. The amplitude misfits are mostly from sites 12-14 in the mid-shelf. Previously, Oey et al. (1995) had noted a similar discrepancy between their model results and observations. It is likely that the current meter data used in the Moody atlas are subject to the surface wave contamination (Mayer et al., 1979), as the data for sites 12-14 were all collected during the stormy winter season (December 1979-February 1980) using Aanderaa current meters.

㈡布拉克峽灣數值模擬結果與CODAR實測資料比較

圖十四是高頻測流雷達實測資料與數值模擬在布拉克峽灣的比較。潮汐橢圓長軸平均誤差約為10.8cm/s，潮汐橢圓短軸平均誤差約為4cm/s，方向平均誤差約29°。每比較點誤差並非相同；在布拉克峽灣口吻合率很高，在長島灣口吻合率較低。Kenefick (1985)和Chant(1992)在研究長島灣口時指出，該地潮流可達100cm/s。Codiga, D.L (2006)用艦置ADCP研究長島灣口通量(mass flux)時，也發現潮流流速約為100cm/s。本研究的數值模擬結果為96cm/s，是相當可信賴的。高頻測流雷達實測資料在此區域效果不佳。

B.Comparison of Model results with CODAR measurements in the Block Island Sound

Figure 14 compares CODAR and model results over the entire CODAR grids. The averaged amplitude misfits are 10.8cm/s for semi-major axis and 4cm/s for semi-minor axis, and the orientation misfit is 29°. The misfits though are not homogeneous. The model and CODAR are in much better agreement in the mouth and outside of BIS. However, at the mouth of LIS, the model currents are considerably larger. Kenefick (1985) and Chant (1992) showed that at the mouth of LIS the tidal currents are predominantly rectilinear and reach maximum amplitudes of 100cm/s. Since the tide is the dominant tidal constituent, the model current of 96cm/s for semi-major axis and 11cm/s for semi-minor axis is quite believable. This suggests that the CODAR data quality probably is poor in this region.

㈢布拉克峽灣數值模擬結果與垂直ADCP實測資料比較

圖十五是布拉克峽灣數值模擬結果與ADCP垂直實測資料的比較。所有潮汐橢圓都是順利時鐘轉，而且都是垂直於布拉克峽灣入口。基本上，值模擬結果與ADCP垂直實測資料是相當吻合的。誤差較大的發生在秋季E站位。在E站位，ADCP垂直實測資料顯示表面潮汐橢圓朝向西北方（約350°T），順時鐘隨著深度變化轉向北方；同時，潮汐橢圓變小（速度變低）。然而數值模擬結果一直朝向西北方（約340°T），潮汐橢圓只有在接近海底時才因海床底質磨擦力而變小。

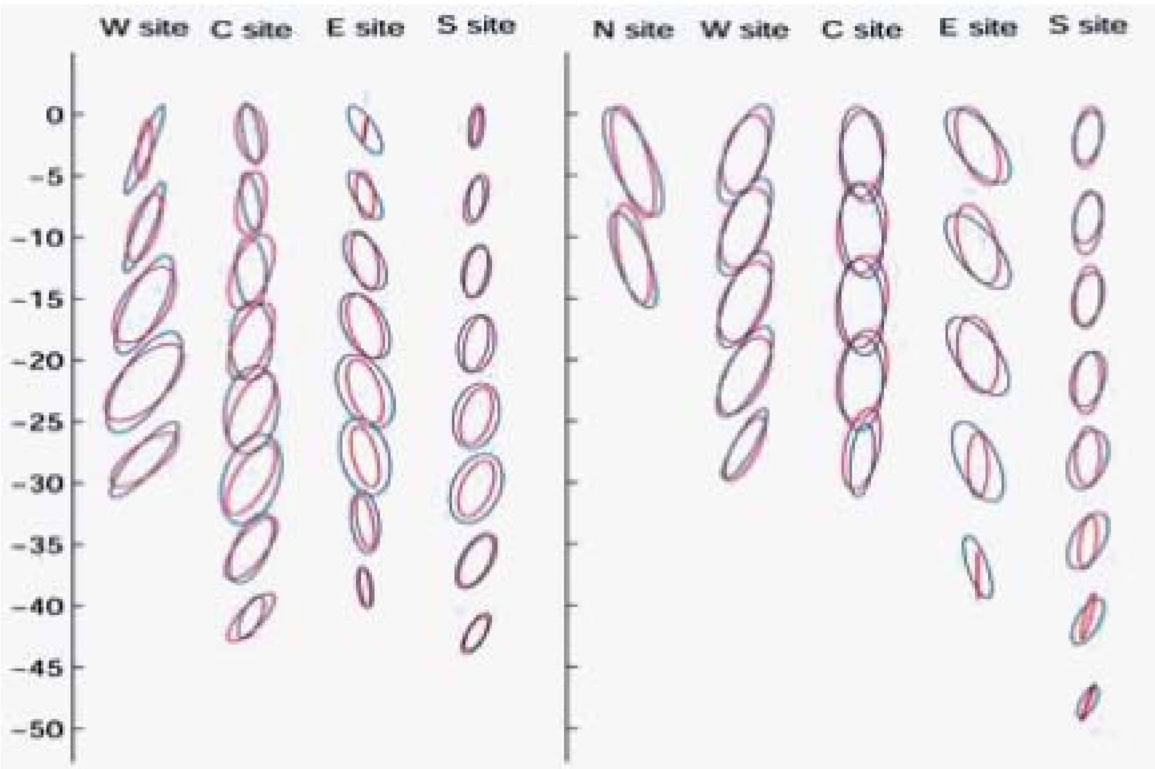
C.Comparison of model results with vertical ADCP measurements

Figure 15 shows the comparison of model results with vertical ADCP measurements. The tidal ellipse major axes generally rotate clockwise towards the bottom, and the velocity amplitudes decrease sharply near the bottom. The model tidal currents and ADCP observations are generally in good agreement. The only significant discrepancy is for the tidal ellipse orientation at site E. Observations show that the tidal ellipse is aligned in the northwest direction at the surface (about 10° counterclockwise from the north), and turns clockwise to the true north near the bottom. The model tidal ellipses, on the other hand, are always aligned in the northwest direction (about 20° counterclockwise from the north). Since site E is located in the submarine canyon, the error likely is due to the unresolved fine-scale topographic features.

㈣誤差計算

圖十五　數值模擬結果與實測資料(ADCP)在布拉克峽灣針對垂直潮流(tidal currents)進行比較

紅色爲ADCP實測資料；藍色爲模式計算結果。Y軸代表水深；X軸代表各站位。



資料來源：作者自繪。

數值模擬結果先經由大範圍區域（紐約灣）歷史ADCP資料開始進行比對，進而比對小區域範圍（布拉克島峽灣）CODAR和ADCP資料。從表面水流開始進行資料比對(CODAR和ADCP)，進而比對深水水流(under currents)資料(ADCP)。此種方式已驗證了數值模擬結果相當準確，也達成本研究的第一目的。本研究的第二目的，就是並利用校正好的模型結果去比對高頻雷達所測出來海水表面水流，詳細量化高頻測流雷達的誤差。

D.Error calculation

Comparison of model results with observations start with the larger domain (New York Bight) with historical ADCP data, and then with the smaller area (Block Island Sound) with CODAR and ADCP observations, including surface and vertical current profiles. This method is used to successfully verify the accuracy of model results. The second purpose of this paper is to validate and qualify the error of CODAR observations.

高頻測流雷達實測資料是把每10分鐘的所測放射性方向速度，累加平均成爲每小時資料，資料點也是用least squares fitting方法，以半徑約2.5km的距離插補(interpolation)而成。爲了量化CODAR的誤差(error)，最好的方法就是檢驗每個(individual)雷射的放射性方向速度。我們以下列兩個統計方程式來計算

The CODAR currents are constructed from the measured radials using vector sum (7 10-minute measurements). At a particular position, the vector velocity is obtained from least squares fitting of all available radials located within a 2.5-km radius. To quantify CODAR errors, the bias and rms difference between model and CODAR are calculated

誤差(bias)=$\overline{A_m}$-$\overline{A_{HF}}$

均方根(Root Mean Square, rms)=

$$\left\{\frac{1}{N}\sum_i\left[\left(A_m-\overline{A_m}\right)-\left(A_{HF}-\overline{A_{HF}}\right)\right]^2\right\}^{1/2}$$

N表示放射性方向速度資料個數，A_m and A_{HF}表示模式(model)與CODAR放射性方向速度資料，以及每組資料的平均值。

bias= $\overline{A_m}$-$\overline{A_{HF}}$

$$\text{rms}=\left\{\frac{1}{N}\sum_i\left[\left(A_m-\overline{A_m}\right)-\left(A_{HF}-\overline{A_{HF}}\right)\right]^2\right\}^{1/2}$$

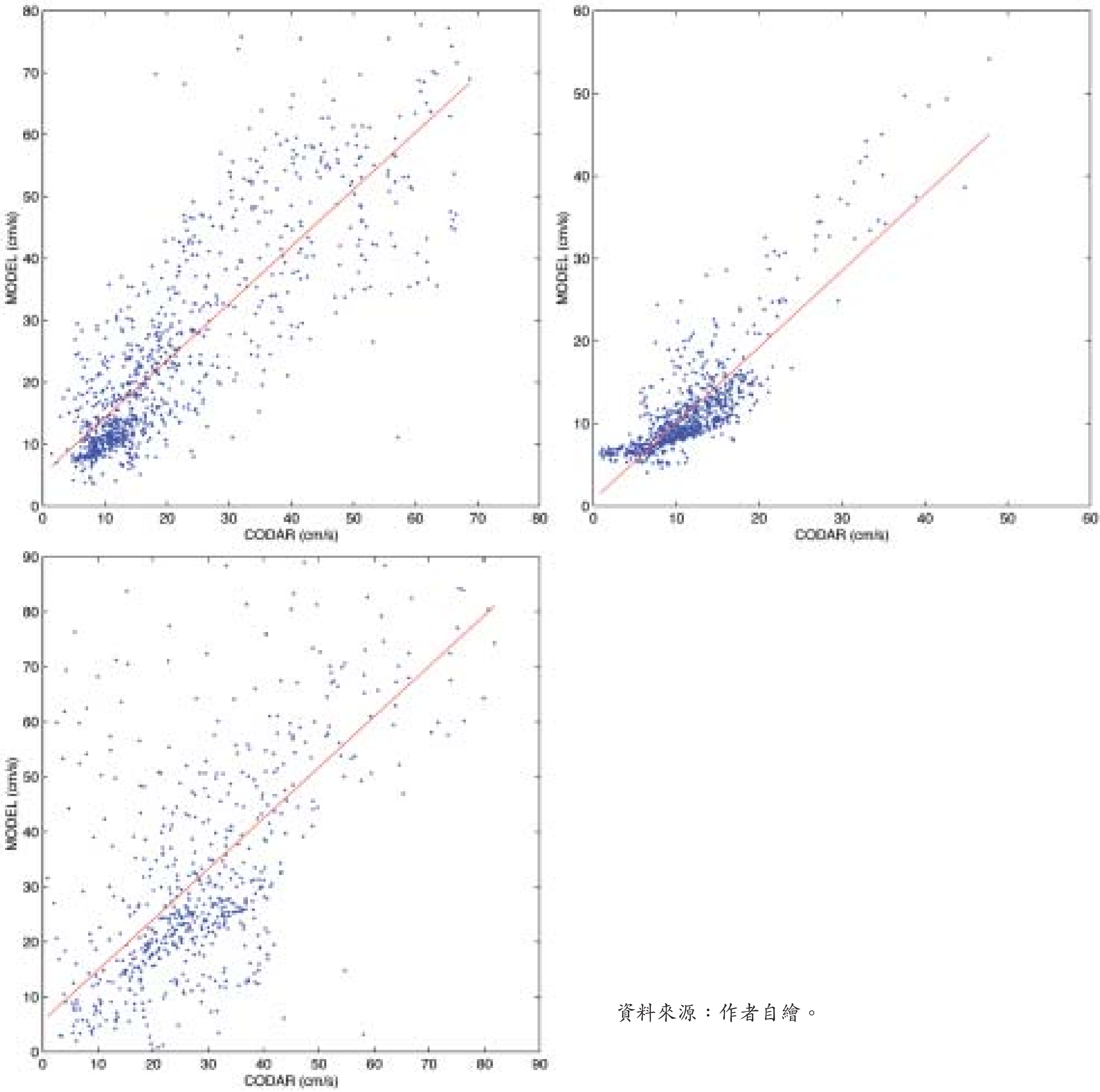
where N is the number of radials, A_m and A_{HF} are respectively the model and CODAR radial amplitude, and overbar indicates the average.

第一、二個雷達點，模式結果與CODAR資料相當吻合。在Montauk Point，計算顯示：均方根=9.7cm/s，誤差=3.4cm/s，準確性 γ^2=0.82。在Block Island，計算顯示：均方根=3.5cm/s，誤差=-0.1cm/s，準確性 γ^2=0.84。然而，在Misquamicut，模式與CODAR資料誤差相當大。計算顯示：均方根=17cm/s，誤差=3.3cm/s，準確性 γ^2=0.62。研究顯示在Misquamicut的雷達資料是不可信的。

The model and CODAR radials are generally in good agreement at Montauk Point, (rms difference= 9.7cm/s, bias= 3.4cm/s, and correlation coefficient γ^2= 0.82) and Block Island (rms= 3.5cm/s, bias= -0.1cm/s, and γ^2= 0.84). However, for Misquamicut, the model and CODAR radials differ considerably, rms= 17cm/s, bias= 3.3cm/s, and γ^2=0.62. This indicates that the Misquamicut site is not reliable. It is noted that for all three radars the regression coefficient is about the same and is close to unity (0.92).

圖十六　以線性回歸分析高頻測流雷達實測資料與數值模擬結果之比較圖

左上圖爲1號雷達；右上圖爲2號雷達；左下圖爲3號雷達。X軸爲高頻測流雷達實測資料；Y軸爲數值模擬結果。



資料來源：作者自繪。

肆、結　　論

高頻測流雷達實測資料與數值模擬之比較，一般而言，結果相當的好。雖然在長島峽灣口吻合率較低，但本文已指出設在康乃狄克州的高頻測流雷達有問題（地理位置選擇不良），導致達實測資料有誤差。另有一篇論文(Mau, 2007)亦支持此種看法[註卌]。本文研究目的爲運用海洋數值模型，並將模型結果與都普勒測流儀所測得之資料進行比對，

[註卌] Mau, J.-C.; D-P Wang, D. S. Ullman and D. L. Codiga. 2007.Comparison of observed (HF radar, ADCP) and model barotropic tidal currents in the New York Bight and Block Island Sound. Estuarine, Coastal and Shelf Science 72 (2007) 129-137.

並利用校正好的模型結果去比對雷達測出來海水表面水流，詳細驗正高頻測流雷達的準確性。本文證明高頻測流雷達實測資料相當準確，而且運用起來，方便且可信度高。

4.Conclusion

In general, comparison of model results and observations is quite consistent, although there is less consistent at the mouth of LIS. However, our study indicates that CODAR at Misquamicut shows a larger error probably due to the fact of CODAR installation (geographical bias). Mau (2007) also supports this argument. The purpose of this paper is to use a ocean numerical model, validated with ADCP observations, to verify the accuracy of CODAR observations. This study shows that CODAR observations are quite accurate which are convenient and quite reliable.

而為什麼美國海軍這麼重視高頻測流雷達，這與海軍作戰有關嗎？大部分的海洋物理現象與參數都可以藉由電腦模擬來並進行預測。但是，沒有實測數據加入的電腦模擬與校正，模擬資料都不準確。因為，電腦模擬資料都是數學公式算出來的，必須有實測資料來比對，並對電腦進行校正，才有實用價值，校正過的電腦預測資料，也才值得相信。研究海洋數值模型的人都知道，校正過的海洋數值模型是值得信賴的。海水是一個連續且有規則的流體。只要表面水流準確，海底的溫度、鹽度一定準確，因為海底的溫度、鹽度變化，一定會反映到表面水流上與海底暗流之上。因此，一個校正過海洋數值模型，海水就是一個透明體。而兩棲作戰與潛艦作戰最需要的就是作戰區域的水文與底流資料。

Why does the USN so care about coastal current radars? Are coastal current radars related to naval warfare? Ocean numerical models can simulate most of oceanic phenomena and parameters in the ocean. However, without correct initial for model and validation with observations, model results can not fit the real world. All of model results are just numerical digital numbers calculated from theoretical and mathematical formulas only, which really need to validate with real observations for correction and alignment of computing. With validation of observations, model results are trustful and useful. All of ocean modelers know that model results are very trustful if model is verified with observations. Ocean is the continuous water mass, of which properties are related together. Once one parameter is correct, the other parameters are correct, too. The variation of temperature and salinity must reflect to the currents (surface and underwater currents). With a validated ocean model, three-dimensional ocean is transparent water mass. Amphibious warfare and submarine warfare do need this environmental information of hydrograph and underwater currents.

美國海岸巡防隊與國土安全部以將全美國沿岸佈設高頻測流雷達，以測知海象，提供即時航行服務，同時空難與海難時，可以預知海流方向，當然對本土防衛作戰提供了絕佳的三度空間海洋戰場環境資訊。事實上，美國海軍已經把高頻測流雷達放在作戰艦艇[註五]與偵察機與反潛機P3-C[註六]。艦艇與飛機到作戰海域上繞一圈，把整個海面海流資料傳回海洋數值模擬中心，作為電腦數值模擬的校正資料。雖然高頻雷達測流儀只能

註五 http://ifmaxp1.ifm.uni-hamburg.de/Schiffs_CODAR.shtml
註六 High Frequency Radars for Coastal Oceanography, 1998. Oceanography Vol 10, No 2.

觀測到海表面的流場資料，但是透過數值模式計算與資料同化(data assimilation)技術，將可提升數值模式計算之準確性，進而獲得海面下之流場與水文資訊。

The US Coast Guard and US Department of Homeland Security have completed the installation of coastal current radars in the both sides of US coastline to provide instant services of navigation and rescue information. Of course, with validation of CODAR observations, a three-dimensional ocean model provide great oceanic environmental information for homeland security. In fact, USN has developed airborne (P3-C) and shipboard current radars. With cruise of warships and P3-C in the operation area (engagement area), surface current data are measured and send back immediately to the numerical model center. With these instant surface current observations, numerical model results calculated with data assimilation show high accuracy of battlespace environmental information on underwater current fields and hydrograph information.

我國是海島型國家，四周環海。以一峽（臺灣海峽）之隔面對假想敵——中共。臺灣海峽長350公里，寬200公里，平均水深80公尺，非常適用佈設高頻測流雷達。如果在臺灣沿岸佈設5-6個座長距離高頻測流雷達（有效距離250公里），就如同美國一樣，能提供即時航行服務（表面水流），同時空難與海難時，也可以預知海流方向，提供有用搜救資訊；當然對國軍也提供了絕佳的即時實測資料，對國軍「戰場環境即時預報系統」[註三]的預測準確性，提升一大步。同時，我國向美購買反潛機P3-C，應該要求加裝與美軍相同設備－高頻測流雷達。

Our nation is kind of island country surrounded with waters. In the opposite side of Taiwan Strait is the supposed enemy of the R.O.C.- the People Republic China (P.R.C.). The dimension of Taiwan Strait is 350km long and 200km wide and with average depth of 80 meter deep. In this case, Taiwan is very suitable to use HF coastal current radars to map surface currents in the waters surrounding Taiwan. As the US did, 5-6HF coastal current radars are recommended to place along the coastline around Taiwan Island, providing instant services of navigation and rescue information. Of course, it also provide great in-situ observations for numerical model validations, which increase the accuracy of 'NOWCAST model for marine battlespace environment'. At the mean time, with army sale with the US, we should ask for installation of airborne HF current radars onboard.

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