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呂宋海峽線型內波的產生機制(III)--總計畫 研究成果報告(精簡版)

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摘要

從歷年的衛星影像及現場觀測中可以發現非線性內波 (NLIWs) 在南海 (SCS) 北部海域中橫越傳遞。為了解釋衛星影像及現場觀測資料，過去有許多對於南海北部非線性內波起源以及生成機制的推測。其可能的產生區域包括巴擔島之間水深較淺的海檻、位在水深較深處的恆春海脊、黑潮的西邊界、東沙環礁附近的大陸棚裂以及等溫線的不穩定...等等。其推測的產生機制又隨著產生地點的改變而有所不同。而南海北部觀察到的非線性內波可追溯其來源至呂宋海峽。在恆春海脊(121E)以西 400 公里東沙環礁區域，所觀測到的非線性內波波形以及傳遞速度可用 KdV 方程式作有效的描述誤差約在 5%以內。而沿著 20.4N 緯度線 119E 到 120E 之間(或恆春海脊以西 100~200 公里位置)，由 2005~2007 現場觀測得知，其中的非線性內波則多呈現波包的形式。位在恆春海脊以西 20 公里內，並未發現有非線性內波生成；而到了恆春海脊以西 40~100 公里處，則可以發現 1~2 個內波波前；再到了恆春海脊以西 100 公里外，則內波可演化為 2~6 個內波波前非線性內波的能量來源相信來自於正壓潮流經由恆春海脊以及巴擔島中間海檻所引發的垂直擾動，然而他們之間的相對貢獻仍然在研究當中。在 2005 年五月 120E 所觀測到內波可以歸類屬於強非線性內波，而傳遞到了 119E 位置則又較類似於第一模態的非線性內波，此時可以用描述弱非線性內波的 KdV 理論來加以解釋。對於非線性內波的演化和生成過程則尚需要更多的現場觀測以及數值模擬實驗來作更深入的研究。

關鍵字：非線性內波，巴擔島，恆春海脊，kdV 理論

前言與研究目的

內波於海洋中隨著傳遞距離的增加，非線性效應逐漸增強，則由線性狀態隨著演化的過程逐漸轉變為非線性的型態在海洋中傳遞，即為非線性內波 (Non-Linear Internal Wave)。非線性內波的運動方程式中主要包含有兩項：非線性項與分散項。當非線性內波隨著時間繼續演化，非線性作用增加到一定程度時，非線性內波的前緣則會脫離出孤立子，而形成孤立波。由於非線性項和分散項兩者間互相平衡，因此使得孤立波能傳遞很長的距離而能量不會消散。

內波在海洋中傳遞時，由於上下水層流速相反產生相當大的剪應力，因此在內波活動頻繁的海域，伴隨內波而來的海流常會影響海上工程、海上建設和軍事活動等，因此更顯得研究內波的重要。

從早年的可見光衛星影像 (Bole et al., 1994)，或是近年來的 SAR (Synthetic Aperture Radar) 影像 (Hsu et al., 2000; Liu and Hsu, 2004; Liu et al., 2004) 和 MODIS (Moderate-resolution Imaging Spectroradiometer) 影像資料，均可觀測到南海非線性內波活動的證據。綜合上述影像的觀測結果，非線性內波的出現區域大都集中於南海北邊的大陸棚。Liu and Hsu (2004) 收集了上百張的 ERS-1/2、RADARSAT 的 SAR 影像，並繪出南海北部非線性內波分布圖。從 SAR 影像得知非線性內波多為由東向西傳遞，波前長度可達 200 公里 (Hsu et al., 2000)。Liu et al. (1998) 預估此海域非線性內波所引發的最大振幅可達 100 公尺；Yang et al. (2004) 於 1999 年在東沙環礁東北邊量測到振幅約為 106 公尺的非線性內波；Ramp et al. (2004) 更於 2001 年量測到振幅高達約 140 公尺，此振幅遠大於其他海域所觀測到的非線性內波振幅，蘇祿海 (Sulu Sea) 所量測最大振幅約為 90 公尺 (Apel et al., 1985; Liu et al., 1985)、安達曼海 (Andaman Sea) 最大振幅約為 60 公尺 (Osborne et al., 1980)。

近年來對於南海北部非線性內波的研究上，規模最大的國際交流合作計畫為 ASIAEX (Asian Seas International Acoustics Experiment，亞洲海域國際聲學實驗)，由美國主導，台灣、新加坡、加拿大、中國大陸等共同參與，在 2001 年的兩個主要實驗中，一個在東海 (East China Sea) 研究聲波在海床上的反射，另一個在南海 (South China Sea) 研究內波和聲學的交互作用。台灣主要是參與南海實驗為主，ASIAEX 的研究區域中心約為北緯 $21^{\circ}55'$ 、東經 $117^{\circ}20'$ ，距離台灣最南端約 370 公里，選在此區域的原因主要有三個：

- (一)、此區域有從呂宋海峽產生的高頻率且大振幅的非線性內波通過。
- (二)、當地的潮流強度足以產生強大的內潮。
- (三)、猜測由黑潮入侵南海時所產生的渦流會主導著大陸斜坡次潮流 (Subtidal current) 的變化。

由 1995 年 ERS1-SAR 影像中 (Liu et al., 1998)，可觀測到南海北部的巨大內波，波前長度可達 200 公里。且在 120°E 以東的呂宋海峽便可觀測到十分明顯且巨大的非線性內波的訊號。本計畫主要研究目的為觀察呂宋海峽大型線型內波如何傳遞、其產生機制與起源，以及內波經過時對該區產生的影響和其演化。第一年的工作是確認巨型內波自呂宋海峽向西傳播，我們透過現場觀測及多重衛星遙測等方式，觀察到振幅達 140m，波速達 2.85m/s 的巨型內波。第二年的研究重點在內波產生後的演化過程 (evolution process) 及其對表面波譜的影響。

研究方法與結果

從歷年的衛星影像及現場觀測中可以發現非線性內波 (NLIWs) 在南海 (SCS) 北部海域中橫越傳遞。為了解釋衛星影像(圖 1 及 2)及現場觀測(圖 3)資料，過去有許多對於南海北部非線性內波起源以及生成機制的推測。其可能的產生區域包括巴擔島之間水深較淺的海檻、位在水深較深處的恆春海脊、黑潮的西邊界、東沙環礁附近的大陸棚裂以及等溫線的不穩定...等等。其推測的產生機制又隨著產生地點的改變而有所不同。而南海北部觀察到的非線性內波可追溯其來源至呂宋海峽。在恆春海脊(121°E)以西 400 公里東沙環礁區域，所觀測到的非線性內波波形以及傳遞速度可用 KdV 方程式作有效的描述(圖 4)，誤差約在 5% 以內。而沿著 20.4°N 緯度線(圖 5)，119°E 到 120°E 之間(或恆春海脊以西 100~200 公里位置)，由 2005~2007 現場觀測得知，其中的非線性內波則多呈現波包的形式。位在恆春海脊以西 20 公里內，並未發現有非線性內波生成；而到了恆春海脊以西 40~100 公里處，則可以發現 1~2 個內波波前；再到了恆春海脊以西 100 公里外，則內波可演化為 2~6 個內波波前(圖 6 及 7)。非線性內波的能量來源相信來自於正壓潮流經由恆春海脊以及巴擔島中間海檻所引發的垂直擾動，然而他們之間的相對貢獻仍然在研究當中。在 2005 年五月 120°E 所觀測到內波可以歸類屬於強非線性內波，而傳遞到了 119°E 位置則又較類似於第一模態的非線性內波，此時可以用描述弱非線性內波的 KdV 理論來加以解釋。對於非線性內波的演化和生成過程則尚需要更多的現場觀測以及數值模擬實驗來作更深入的研究。

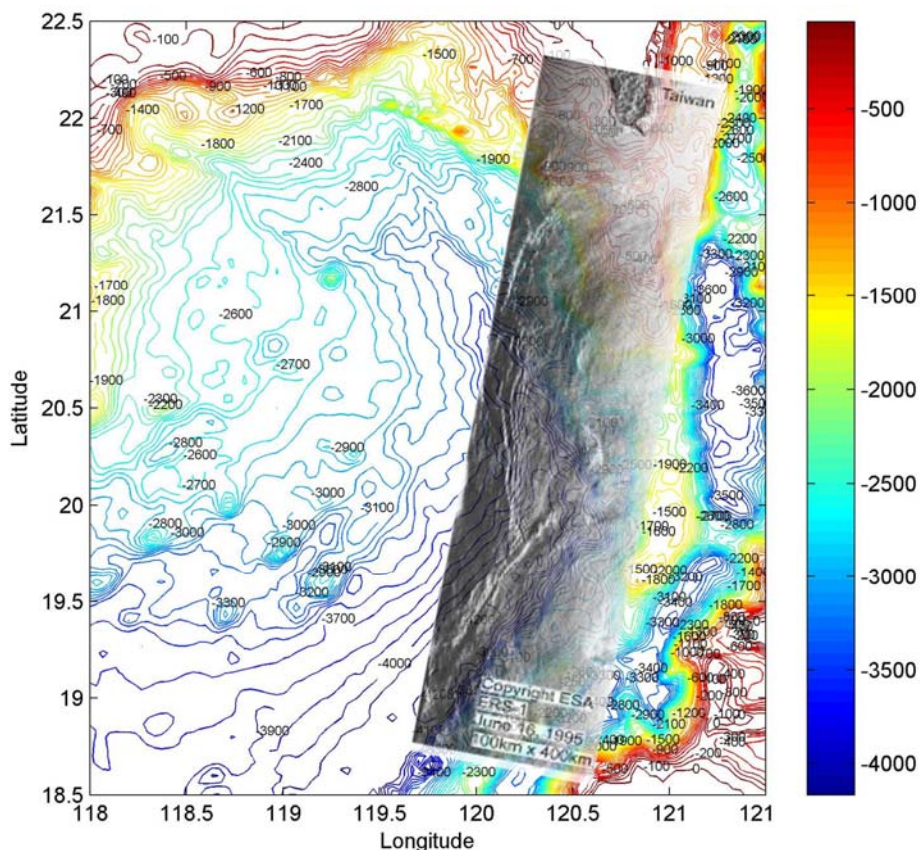


圖 1、1995/6/16 ERS-1 SAR 的衛星影像攝得之在台灣西南方呂宋海峽的非線性內波。彩色等深線為水深(公尺)。在台灣與呂宋島之間 (18.7°N~21.3°N)，非線性內波的波前沿著 2000 公尺的等深線與恆春海脊的東側斜坡平行

對內波產生區域的不同假設

Ebbesmeyer et al. (1991) 假設北南海的非線性內波起源於呂宋島東北方巴擔島之間較淺的海檻，就如同蘇祿海東南方觀測到的非線性內波一樣，源自於島嶼之間的海檻。但是此假設有 3 個疑問尚待驗證：①由衛星影像來看，海檻的位置並不在非線性內波波前弧線的中心。②衛星影像上在巴擔島和恆春海脊的中間並未發現明顯的非線性內波訊號。③在模式中假設巴擔島為起源處的話，則當非線性內波傳遞至東沙環礁時，模式預測結果其波前行進方向為向北，與衛星影像(圖 2)不合。

黑潮的西方邊界碰撞所造成的不穩定引發非線性內波產生的假設。在潮流轉變相位的時候，因為地形與黑潮邊界的交互作用可能引發水層結構的不穩定，然而，這個假設欠缺任何資料佐證，1995 SAR 影像中非線性內波波前的位置與方向，與同緯度的黑潮邊界相比，方向並不吻合，目前也沒有任何理論可以把不同方向的兩種東西來作連結以及解釋。

另一個可能的假設，相較於其他產生內波的地區，平均水深較深可達 1200 公尺的恆春海脊，由於衛星影像上非線性內波線型的波前形狀排列與恆春海脊東邊斜坡以及向西南延伸的一致，而此區又是算呂宋海峽中地形變化最陡峭的位置，所以當強烈的潮流上下的移動等密面時，恆春海脊所在的頂部可以產生出山後駐波。因此在這個假設下，我們相信恆春海脊是呂宋海峽中非線性內波的主要產生處，巴擔島附近則可能為次波源，它提供了部份的內潮能量使得在恆春海脊處產生出非線性內波。我們採用圖 3 所列的方法，探討南海內波的形成與傳播。

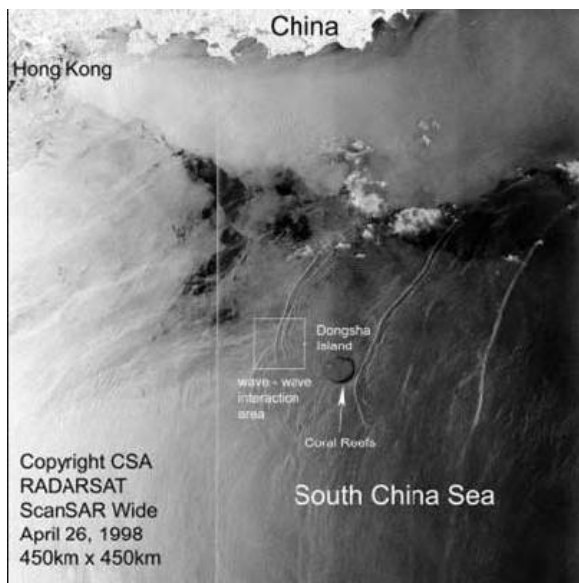


圖 2. Radarsat SAR 在東沙環礁處的衛星影像顯示內波的起源處應該位在呂宋海峽這個區域

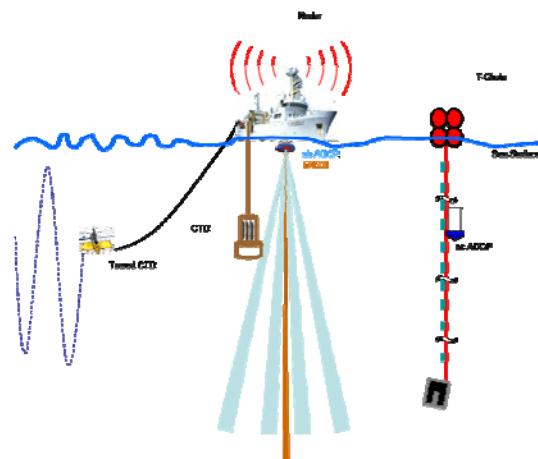


圖 3. 現場量測非線性內波的工具以及方法示意圖

對恆春海脊非線性內波產生機制的假設

潮流經過地形的效應(例如：流經海檻或者是海底的海脊)，其垂直的運動可以引發出內潮，而內潮的波谷行進速度較波峰來得快，經過數小時的傳遞後，波峰與波谷的距離會由 50 公里縮短到 20 公里，此時非線性效應的尖銳化結果會使得波峰與波谷間的距離再拉近至 10 公里。

或是當潮流以很快的速度越過地形時，此時的福祿數可能大於 1，向上游傳遞的擾動

可能會被地形給限制住，而水躍 (hydraulic jump) 的現象即有可能發生，當以最大的流速減弱時，水躍造成的擾動將會開始向上游處傳遞 (Apel et al., 1985)。以呂宋海峽為案例，這個向上游傳播的擾動可能會在連續分層的流體下以點波源的形式形成內波來傳遞，或者有如平面波在波導管中的傳遞(假如整層水柱同步震盪)。由於在恆春海脊上的擾動能量集中於上層 1500 m 水柱。根據線性內波理論，內波能量可能無法到達 120E 以東的底層水柱 (圖 8)，形成非線性內波波前。

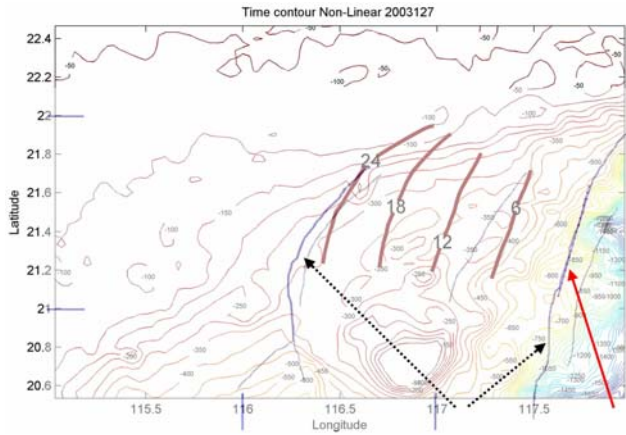


圖 4. 2003/05/07 Terra MODIS 的衛星影像中非線性內波波前位置(細藍線)與 6、12、18、24 小時後的波前預測關係(粗棕線)，初始位置為紅箭頭處，黑箭頭指出源自同區域，但是相位相差 24 小時的非線性內波。

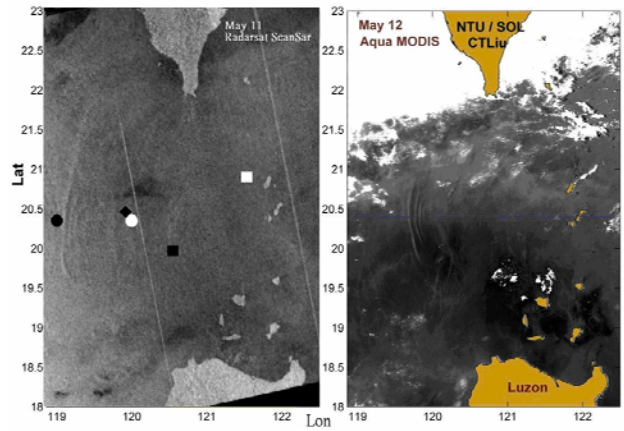


圖 5. 根據 Niwa & Hibiya (2004) 內潮模式建議，沿著 20.4N 內潮能量最大的位置進行現場觀測，May 11, 2005: ●: FB1 (20.4°N, 119°E), ○: FB2 (20.4°N, 120°E), ◆: Revelle (20.5°N 119.9°E), ■: OR3 (20°N, 120.5°E), □: FR1 (21°N, 121.25°E) 與遙測資料： May 11, RADARSAT ScanSAR 衛星影像, May 12, MODIS 影像的比較。

KdV 模式在內波振幅小於 0.4 倍水深的情況下($r=h/d < 0.4$, Grue et al., 1999)，適合用來模擬弱非線性內波的波形以及傳遞，在圖 6 (120°E, 20.4°N)的情況下， $r > 1$ 表示此處屬於強非線性內波，基本假設為穩態以及弱非線性效應的 KdV 理論則不適用。

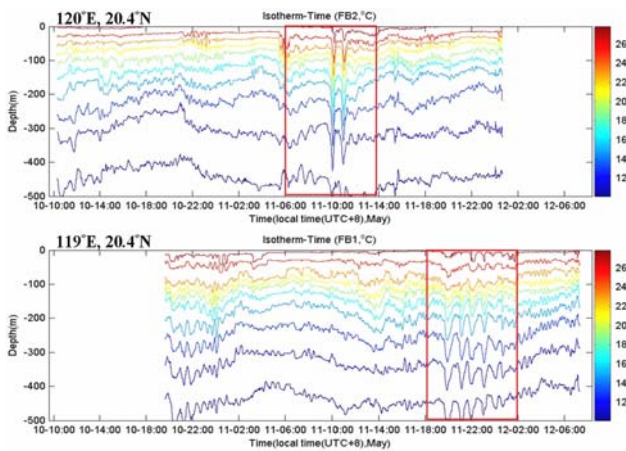


圖 6：上層 500 公尺溫度資料，對齊時間軸觀測等溫線隨時間變化的情形

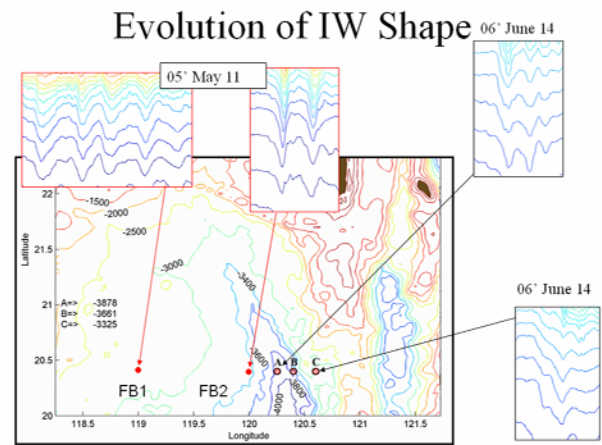


圖 7：恆春海脊以西(120.5°E, 20.4°N)，溫度計串在不同經度位置所紀錄到非線性內波通過時的等溫線隨時間變化的情形

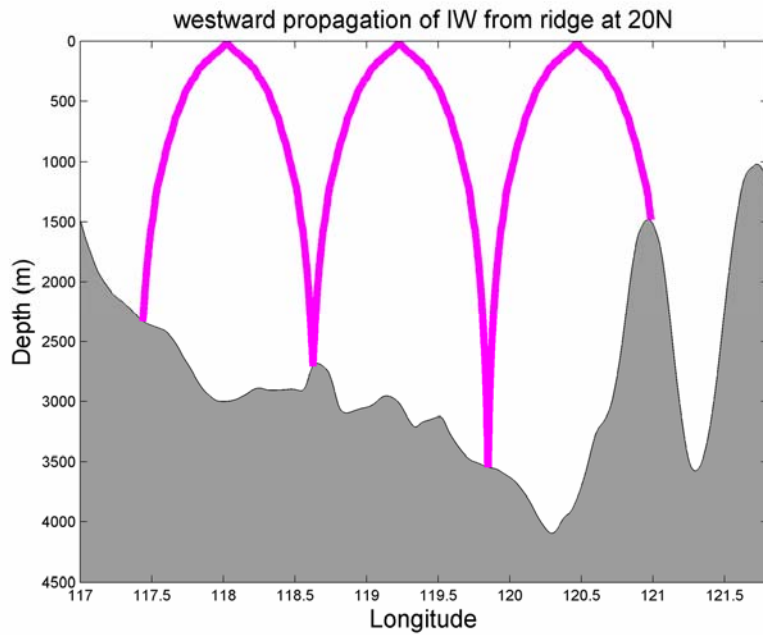


圖 8：從恆春海脊東側產生並越過的 M2 內潮能量傳遞路徑

討論與結論

在衛星影像上，南海北部非線性內波多集中在大陸斜坡的東沙環礁附近，這是由於此區域有較多的衛星影像觀測，此區的非線性內波已經演化為多個波前的型態，而且淺水區域的非線性內波對於海表面粗糙度的改變有較強烈的影響，因此此區在衛星影像上，也特別較於容易觀測。

在非線性內波的傳遞及演化上，大部份在大陸斜坡上的非線性內波，其起源來自於 $120^{\circ}\text{E}\sim 122^{\circ}\text{E}$ 的呂宋海峽，在 120°E 以西可用一階的 KdV 理論來描述其波形及傳遞速度，而從 $120.5^{\circ}\text{E}\sim 119^{\circ}\text{E}$ 的演化過程，則可由 KdV dnoidal function (Apel, 2003) 來模擬(圖 9)。至於非線性內波的產生機制尚需要更多的研究以及更多往上游位置的現場觀測，目前較多人支持的假設有二，從巴擔島產生的內潮所演變(Chao et al., 2006)或者是由恆春海脊處的山後駐波所衍生。前者假設沒有恆春海脊，非線性內波的振幅將有可能會更大，但是卻遺漏了假如沒有巴擔島，恆春海脊也會產生非線性內波的可能性。而後者的假設則推測由於強烈的亂流以及消散性環境影響，使得巴擔島以東的山後駐波無法在恆春海脊與巴擔島之間產生非線性內波，恆春海脊以西的山後駐波也無法向東形成非線性內波。

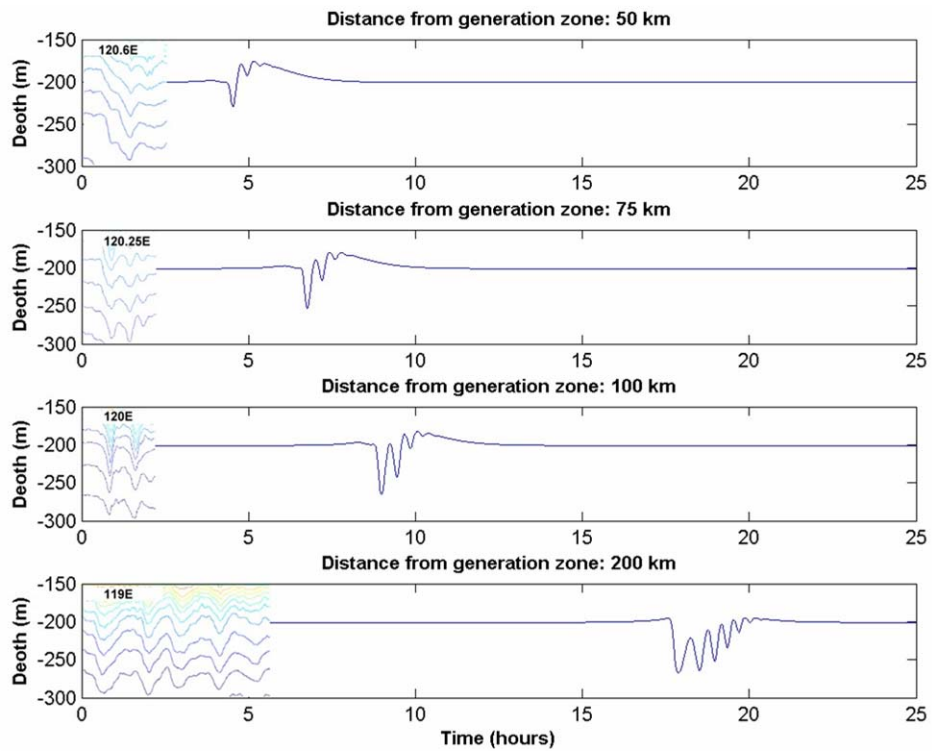


圖 9：將 2005、2006 年的錨碇觀測資料與模擬結果比較

發表或投稿之文章

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出席國際學術會議心得報告

計畫編號	NSC 95-2611-M-002-021
計畫名稱	呂宋海峽線型內波的產生機制(III)--總計畫
出國人員姓名 服務機關及職稱	劉倬騰,台灣大學海洋研究所,教授
會議時間地點	Girdwood, Alaska U.S.A 2007年8月26至31日
會議名稱	美國海軍研究室主辦的南海內波研究研討會
發表論文題目	Remote Sensing Surface Roughness and Nonlinear Internal waves from Luzon Strait

一、參加會議經過

本會議是由美國海軍研究室物理海洋研究的計畫經理，與水下聲學研究的計畫經理共同主持，出席人員包括台美雙方參與南海內波研究的物理海洋科學家，各自報告在過去三年內，共同研究南海內波及內波對水下聲學的影響的研究心得，以及參與討論。

南海的內波是世界上最大的內波，這已經經過與會學者多方面證實。由於內波的振幅巨大，使得他的非線性現象非常特殊，一般的線性波浪理論根本無法解釋南海內波的形成、行進、演變等等的現象，且參與的學者都只能夠捕捉到內波片面的訊息，所以要舉辦這次的會議，讓與會的學者，各自發表其在海上偵測到的內波現象。

本人的報告如附件一，報告的重點是我們在三年來對於南海巨型內波的形成、位置及演變過程的研究，基本上我們認為南海巨型內波是在恆春海脊上形成的，當然，巴擔島已經將部份的正壓潮轉換成斜壓潮，對於內波的形成也是有貢獻的。至於議程及其他與會人員的報告，也摘錄於附件二與三中。

二、與會心得

聽過各人的南海內波研究，對於南海內波的複雜性，有充份的體認，似乎還沒有人能夠充分了解南海內波是如何形成的，大家對於南海內波的行進與演變，意見較一致，只是研究資源有限，要再次共同執行大型研究將是數年之後了。

南海內波的研究，由於美方多數學者的參與，在國內才受到重視，可見我國對科學研究的重要性，缺乏自主性，這種現象也很可能發生在其他的學門。

海洋研究裏面，耗費資源最多的就是船期，在這方面，全數由我方支援似乎不盡合理，且我方所學到的科技，與所付出的船期費用，似乎不成正比，因為船期的每日實際費用在新台幣40萬元以上，唯有將船期的費用列成計畫經費的一部份，才能合理反應我方所投入台美雙方合作研究南海內波的資源。

台美雙方合作研究，我方雖可學到一些新的科技，但是海研一號探測人員的感受是，出海的航次安排及海上實驗，幾乎都由美方資深教授主導，主因是我方派出的學者，常常是年資淺，或者內波知識不足，因此，這方面有極大的改善空間，希望未來的國際交流計畫，能夠以我國資深學者對應外國資深學者，才會有適當的交流方式、過程與成果。

附件一：劉倬騰出席美國海軍研究室主辦的南海內波研究研討會報告

**Remote Sensing Surface Roughness
and Nonlinear Internal Waves from
Luzon Strait**

2007/8/28 @Girdwood, AK

Cho-Teng Liu
Institute of Oceanography
National Taiwan Univ.

M-K Hsu, H-W Chen, D-J Doong

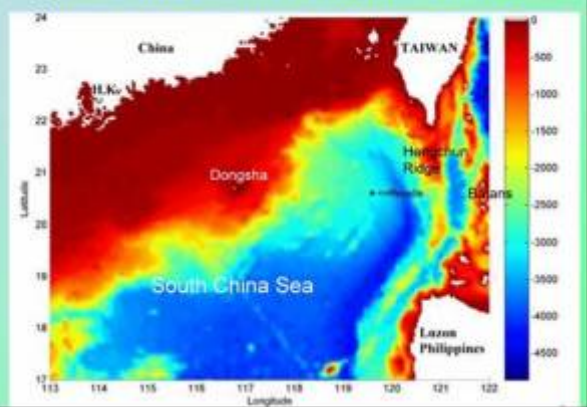
topics

- Field work of 2005~2007
- Interpretation of NLIW in deep part of SCS
- Prediction of NLIW propagation over shelf with RS image only
- Simulation of NLIW evolution (Apel's model)
- Location of surface roughness: SAR vs. eyes
- Future work: RABBI project

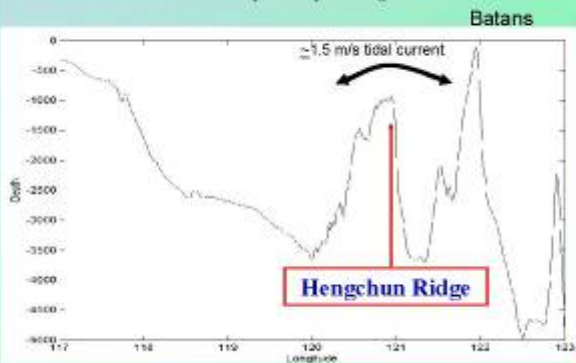
Luzon Strait is the only deep channel
between South China Sea and Pacific Ocean



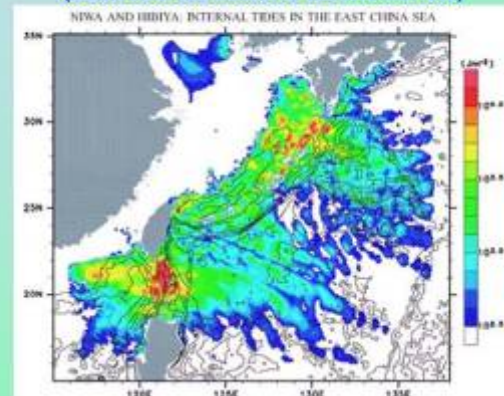
Geography and bathymetry of the South China Sea (SCS)

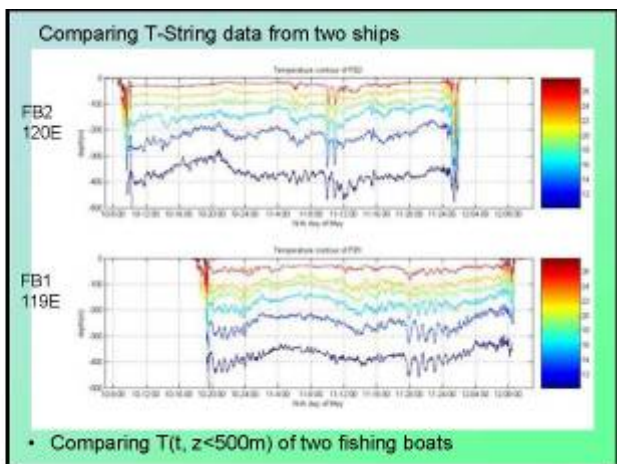
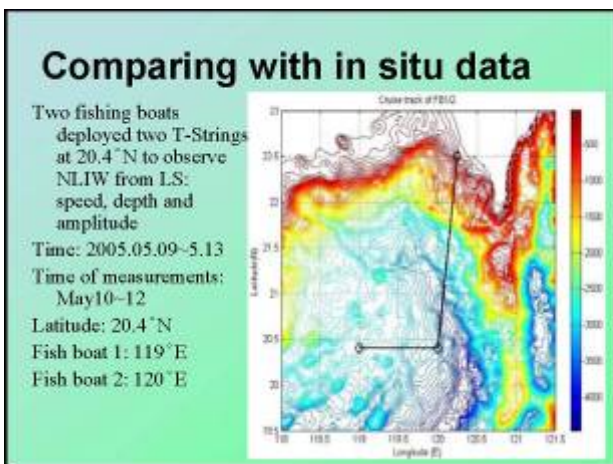
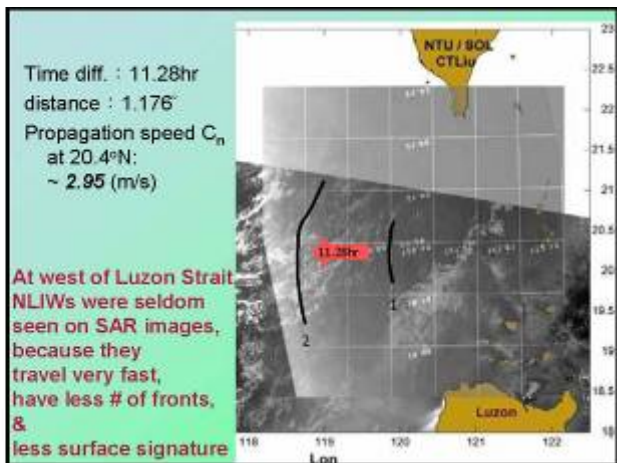
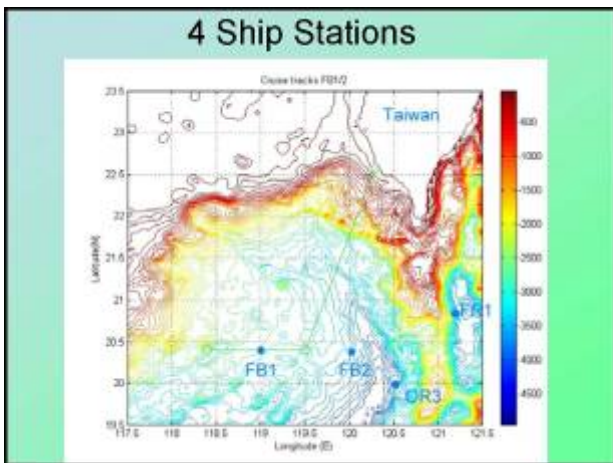
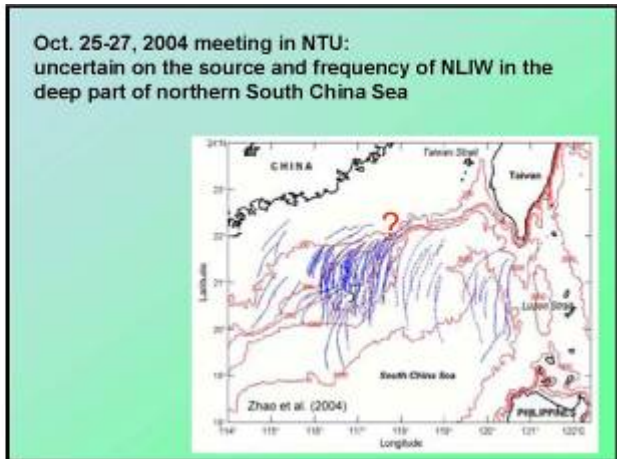
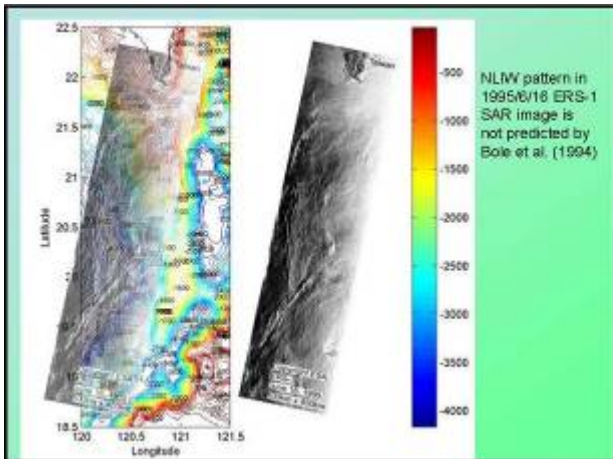


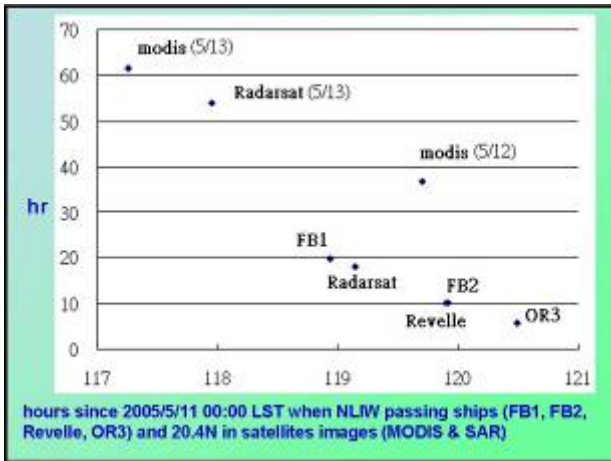
Bathymetry along 21N



M2 internal tidal energy density near Luzon
(20.4N near the center of M2 internal tide)







A steady-state, weakly non-linear internal waves are best

described by **Korteweg de Vries (KdV)** equation:

$$A + CA^2 + \alpha AA_x + \gamma CA^3 = 0$$

$$A(x,t) = A_0 \operatorname{sech}^2 \left(\frac{x - C_1 t}{L} \right)$$

where A_0 is the amplitude of NLIW, α

is the coefficient of dispersion term, L is half-width of NLIW,

C_1 = phase velocity of mode 1 of linear internal wave (LIW) theory. C = phase velocity of non-linear internal

wave

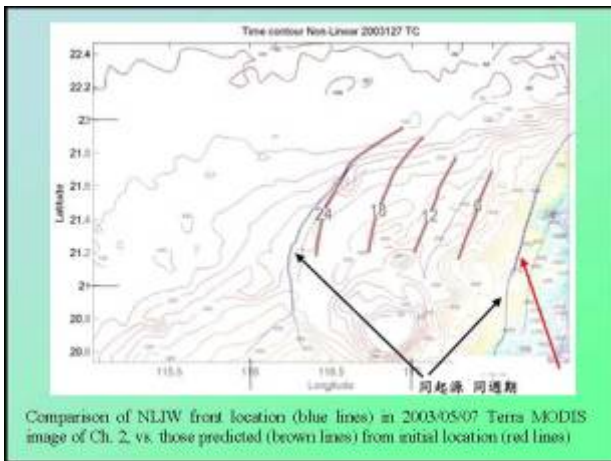
$$\Rightarrow C = C_1 + \frac{\alpha A_0}{3}$$

Prediction of NLIW Propagation over

NSCS Shelf:

Using RS images and KdV eq.

Case	Satellite	System	Date	UTC	Amplitude (A)	Starting Longitude (B)	Predicted Propagation Distance (km)	Percentage Error
2.1	Terra	MODIS	2003041	2:55	A	117.8°	126-133	-2.4%
	Terra	SAR	8	3:25	A	E		%
		MODIS	2003050			117.8°		-4.7%
		SAR	7			E		%
		MODIS	2005042			117.5°		4.8%



Evolution of NLIW

steady state solution of KdV equation:

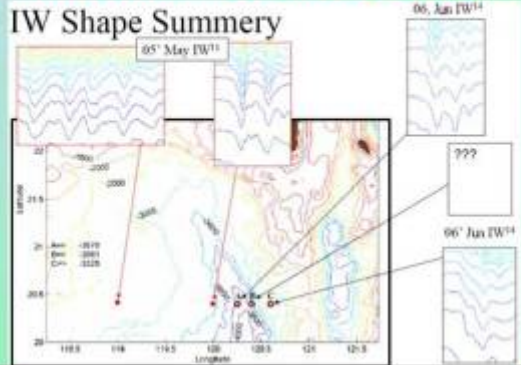
$$A(x,t) = A_0 \operatorname{sech}^2 \left(\frac{x - C_1 t}{L} \right)$$

Apel (2003) asymptotic solution to KdV Eq, using elliptical functions:

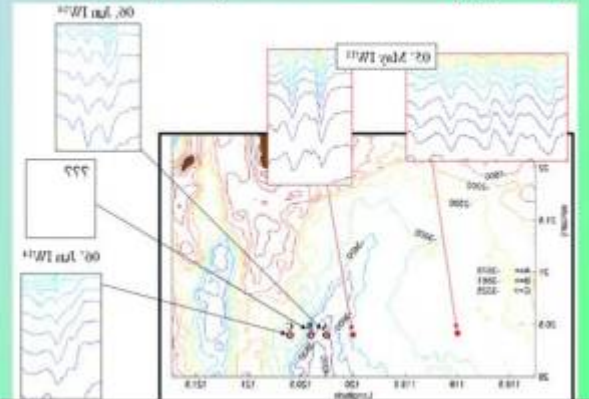
$$\eta(x, z, t) = \eta_0 \operatorname{sn}^2 \left(z - W(x, t) k^{-2} \operatorname{sn}^2(x) \right) \left\{ 2 \operatorname{dn}^2 \left(x \left[\frac{1}{2} k_0 (x - C_1 t) \right] - [1 - s^2(x)] \right) \right\}$$

Elliptical parameter s : $s^2=0$ for linear sine wave, $s^2=1$ for solitary nliw

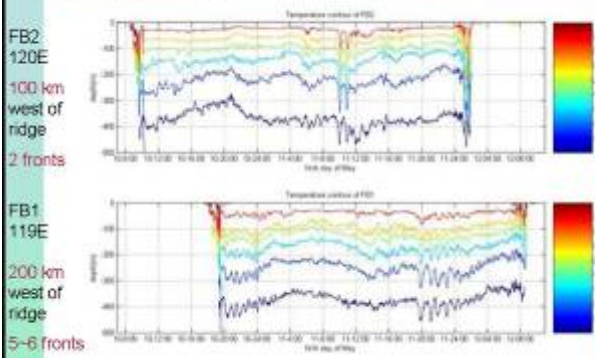
NLIW shape from T-chains (time series)
 no NLIW was found east of c-mooring, field or RS



NLIW shape - spatial distribution (approx.)



Comparing T-String data from two ships



• Comparing T(t, z<500m) of two fishing boats

Simulation with [Apel's model \(2003\)](#) of asymptotic solution to KdV Eq. of weakly nonlinear internal waves

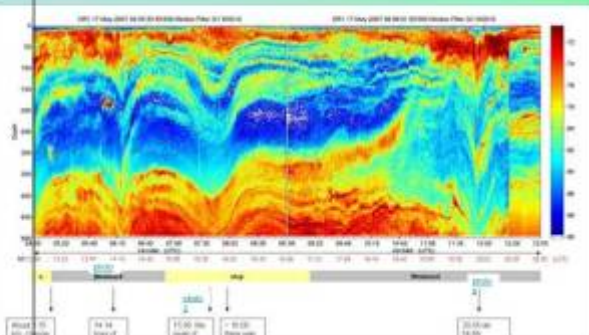
Relation between rough band in radar images, in surface picture and in sonar data

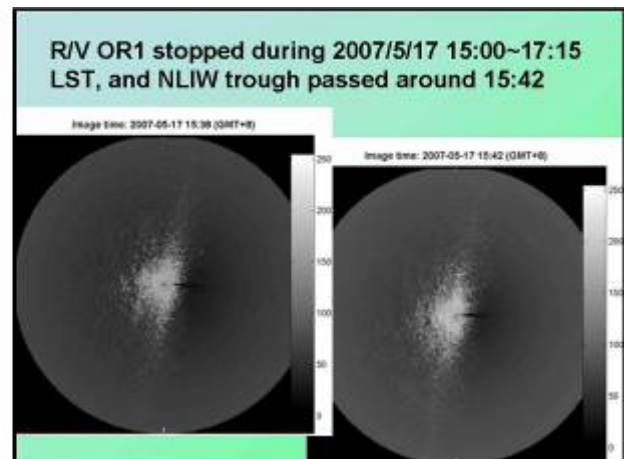
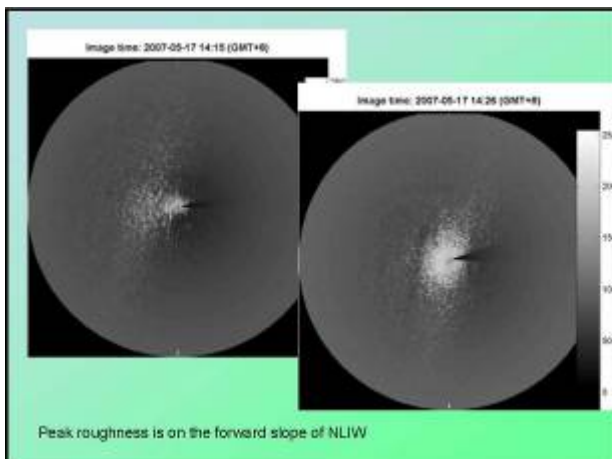
This is one the topics of May 2007 cruise:
 C-T Liu, B. Plant, M-K Hsu, D-J Doong

Existing theory:

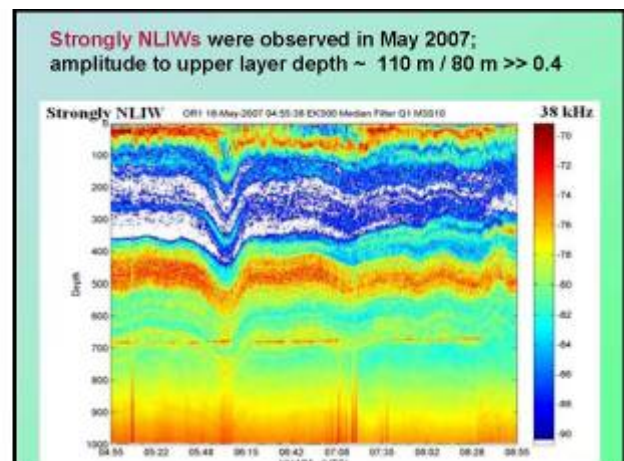
1. Short gravity waves and capillary waves were concentrated by the convergence of horizontal velocity that is induced by the passing of NLIW;
2. The location of maximal roughness (center of white band in SAR image) is the place of max. convergence; max divergence corresponds to the darkest line in SAR images

R/V OR1 sailed westward at 11 knots during 2007/5/17 13:15~15:00 LST, and crossed NLIW trough around 15:42





- **Discussion:**
The simultaneous ship radar and sonar data seem to indicate that the maximal **surface roughness is located** somewhere between the maximal horizontal convergence and the trough of NLIW
- **Hypothesis:**
Both convergence and counter current play roles in making rough surface; waves propagating against the current will be slowed down by the current, which resulted increased amplitude and surface roughness, and they may break before NLIW trough arrives or even reflected by NLIW



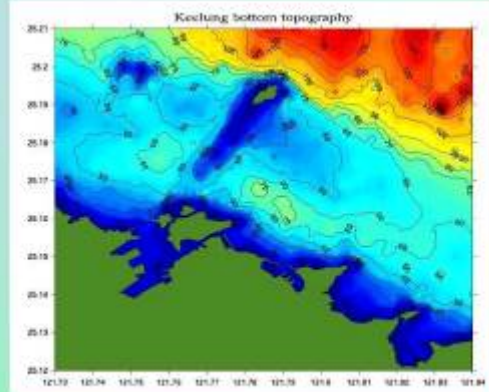
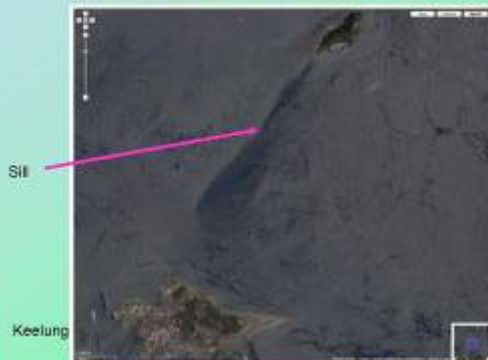
Continuing work

- To study puzzles on the location of max surface roughness:
surface roughness may have different meanings:
 1. in wave gauge data
 2. in Satellite SAR images
 3. in Satellite optical images
 4. to human naked eyes, camera on the ship
 5. to camera on the model airplane

Field experiments

- **Mapping spatial distribution of surface wave spectra vs. NLIW trough is difficult,** because NLIWs propagate at over 5 knots in the deep NSCS
- The tidal flow **over a sill** has similar effect on surface waves, like NLIWs do.
- **Observation:**
Surface wave spectra, optical images and Envisat ASAR images will be studied to clarify the meaning of roughness in them

Image from Google



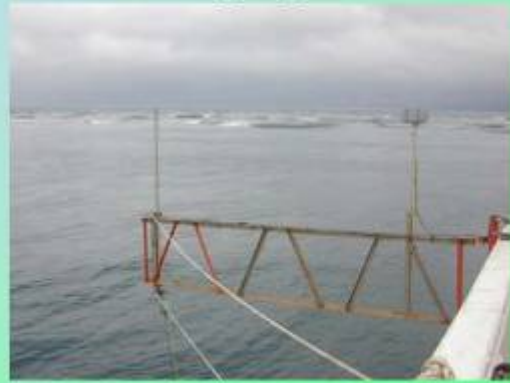
From Prof. Lo of NTOU

Camera on ship

[movie clip](#), 1 frame per minute



Wave gauge data



UAV

(1st flight: 2007/10/11)



PI of RABBI

- RAdar Backscattering influenced by Bathymetry and Internal waves (RABBI)
- Cho-Teng Liu (NTU) – optical images from ship, UAV and hill top; field work
- Ming-Kuang Hsu (NTIST) - SAR
- Hsien-Wen Chen (CPU) – field work
- Dong-Jiing Doong (NTOU) – wave spectra

Cruise days now ~ 2008/7/31:
8 of OR1, 5 of OR2, 7 of OR3

附件二：南海內波研究研討會議程

August 26-27 QPE sessions

Date/Time Person/Group presentations

Tue Aug 28

800 T Paluszkiwicz - opening remarks
810 TY Tang on SCOPE subprojects
830 RC Lien on trapped core behavior of NLIW on shelf
845 M. Alford M2 vs. K1, and energy flux of NLIW
900 YJ Yang on MODE-2 waves
915 R Pintel, J Klymak on modeling energetics
930 L St. Laurent, H Simmons
945 YH Wang on Dongsha bio production vs. NLIW
1000 P Niiler, L Centorini on determining C_p with ≥ 3 GPS drifters
1015 S Ramp on moorings between Batanes
1030 D Farmer on IES data & TC movement
1045 B Reeder
1100 M Huei, JH Tai
1115 C Lee, YT Chang, J Martinon AUV
1130 D Rudnick on best path of AUV
1145
1200 lunch
1300 J Lynch on SW06, shallow water acoustics of NJS
1315 J Nash,
1330 D Susanto on acoustic reflectivity with CTD data
1345 Q Zheng on generation of NLIW
1400 C Jackson empirical model of NLIW source at 121.5E
1415 Y Zhao, T Liu deriving ocean current from contiguous SAR
1430 CT Liu NLIW evolution west of Hengchun Ridge, RABBI
1445 break
1500 T Peacock
1515 D Holm MLCM on modelling strongly non-linear
1530 K Helfrich discussion of energetics from IT
1545 O Fringer SUNDANS model
1600 P Gallacher ONR models
1615 D Ko NFS model on predicting NLIW
1630 K Winters
1645 SY Chao, PT Shaw

Wed Aug 29

800 T Duda
830 J Moum, E Shroyer modelling evolution of NLIW
845 S Glenn, K Shearman, G Gawarkiewicz
915 A Scotti
930 F Henyey on Hamiltonian expression for NLIW & towed 48 CTD
945 break
1000 H Graber, N Williams
1015 M Caruso
1030 W Choi, D Lyzenga
1045 B Plant on coherence radar view of roughness in NJS & SCS
1100 N Malinas, C Wackerman
1115 E Lettvin
1130-1900 Field Demonstration

Thur Aug 30

800 groups meet to discuss projects (rapporteurs needed)
945 break
1015 group meetings continue
1200 lunch
1300 rapporteurs report on group meetings
1430 group meetings
1830 NLIWI dinner

Fri Aug 31

830 individual discussion with Terry
1200 ONR closes meeting

附件三：會議報告摘要

2007/08/28 AM

Laurent: opening remarks. 3 & 1 minute warning with paper

Ren-Chieh Lien:

Trapped core as seen in mooring data;

K.E. changes along propagation

Energy level alternates, largest at spring tide (2005/4/22), and slightly smaller at next spring tide (e.g. 2005/5/6)

None in Jan/Feb;

Spring 2006/2007, 1 wave/day; July-Sept: 2 waves / day; vs. OSU model

Tang TY: Briefing on sub-projects in SCOPE, nothing on his own project.

Mathew Alford:

K1 & M2 spring tide; M2 tide dominates, but NLIW happens once per day

(**LCT:** NLIW happens when K1 & M2 are in phase in changing from east to westward current, which happens at most once per day;

LCC: name and list events of NLIW as observed in SAR & modis images, plot $u(t)$ for K1, M2, and K1+M2;

mark the phase of changing current, list the time;

also, estimate their crossing time at 120E)

Diurnal flux of 20 kW/m at Spring tide? (or in Spring season?), mean -7.25 kW/m

Yang YJ: Mode-2 wave

Jody Klymak & Pinkel:

Bathy effect in LIW & NLIW

energy flux is about 17 kW/m from $p'u'$

internal tidal rays from shelf break towards shallow water: mostly dissipated, little reflected

This is a study using 2-D model of GCM type, at 50 m resolution

Laurent:

Based on Chris Jackson's prediction to track NLIW

Chang et al. ~ 10kW/m towards shelf, only 0.5 kW/m on shelf

YH Wang:

Dongsha Atoll has 6% slope outside the rim of coral.

O1-u (?) has 180-degree of phase change at thermocline, ~75 m depth.

L. Centorini & P. Niiler

3 or more Drifting T-chains ($dz < 2.5$ m) can give phase velocity of NLIW (amplitude and direction)

$C_n \sim 1.069$ $C_1 \sim 1.069 * 2.61$

Steve Ramp

Moorings near Batan Islands

Large tilt of mooring, may be over 20 degrees

Towed ADCP fish has little pitch during towing motion

Maximal 1 m/s westward and 1.5 m/s eastward, change in 6 hours

Range of ADCP was 80 m in 120 m depth)

The tide in the channel is already baroclinic

Phase: like surface wave; high tide, high current

David Farmer:

IES from URI

Mode-1 measurement, insensitive to M2

Sees tc movement in each tide

Trying to find high frequency part of NLIW

8/28 1pm

Jim Lynch

The low frequency component of the shallow water acoustic experiment

Craig Lee: Glider-based observation of the Kuroshio

Glider observed strong B.C.

Char. Annual cycle and associate meso-scale

Spray – 50 kg & 2 m length, dive 1000 m depth

Seaglider – behave like long-term mooring

Dan Rudnick

Crossing Kuroshio path of T_{min} & L_{min} are different (minimal time vs. minimal distance)

Repeated occupations of a section

e.g. S_{min} core moved offshore during these repeated cross sections

mesoscale current dominates over variation of Kuroshio

Zheng QA

Tide and other dynamic parameters determine the density strength

Reynolds #: $Rc = UD/A_h$

Dwi Susanto

Acoustic reflection coeff. (R) as the indicator of thermocline variability in SCS

$R = (\rho_2 C_2 - \rho_1 C_1) / (\rho_2 C_2 + \rho_1 C_1)$

CTD data gives $\rho_i C_i$ of each layer, then R can be computed

Chris Jackson

MODIS images of sun glint shows NLIWs well

2007/4/21 shows big ring that centers at 121.5E

Max. westward current is lag/lead (?) 2.5 hour of ??

=> On/off switch of NLIW generation in Luzon Strait

=> LCT: line-segment along 121E should be a better source

2007/8/6, 8/4, NLIW east of Luzon

Darryl Holm

MLCM (Multiple-layer columnar Model)

Strongly nonlinear model

Relative relation among models:

SUNTANS (fully nonlinear, 3d model) \Leftrightarrow MLCM \Leftrightarrow ROMS

Finite volume code, 20 min for 10 steps with 1500 nodes on Intel 2 GHz PC

Stabilize BT mode, smoothes non-hydrostatics pressure

Karl Helfrich

Dynamics of the emergence from the internal tide

Oliver Evinger

Simulation of NLIW in the SCS using SUNTANS model

Generation region seems to be at the 121E

Peak NLIW in source region seems to be in phase with eastward (towards Pacific) current

Hydrostatic, hydrojump, left of sill, flood tide

Lee waves vs. flood (?) wave

As ebb tide slows down, the hydraulic jump moves leftward, and water sinks at east of sill, and forms the forward slope of nliw

Patrick Gallacher / Michael (NRL models)

$dx = 100 \text{ m} \Rightarrow$ sees NLIW

$dx = 500 \text{ m} \Rightarrow$ NLIW develops too slow

$dx = 1000 \text{ m} \Rightarrow$ no NLIW

Internal Tide develops into internal bore

DS Ko

2 km NFS model can predict the location of LIW front that co-locate with NLIW front

Chao, Ko et al. suggest western ridge dampens the IW energy,

Kraig Winters (SIO)

modelling NLIWs in SCS is not simple

1. How do they dissipate? (DJL iwp's)
2. How are they formed? (IB, high resolution, $dx \sim 30 \text{ m}$ is still too coarse)
3. How do they evolve (may be workable)

NLIW starts at about 70 km west of SILL

Mode 2 travels at about $4/9 \sim 4/10$ speed of mode

Intensification + dispersion < 250 km

Dissipation+ dissipation at 300 km

Changing stratification still result large jump

08/29 AM

Nash & Duda: SW06 Briefing

All arrival times are possible – $(-\pi, \pi)$ vs. tidal phase

Large u at shelfbreak, but weak u at inner shelf

Weak u at shelfbreak, but large u at inner shelf

(Ping-Tung's comment: large U at shelf break means large mixing, less stratification, therefore, difficult to generate NLIW, and weak NLIW at inner shelf)

Shelfbreak is the source of NLIW going both directions (to inner shelf and to deep sea); model result shows the energy propagation vs. (x, t) , NLIW propagate to inner shelf is more energetic

Jim Moun

K.E.. ~ APE in SCS and in NJ Shelf

Mode-2 waves are Varicose waves that are less energetic, but more turbulent

Transition from depression wave ($\eta < 15 \text{ m}$) to elevation wave ($\eta < 5 \text{ m}$)

In 2-layer model with mean flow: $h_1/h_2 = (C-U_0)/(C+U_0)$

A. Scotti

Modelling on subcritical generation of NLIW in NJS

Barotropic tide at shelfbreak creates a rich baroclinic field, even at subcritical speed

Frank Henyey (UW/APL):

Towed CTD Chain, 48 CTD @1.5 m spacing at 45-degree wire angle

Bill Plant

HH is stronger than VV

For the same wave field, radar images are different for view along wave propagation and against wave propagation. Some short waves and breaking waves are blocked by wave crest for radar glances sea surface at low inclination angle. Viewing angle is not a problem for airborne radar.

Max sigma (radar back scattering) is at the peak of NLIW, not at max. convergence.

SAR data represents sqrt of RCS (Radar cross section)

$Sech^2$ () often does not match SCS data

DJL model works on some data

Session off at 11:20 for Field Demonstration Trip

08/30 08:00 General Discussion

Terry: Discussion on dividing groups

Session 1: RS & model group; mooring group, acoustic group

Session 2: report of each group

8/30 13:00

1. Hans:

R. Pinkel

When wind speed $W > 10$ m/s, or 14 knots (ship speed or wind speed?), satellite can (cannot) see NLIW
NLIW: naked eyes, ship radar and coherence radar can see all NLIW, why satellite could not see them all?

LCT:

1. because satellite data are not available at everyday, nor at every place, therefore, most NLIWs were not mapped by satellite.
2. In 2005 experiment, every NLIW packet in the satellite image was observed by satellite. But, SAR image often shows only the leading wave or the first two waves in a NLIW packet.

2. J. Moun:

PE, APE are not well defined, only KE is. F. Henyey will clarify this.

Frank Henyey: relation between PE & KE are best defined in DJL equation.

Hamiltonian gives a better expression.

DJL is based on energy balance and is a better equation to work on.

3. Ben:

Acoustics: Physics of acoustic propagation

Surface wave, IT, fronts, seabed, NLIW and anisotropy – all influence acoustic propagation

Terry: naming the NLIW events in SCS for easy cross-referencing.

4. Oliver

Strongly NLIW models (2d + MULTILAYER)

Weakly NLIW (KdV, eKdV)

Surface currents U_{iw} of NLIW & U_{bg} of background

$D_x < 100$ m is necessary

Surface wave models

wave action equation $\Rightarrow O(1 \text{ m})$ for resolution

Model for the wave spectral form $\Rightarrow O(1 \text{ cm})$

and predict small scale wave from large scale wave

\Rightarrow backscattering models for remote sensing

\Leftrightarrow Empirical models using tidal information to predict arrival of NLIW

(Chris Jackson: phase in $\pm 10\%$, amplitude ?)

Understand all the NLIW models \Rightarrow strongly NLIW models

Quantifying uncertainties in every step

1. Surface wave models

- initial spectra

- surface currents

- greatest uncertainty: wind forcing, dissipation, wave-wave interaction

2. Remote sensing

3. NLIW:

arrival time (phase): $+10\%$ from tidal cycle

greatest uncertainty: u , du/dx , amplitude, # of waves in a packet

\gg resolution, < 100 m in SCS, < 20 m in NJS

\gg bathymetry

\gg stratification/currents due to seasonal and meso-scale variability

4. Develop/Implement test problems to quantify uncertainty by comparing in situ and RS data to models