海洋對熱帶氣旋風應力之回應：評介

張偉正

美國海軍研究院

摘　　要

在海洋對熱帶氣旋風應力作用下所產生之運動、高度變化研究方面，O'Brien (1967)引用呈中心對稱之海洋斜壓模式得到當強風開始引入之初期在中心產生下沉和輻合運動，數小時後中心附近成爲湧升運動，而此湧升流的範圍在最大風速半徑之二倍距離內。湧升或下沉運動主要取決於切向風應力之徑向梯度，踴升速度則存在周期性之振盪，其頻率近似於慣性頻率，回應之流場則包含了渦旋和在徑向傳播之內重力波。

Geisler (1970)以二層無摩擦線性模式得到結果顯示當氣旋之移速大於斜壓長波運動速度時在氣旋後方存在近似靜態之內波尾流，而因爲氣旋之尺度大於斜壓之變形尺度因此尾流區之夾角很小，在尾流波動逐漸消散後，地轉平衡之斜壓脊仍留在氣旋路徑上，而其範圍大致相當於正壓變形尺度。

Chang 和 Anthes (1978)引用三維非線性非對稱模式研究海洋運動受颱風影響，在他們的模式裡風應力所造成之垂直　均作用是透過擾流動力能量參數處理。他們發覺在北半球裡氣旋導致海水運動或變化在路徑右側較左側明顯，海洋之最大感應流和氣旋之速度間之關係並不明顯但是海水溫度之改變則和氣旋之速度有關。

在 80 年後，Price (1983)比較模擬和觀測之異同，他引用多層模式模擬颱風 Eloise (1979)所引致之洋流，其結果和 EB－10 buay在 53 公尺深之觀測結果在振幅、相位等皆十分相似。

在討論熱帶氣旋所導致正壓與斜壓模之運動，Chang (1985)之模擬顯示風應力首先導致斜壓運動，而經由壓力梯度項產生正壓運動，而此正壓運動則有深厚之旋流使溫度、運動變化傳至深海，垂直運動則存在整層之海水中，此結果和颱風Eloise通過時曾經觀測到 57 公分之洋面變化相當。

透過最新之觀測設備、理論模式及數值模擬，Shay、Chang 和 Elsberry (1990)分析海洋受颱風 Frederic (1979)之影響。他們的理論模式得到最大之洋面改變約爲 20 公分，導致之轉動洋流則以約 1－2%高於慣性頻率運動，其最大振幅爲 11cm/s，位於颱風路徑之右側於最大應力離中心兩倍距離處。他們的三維模式模擬結果得到 18 至 20 公分之洋面變化，並產生深厚平均約 10－11cm/s之洋流，模擬與理論模式兩者近似。這些結果也與在 100－950 公尺間觀測所得 5－11cm/s相似，此表示了海洋對熱帶氣旋風應力在正壓運動之作用是一種線性的過程。

Ocean Response to Tropical Cyclone Wind Stress: A Review

Simon We-Jen Chang

U.S. Naval Research Laboratory, Washington, DC 20375

Abstract

An axisymmetric, baroclinic, two-layer ocean models was used to study the ocean's response to the wind stress fields of stationary tropical cyclones (O'Brien, 1967). The initial onset of the cyclonic stress field produces a downwelling and convergence at the center. Intense upwelling, which occurs several hours later, is confined to within twice the radius of maximum winds. The upwelling and downwelling depend on the radial gradient of the tangential stress. The upwelling velocity contains oscillations at the near inertial frequency. Induced current field consists of a vortex component and a radially propagating wave mode.

Geisler (1970) used a linear, inviscid two-layer model on an f-plane to describe the ocean's response to a moving tropical cyclone, represented by a positive stress curl and a negative pressure anomaly. The steady-state solution indicates that there is an internal wake behind the storm, if the translation speed of the tropical cyclone exceeds the baroclinic long wave speed. The angle of the wedge of the wake is small, because the scale of the tropical cyclone is larger than the baroclinic radius of deformation. After the wake disperses, a geostrophic balanced baroclinic ridge remains along the storm track. The surface perturbation field in the form of a balanced trough follows the storm and is distributed over an area which has a radius of the order of the barotropic radius of deformation.

A 3D, asymmetric nonlinear model was employed by Chang and Anthes (1978) to investigate the ocean's response to moving tropical cyclones. A turbulent kinetic energy budget is used to parameterize the stress induced vertical mixing. They found the storm induced response was biased to the right side of the track in northern hemisphere. They also found that the maximum induced current in the mixed layer was not sensitive to the speed of the storm, but the induced temperature change was. Alternating vertical motion patterns were found in the wake where there was a narrow ridge of the thermocline.

Price (1983) examined the baroclinic response in the wake of a hurricane using a multi-layered model and obervations acquired during Hurricane Eloise (1979) at the EB-10 buoy. The amplitudes and phases of the simulated currents agreed fairly well with the observed ocean current at 53 m.

Using a multi-level, axisymmetric ocean circulation model with a free surface and a rigid bottom, Chang (1985) modeled both the baroclinic and barotropic ocean responses to tropical cyclones. He found that the wind stress field first excited a baroclinic mode and through the pressure gradient term generated a bartropic response, with the associated deep ocean overturning circulation, produced current and temperature changes in the deep ocean. The vertical motion filled the vertical column from the bottom to the surface. A 57 cm maximum surface depression was found for Hurricane Eloise.

Aided by in situ observations, an analytical model and a nonlinear 3D ocean circulation model with free surface, Shay et al (1990) analyzed the free surface effects on the near-inertial ocean current response Hurricane Frederic of 1979. The origin and role of the depth-averaged component of velocity were investigated by forcing both the analytical and the 3D models with estimated stress of Frederic. The analytical model produced a maximum sea surface depression of 20 cm with a barotropic current velocities rotating inertially with periods 1-2% above the inertial period and a maximum amplitude of 11 cm s^{-1}, located two radius of maximum stress to the right of the track. The 3D model simulated a 18-20 cm surface depression with a depth-averaged current of 10-11 cm s^{-1}. These results suggested that the ocean's barotropic response to tropical cyclone is a linear process. The magnitude of the depth averaged current generated by the models agreed well with the 5-11 cm s^{-1} depth-averaged component measured by ocean current meter arrays in water depth 100-950 m.

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