Rapid deepening of tropical cyclones in the northeastern Tropical Pacific: The relationship with oceanic eddies

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RESUMEN

Los datos del archivo de trayectorias mejoradas (best track) del Centro Nacional de Huracanes de Miami para el Pacífico nororiental tropical incluyen ciclones tropicales (CT) que exhiben profundización rápida y/o explosiva durante el periodo 1993-2009. Al mismo tiempo, observaciones de altimetría satelital muestran al Pacífico nororiental tropical poblado por remolinos oceánicos ciclónicos y anticiclónicos. Estas dos fuentes de datos se utilizan para estudiar el papel de los remolinos oceánicos en la distribución espacial del calor oceánico y la profundización rápida y/o explosiva de los CT del Pacífico nororiental tropical. El análisis de los resultados demuestra que: 1) la interacción entre CT y remolinos oceánicos anticiclónicos ocurrió en ~ 73% de los CT del periodo analizado; 2) de los CT que alcanzaron la categoría de huracanes, 90% había interaccionado con los remolinos oceánicos anticiclónicos; 3) ~ 18% (3%) de los CT se caracterizaron por profundización rápida (explosiva), 74% de éstos alcanzaron el estado de profundización después de su interacción directa y/o indirecta con remolinos oceánicos anticiclónicos, y de ellos el 86% alcanzó la categoría de huracán mayor. El análisis de las condiciones atmosféricas demuestra que la intrusión de aire seco a lo largo del perfil vertical de la atmósfera inferior desempeñó un papel importante como inhibidor de la profundización.

ABSTRACT

The National Hurricane Center best track archive data for the northeastern Tropical Pacific includes tropical cyclones (TC) that exhibited rapid and/or explosive deepening during the period 1993-2009. Concurrently, satellite altimeter observations show the northeastern Tropical Pacific populated by cyclonic and anticyclonic oceanic eddies. These two sources of data are used to study the role of oceanic eddies in the spatial distribution of the oceanic heat content and the rapid and/or explosive deepening of TCs in the northeastern Tropical Pacific. Analysis of the results demonstrates that: (1) Interaction between TCs and anticyclonic eddies occurred in ~ 73% of the TCs within the analyzed period; (2) 90% of the TCs that reached major hurricane category had experienced an interaction with anticyclonic eddies; (3) ~ 18% (3%) of the TCs were characterized by rapid (explosive) deepening and 74% of these TCs reached the deepening status after direct and/or indirect interaction with anticyclonic eddies; moreover, 86% of them reached a major hurricane category. Analysis of the atmospheric conditions demonstrates the important role of dry air intrusion along the vertical profile of the lower atmosphere as an inhibitor of tropical cyclone deepening.

Keywords: Tropical cyclones, oceanic eddies, rapid deepening.

1. Introduction

The glossary of the National Weather Service of the National Oceanic and Atmospheric Administration (NOAA) (http://forecast.weather.gov/glossary.php) defines rapid deepening (RD) of a tropical cyclone (TC) as a decrease in its minimum sea-level pressure of 1.75 hPa/h or 42 hPa during 24 hours. Explosive deepening (ED) occurs in a cyclone when the central pressure decreases 2.5 hPa/h for at least 12 h or 5 hPa/h for at least 6 h. Such changes in the structure of a TC can be associated to large-scale atmospheric forcing (e.g., advection of moisture that may protect individual convective towers and/or reduction in the vertical shear of the horizontal wind, among others) and as recent studies have suggested, to mesoscale oceanic features.

While the oceans have been recognized as the energy source for hurricanes for more than half a century (Palmen, 1948; Fisher, 1958; Leipper, 1967; Perlroth, 1967), subsequent studies indicate that the maximum hurricane intensity was constrained by thermodynamic effects principally related to the sea surface temperature (SST) (Miller, 1958; Emanuel, 1986). More recent studies for hurricanes Katrina and Rita (Jaimes and Shay, 2009) showed that decreases of the sea-level pressure were better correlated with the large depth of the 26 ºC isotherm and the ocean heat content (OHC) than the SSTs, which were essentially uniform for those cases. The concept of OHC was originally defined by Leipper and Volgenau (1972).

Over the last decades, several studies have highlighted the interactions between ocean features and TC evolution in several cyclogenetic basins. During the 1995 North Atlantic tropical cyclone season, hurricane Opal (the most intense in that season) experienced a sudden and unpredicted intensification 24 h before its landfall. During the rapid deepening from 965 to 916 hPa over 14 h, Opal moved over an anticyclonic oceanic eddy that had been shed from the Loop Current in the Gulf of Mexico (Hong *et al.*, 2000). After the interaction with the eddy, the 1-min surface winds increased from 35 to more than 60 ms^{-1} and the radius of maximum winds decreased from 40 to 25 km (Shay *et al.*, 2000).

In the western North Pacific, supertyphoon Maemi (the most intense of the 2003 season) intensified (in 1-min sustained wind) from 41 to its peak of 77 ms^{-1} during its 36 h interaction with an anticyclonic oceanic eddy. Lin *et al.* (2005) demonstrated that the anticyclonic oceanic eddy acts as an effective insulator between the typhoon and the deeper ocean cold water, inhibiting the effect of the negative feedback (Chang and Anthes, 1978) between the ocean and the typhoon.

Hurricanes Katrina and Rita (the third and second most intense cyclones of the 2005 North Atlantic season) experienced rapid deepening during their respective encounter with an anticyclonic oceanic eddy in the Gulf of Mexico. Jaimes and Shay (2009) have studied these cases using a variety of datasets to evaluate the rapid increase in intensity observed during their respective passages over mesoscale oceanic features such as an anticyclonic oceanic eddy and the Loop Current. The authors conclude that in each case the observed decrease in central pressure correlated better with the depth of the 26 ºC isotherm and the OHC relative to this isotherm than with the SST.

The presence of oceanic eddies has a direct impact in the vertical structure of the near-surface oceanic layers, modifying the structure of the energy source for TCs. In the northern hemisphere, the anticyclonic horizontal flow of a geostrophically balanced eddy induces a secondary circulation directed towards the center of the gyre, producing a high pressure region in the surface, which also increases the depth of the thermocline. The result is a local pool with OHC higher than the surrounding waters. Such a local pool of high OHC could constitute a localized heat source to tropical cyclones. These warm features are characterized by isotherms displaced downward by several meters at the center of the eddy; in regions like the Gulf of Mexico, the depth of the 26 ºC isotherm can extend to more than 100 m, providing a continuous source of heat for tropical cyclones to intensify under favorable atmospheric conditions (Hong *et al.*, 2000; Shay *et al.*, 2000). Conversely, a geostrophically balanced eddy with cyclonic horizontal flow induces a secondary circulation directed towards the periphery of the gyre, producing a low-pressure region at the center of the gyre in the surface, which reduces the depth of the thermocline and generates a local pool with OHC lower than the surrounding environment. TCs interaction with cyclonic oceanic eddies can also have an impact by weakening their intensity, as it has been discussed by Jaimes and Shay (2009), but in this study we will solely focus on interactions with anticyclonic oceanic eddies.

Chelton *et al.* (2011) analyzed 16 years of sea-surface height (SSH) fields from satellite altimeters to investigate mesoscale variability in the global ocean, revealing that more than 50% of the variability is accounted for by westward-propagating nonlinear mesoscale eddies. Such mesoscale variability is due to linear Rossby waves and nonlinear eddies (Chelton *et al.*, 2007). In contrast to linear waves,

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