IMPACTS OF 2009 TYPHOONS ON SEAWATER PROPERTIES IN THE WESTERN NORTH PACIFIC OCEAN

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ABSTRACT

IMPACTS OF 2009 TYPHOONS ON SEAWATER PROPERTIES IN THE WESTERN NORTH PACIFIC OCEAN

This study focuses on the effects of typhoons on the amount of heat removed and seawater properties, mainly its temperature and salinity. A total of 15 typhoons occurred in the Western North Pacific in 2009, and ARGO floats data before and after the passage of each typhoon were obtained and analyzed to evaluate the changes on the affected areas. It was found out that sea surface temperature (SST) decreased after passage of each typhoon, with cooling ranging from 0.10 °C to 2.97 °C. Sea surface salinity (SSS) increased from 0.01 pss to 0.44 pss after passage of the typhoons. Amount of heat removed after individual typhoon's passing were also estimated, and it was observed that typhoon *Lupit* removed the most heat (841 MJ m^{-2}) while typhoon *Chan Hom* removed the least heat (30 MJ m^{-2}). It was also evident from this study that the ocean's structure (thermocline and halocline) changed after a typhoon had passed over the area. The depth of thermocline and halocline of the affected area deepened by 30.5 m and 29.4 m respectively after the passage of typhoon *Lupit*, mainly due to the increase of mixed layer depth of the ocean. A formulation for the relationship between the change of SST and SSS was also done in this study, and results showed that SSS changes based on the formulation are smaller in a consistent manner when compared to the actual SSS changes (from ARGO floats data). When typhoon's strength (expressed by its wind speed) and ΔSST, amount of heat removed, ΔSSS, change of thermocline as well as change of halocline were individually considered, all showed positive correlation with different coefficients: when typhoon's strength increases, higher changes on each are also observed. Although the life span of a typhoon over an area is relatively short, it has shown to bring positive impacts: as it is a natural heat removal mechanism, transferring of heat from the tropical waters to mid latitude waters will therefore maintain a moderate and suitable temperature for life; as well as increasing the rate of primary production in the ocean from turbulent mixing and upwelling caused by passing of the typhoons.

ABSTRAK

Kajian ini memfokuskan kepada kesan taufan terhadap jumlah haba yang dipindahkan daripada permukaan laut serta perubahan parameter air laut, terutamanya suhu dan saliniti. Secara keseluruhan, lima belas taufan telah berlaku di kawasan barat Lautan Pasifik Utara pada tahun 2009. Data daripada pelampung-pelampung ARGO sebelum dan selepas laluan setiap taufan telah diperolehi dan dianalisis untuk mengkaji perubahan di kawasan yang terlibat. Didapati suhu permukaan laut adalah lebih rendah selepas laluan setiap taufan, dengan penyejukan di antara 0.10 °C hingga 2.97 °C. Saliniti permukaan laut meningkat dalam julat 0.01 pss hingga 0.44 pss selepas laluan taufan. Jumlah haba yang dipindahkan oleh setiap taufan juga telah dianggarkan, di mana taufan Lupit telah mengeluarkan jumlah haba tertinggi (841 MJ m^{-2}) manakala taufan Chan Hom telah mengeluarkan jumlah haba terendah (30 MJ m^{-2}). Telah dibuktikan melalui kajian ini bahawa struktur lautan (termoklin dan haloklin) di kawasan yang terlibat berubah selepas laluan setiap taufan. Kedalaman termoklin dan haloklin di kawasan yang terlibat meningkat sebanyak 30.5 m dan 29.4 m masing-masing selepas laluan taufan Lupit, dan ini secara amnya adalah disebabkan oleh peningkatan kedalaman lapisan permukaan laut. Satu penggubalan formula untuk hubungan di antara perubahan suhu permukaan laut dan saliniti permukaan laut telah dilakukan, dan keputusan menunjukkan bahawa perubahan saliniti permukaan berdasarkan formula adalah lebih kecil nilainya secara setara jika dibandingkan dengan nilai sebenar (diperolehi daripada data pelampung-pelampung ARGO). Apabila kekuatan taufan (berdasarkan kelajuan angin) dibandingkan secara individu dengan perubahan suhu permukaan laut, jumlah haba yang dikeluarkan, perubahan saliniti permukaan laut, perubahan termoklin dan haloklin, kesemuanya menunjukkan hubungan kolerasi yang positif dengan pekali-pekali yang berbeza: apabila kelajuan angin taufan meningkat, perubahan untuk setiap faktor yang disebutkan juga meningkat. Walaupun jangka hayat setiap taufan di satu kawasan tertentu adalah singkat, ia telah terbukti bahawa taufan boleh membawa beberapa kesan positif: taufan adalah satu mekanisma pemindahan haba semulajadi, oleh itu haba dari kawasan tropikal akan dipindahkan ke kawasan perairan latitud tengah dan ini akan memastikan suhu yang sederhana dan sesuai untuk kehidupan dapat dikekalkan.

Selain itu, taufan juga akan meningkatkan kadar pengeluaran utama di lautan melalui pencampuran gelora dan pengalir atasan yang berlaku ketika laluan taufan.

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LIST OF ABBREVIATIONS

ARGO	Array of Regional Geostrophic Oceanography
CTI	Coral triangle initiative on coral reefs, fisheries and food security
FAQ	Frequently asked questions
GODAE	Global ocean data assimilation experiment
GOOS	Global ocean observing system
HYCOM	HYbrid coordinate ocean model
ILD	Isothermal layer depth
MLD	Mixed layer depth
SSS	Sea surface salinity
SST	Sea surface temperature

LIST OF SYMBOLS

Δ	Change
±	Plus minus
ρ	Average density of seawater

CHAPTER 1

INTRODUCTION

1.1 Introduction

In September 2009 alone, Philippines were hit by five typhoons (*Ketsana*, *Choi Wan*, *Koppu*, *Parma* and *Krovanh*), causing so much damage as they hit the nation within days of each other. In fact, 2009 Pacific typhoons season that hit Philippines were considered to have caused among the worst damages in decades. Throughout 2009, approximately 15 typhoons hit the nation, with the likes of *Ketsana* and *Parma* causing the most significant damages and biggest death tolls combined. Together, these two typhoons killed over 600 people and left more than US$ 300 million in damages. Typhoon *Ketsana* poured more than a month's worth of average rainfall on the capital of Philippines, Manila, as well as the surrounding areas in 24-hour period. This has caused about 80 percent of the city to be flooded and submerged, and have also caused more than 3000 houses to be either destroyed or damaged (CNNWorld, 2009). *Ketsana* resulted in the heaviest rainfall in Philippines in over 40 years. A week later, typhoon *Parma* crossed the northern tip of the already affected and storm-battered Philippines over the weekend, triggering landslides that killed at least 12 people, with more deaths reported later. *Parma* poured as much as 20 to 50 mm of rain in areas that was already affected and still flooded from typhoon *Ketsana* that hit during the previous week (CNNWorld, 2009).

When presented with these facts and reports, it is hard to imagine and relate anything else when the word typhoon is mentioned. Typhoons, as it is known in the Pacific region, are also known as tropical cyclones and hurricanes (in the Atlantic). Based on definition by Garrison (2005), a typhoon, by definition, is a vortex or circular storm that rotates counterclockwise in the Northern Hemisphere (clockwise in the Southern Hemisphere) that originates over tropical oceans, usually in period of late summer and early autumn. To categorize a storm as a typhoon, it must have a maximum sustained wind speed more than 120 km/h and may reach up to 250 km/h in very strong typhoons (Garrison, 2005). Just to show how powerful a typhoon can be, its energy, which originates from the latent heat of condensation, can be compared to more than 10,000 atomic bombs the size of bombs used in Nagasaki war. A typhoon's size can range from a few kilometers to several hundred kilometers in diameter (Moran *et al.*, 1994; Hidore and Oliver, 1993).

Typhoons occur only in certain regions of the ocean. According to Hidore and Oliver (1993), typhoons usually originate in tropical oceans between latitudes of 5° and 20° and generally forms over the western sides of the ocean. Areas or countries that are located along the equator are safe from typhoons as there is lack of Coriolis force that is needed for the formation of the typhoon. Major typhoons originating grounds includes: the western tropical North Pacific, South Indian Ocean east of Madagascar, North Indian Ocean including Arabian Sea and the Bay of Bengal, tropical waters adjacent to Australia, the Pacific Ocean west of Mexico and finally the tropical North Atlantic west of Africa including the Caribbean Sea and Gulf of Mexico (Moran *et al.*, 1994). Central and west of the Pacific Ocean experiences an average of 20 typhoons each year, with most occurring from June to October (JTWC, 2009).

1.2 Scientific outlook on the effects of typhoons

It is undeniable that typhoons have brought so many damages and grieves over the years. However, what many of us failed to see or understand is that despite all that typhoons can also brings positive impacts and benefits, for both human beings as well as the marine environment. Firstly, typhoon removes heat from the ocean naturally. As typhoons moves across the tropical waters toward mid latitudes region, large amount of heat are removed and transferred. This is important as the heat removed will lower the temperature of the tropical waters, and warming the mid latitudes waters which will lead to heat equilibrium of the world's ocean.

Typhoons also induce turbulent mixing of ocean waters. When this happens, temperature and salinity structure of the ocean is changed as the mixing will deepens the surface layer depth, cools the temperature of the surface layer (as cold, deeper water is brought up) and also changes the surface layer salinity. This processes (where cold, deeper water replaces the warm surface water) is known as upwelling. Upwelling is known to bring cold deep water rich with nutrients and phytoplankton to the surface layer of the ocean (Babin *et al.*, 2004 and Lin *et al.*, 2003). This enhanced nutrient level at the surface layer of the ocean will trigger more blooms, which will increase the rate of primary production that is a significant contributor in the marine food chain and ecosystem. With phytoplankton being a primary producer, these blooms will utilize large amount of carbon dioxide in the ocean (Garrison, 2005). When amount of carbon dioxide in the ocean is reduced, it will increase the ocean's ability to absorb carbon dioxide from the atmosphere. This chain reaction will indirectly contributes to the reduction of greenhouse gases in the atmosphere, as well as the reduction of global warming that is experienced throughout the world in recent times.

Passage of a typhoon will also change the salinity of the affected body of seawater (Gierach *et al.*, 2009). Typhoons require warm, moist air as its fuel. Latent heat provides the typhoon with energy, driving the typhoon's circulation. During this process, water is evaporated as water vapour (which will later condense into water droplets, releasing back the latent heat which originally evaporated the water). When water is evaporated, volume of water in that area will be reduced, but the quantity of salt in the seawater will remain unchanged. This unchanged amount of salt in the water with less volume will increase the salinity of that water.

This study aims to explain the effect of typhoons on sea water's properties and ocean's vertical structure after passage of a typhoon, and to calculate the amount of heat removed from the affected area. Formulation of relationship between sea surface temperature change and sea surface salinity change after passage of a typhoon will also be done, as well as to discuss the potential positive benefits of typhoons.

1.3 Objectives

The specific objectives of this study are:

1. To evaluate the effects of these tropical typhoons on the water properties (temperature and salinity)
2. To estimate the amount of heat energy removed from the study area after a typhoon passing
3. To formulate the relationship between the change of sea surface temperature (SST) and the subsequent change of sea surface salinity (SSS) after a typhoon
4. To calculate the changes of upper part of the ocean's structure such as isothermal layer, mixed layer depth (MLD), strength of thermocline $(\frac{\Delta T}{\Delta h})_{max}$ and halocline $(\frac{\Delta S}{\Delta h})_{max}$ and also their depths after passage of each typhoon
5. To highlight the benefits of typhoon in removing heat from the ocean and triggering primary production in the ocean

1.4 Hypotheses

The expected results or outcome of this study are:

i. Temperature and salinity structure of the upper ocean will have significant changes after the passage of a typhoon: sea surface temperature will decrease and sea surface salinity will increase
ii. Typhoon is a natural heat removing mechanism, and significant amount of heat energy will be removed after a typhoon has passed: stronger typhoons will remove more heat
iii. Calculated change in sea surface salinity (SSS) based on sea surface temperature (SST) will be smaller than the actual measured change of salinity obtained from the broad-scale global array of temperature and salinity profiling floats (known as ARGO) data

iv. Thermocline and halocline depths of the affected areas will change after the passage of a typhoon mainly because of change in isothermal layer and mixed layer depth

v. Primary production in the affected areas will increase after a typhoon had passed

1.5 Significance of study

Every research project is significant in one way or another to enhance the understanding in science. In this study, the significant features can be itemized as follows:

- Typhoon is a natural heat removal mechanism, and will transfer heat from the tropical waters to the mid latitude waters, therefore maintaining the moderate and suitable temperature for life.
- Amount of heat removed by all individual typhoons that occurred in 2009 will be estimated in this study, to realize the role of ocean and its energy.
- Turbulent mixing induced by passing of a typhoon causes deeper colder water to be mixed with the warm ocean water in the surface layer. When this happens, surface layer depth is deepened, sea surface temperature cools as heat is removed from the water and sea surface salinity is also changed.
- During turbulent mixing caused by passage of a typhoon, phytoplankton and nutrients from cold, deeper layer of the ocean are also brought up to the warm, upper mixed layer. Nutrients apart from availability of sunlight, aids the growth of phytoplankton. Therefore, input of nutrients from deeper water contributes to the increased rate of primary production in the ocean after the passage of a typhoon.
- Phytoplankton utilizes carbon dioxide in the water, and this in turn causes more carbon dioxide in the atmosphere to be absorbed into the water. This may contributes in reducing the amount of greenhouse gases in the atmosphere and warming of the Earth's global temperature.

- When all of the hypotheses have been proven and discussed, it is hoped to change the majority of the public's perception regarding typhoons: although it is undeniable that typhoons can be very damaging and have catastrophic effects, the public should also understand that they also have positive impacts on both the environment and human beings.

CHAPTER 2

LITERATURE REVIEW

2.1 Definitions of typhoons

The terms hurricane and typhoons are specific names for a strong tropical cyclone, based on the region it occurs. Large tropical cyclones are called hurricanes in the North Atlantic and eastern Pacific, typhoons in the western Pacific, tropical cyclones in the Indian Ocean and south Pacific and *willi-willis* in the waters near Australia (Garrison, 2005). To put it in short, typhoons (as it is known in areas west of the dateline), are also known as hurricanes (if it occurs east of the dateline) and tropical cyclone (if it occurs on the dateline). In meteorology, a typhoon is a storm system with a closed circulation around a centre of low pressure, fuelled by the heat released when moist air arises and condenses. It can also be defined as great masses of warm, humid, rotating air (Garrison, 2005). A typhoon can also be defined as a non-frontal synoptic scale low-pressure system over tropical or sub-tropical waters with organized convection, for example, a thunderstorm activity, and definite cyclonic surface wind circulation (NOAA, 2010).

Depending on their strength and location, there are various terms by which typhoons are known, such as tropical disturbance, tropical depression, tropical storm, hurricane and tropical cyclone. According to JTWC (2009), tropical disturbance is a discrete tropical weather system of organized convection. These convections usually are 200 to 600 km in diameter and originate in the tropics or subtropics. As explained by NHC (2010), tropical disturbance have a non-frontal migratory character, and maintains its characteristic for 24 hours or more, and may or may not be associated with a detectable perturbation of the wind field. Disturbances associated with perturbations in the wind field and progressing through the tropics from east to west are also known as easterly waves.

Typhoons with a maximum sustained surface winds (measured or estimated as the top speed sustained for one minute at 10 meters above the surface) that are less than 63 km/h are generally known as tropical depressions. Tropical depressions