HELMHOLTZ INSTABILITY IN OCEAN

Shigehisa Nakamura

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PREFACE

This work is aimed to find a key to the more advanced research work on the bases of the contributions which has been appeared referring to the Shirahama Oceanographic Tower.

This Oceanographic Tower was settled in 1960 off Shirahama in the Northwest Pacific by Professor Shoitiro Hayami after the Science Research Fund from the Ministry of Education.

The Tower was first aimed to contributed for obtaining scientific background for the social needs and for human activity. There have been many researches referring to the observed data at the fixed station offshore. Now, it is yet hard to get the data in-situ with the precise positioning of the survey line of the research ships and boats. We have had our efforts to designing a more effective instrumentation for obtaining a more reliable data which does not affected by drifting of the survey ships.

Now a days, the existing artificial satellites are operating under a precise positioning and a more accurate data with a finer precision and a resolution.

The author has been promoted his research work since the research project was started in 1960 when the offshore fixed tower was settled.

In the new stage of oceanographic research as in the part of geophysical researches, it is necessary to have a new insight at promoting our scientific research work.

At this stage, the author introduces his works in order to give a trigger to find a key to the more advanced research in the scope of the planetary and space instead of simple geophysics.

In this work, three topics are introduced for the author's convenience as seen in the list of the contents as found avoe.

Satellite monitoring in relation to Ekman transport and Kelvin-Helmholtz Waves in Ocean is introduced first. The author would note a brief review for the next step of our research.

Successively, Satellite monitoring of the ocean in relation to structure of the North Atlantic, is noted for the author's convenience, for finding a new key to promote our advanced research work. The ocean water motion should be densimetric balance under the effect of the earth's rotation. Adding to that, it should be reminded that the specific two factors of the ocean water determined the density. Compressibility is also one of the factors to specifying the ocean water in-situ. Then, a formulation of the ocean water motion must be discussed referring to the factors of salinity and water temperature with consideration of bathymetric condition.

What is essential to see interaction of the coastal waters and the oceanic waters, the author introduces a classic data in his modern scope for updating the historical works for these several hundred years with his consideration about the ocean history for more than several thouthand years.

The title is selected as seen the head. The author wishing you to find a key for your advanced research works in the new age.

2011 April 1

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CONTENTS

Satellite Monitoring in Relation to Ekman Transport and Kelvin-Helmholtz Waves in Ocean

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Abstract- Water motion in the upper layer of the ocean, there are two kinds of the water flows. These two flows are known as "geostrophic current" and as "Ekman transport" in the field of physical ocean science. In this work, an outline of these two flows is introduced in relation the existing satellite monitoring of the earth surface. A brief review note is given for helping a dynamical understanding of these historical backgrounds with the striking pattern found after the observation during the oceanographic expeditions in the early age of the ocean science. After a review of the two flows in the ocean, it might be found a key to introduce the existing satellite monitoring in order to promote research works on the motions of the ocean flows as inertia motion in a global scale with a polar orbital path.

1. INTRODUCTION

This work concerns a problem on satellite monitoring in relation to Ekman transport observed in the ocean. There are two kinds of ocean flows, i.e., the one is "geostrophic current", and the other is "Ekman transport". These two kinds of flows have been outside of the interest of the satellite monitoring. In this work, an outline of these two flows in the ocean are introduced first for helping a dynamical understanding of the flows in the historical backgrounds with the striking pattern found during the oceanographic expeditions in the early age of the ocean science. After a review of the two flows, it might be found a key to introduce the existing satellite monitoring techniques in order to promote research works on the motions of the ocean flows as inertia motion in a global scale with a polar orbital path.

2. FORMULATION

The equation of motion for the ocean water is expressed an equation of fluid motion on the rotating earth. Generally, the ocean water is compressible though an approximated solution can be obtained when the equation of fluid motion for an incompressible fluid.

In order to describe the ocean water motion bounded by the ocean surface and the ocean floor covering a part of the earth surface, a spherical co-ordinate system is usually introduced. As for a local problem, the equation of motion is referred to a local rectangular co-ordinate system for convenience.

In case of the ocean water flows, an ultimate brief expression must be written as follow for a steady state under a hydrostatic condition, that is (for example, [1]),

$$\rho\,[fv,\ -fu,\ -g] = [\partial p/\partial x,\ \partial p/\partial y,\ \partial p/\partial z]\,, \qquad (1)$$

where, velocity vector is $(u(x),\ v(y),\ w(z)) = (u,\ v,\ 0)$ for the fluid density ρ in a field of pressure p. The Coriolis parameter is expressed as $f=2\Omega\sin\phi$ for the interested latitude ϕ in the co-ordinate system of $(r,\ \theta,\ \phi)$.

For many cases of local ocean flow problem, the parameter f is taken as a constant only for the problem of the interested local area, for convenience. In some cases of numerical ocean modeling, the parameter is taken as a constant though mathematical singularity is at the equator, i.e., singularity at ϕ =0.

When time derivatives of $(u, v, 0)$, the above equation of motion is rewritten as many scientists have had expressed in their formulation, that is (for example, [2]),

$$[\partial u/\partial t,\ \partial v/\partial t] + f[-v,\ u] = (-1/\rho)[(\partial p'/\partial x + \partial X/\partial z),\ (\partial p'/\partial y + \partial Y/\partial z)]\ , \ldots(2)$$

where, the pressure p' and the stress [X(x, y, z; t), Y(x, y, z; t)] for geostrophic velocity, $[u, v]=[u_P+0, v_P+0]$. In the ocean, the interested layer is thick in the range of 10m to 100m).

3. EKMAN TRANSPORT

In any case of application for the actual ocean processes, the problem is not so simple to obtain the solution in any simple form, say, even in a case of any processes formulated in a linear equation. When the velocity vector is $(u, v, w)=(u_E, v_E, 0)$ only for $[X, Y]$, then, the problem for the equation (2) can be taken as the problem of the case for the velocity field $[u, v] = [u_p+u_E, v_P+v_E]$.

So that, we have Ekman's theory (1905) about the velocity in the boundary layer (for example, [3]) when $[u, v]=[0+u_E, 0+v_E]$. Gill has a brief note about this Ekman's theory in 1982 [2]. In a case of steady current field, the Ekman volume transport is directed at right angles to the surface stress when the integral about z of the velocity $[u_E, v_E]$ is obtained.

The author has had found that there are many works on the ocean currents assuming the condition of steady flow in a stratified ocean layer. This assumption must be proper when the approximation fit well to the interested flow field.

Nevertheless, the author has to notice here that the concept of the Ekman transport has had been used for researches on the ocean currents without any confirmation of the assumed conditions to be appropriate for the purpose. As Gill (1982) pointed out it [2], Ekman transport is used many times though there has had been left that the difficulty is left yet after the observational confirmation for the purpose.

4. INERTIA MOTION

As for a case of that the ocean is at rest and a wind stress in the x direction (i.e., a westery wind) suddenly rises and is maintained at a constant value $X=X_s$, the equation (2) can be rewritten as follows, that is,

$$(\partial/\partial t)(U_E + \mathrm{i}V_E) + \mathrm{i}f(U_E + \mathrm{i}V_E) = (X_s/\rho)\ \ldots\ldots(3)$$

where, $\mathrm{i}^2= -1$.

The solution of the equation (3) can easily obtained in a following form (for example, Gold in 1908 [2]).

$$U_E + \mathrm{i}V_E = -\mathrm{i}(X_S/\rho f)[1 - \exp(-\mathrm{i}ft)]\ \ldots\ldots(4)$$

At first, the Ekman transport is in the direction of the wind, but as time elapse the Coriolis effect causes it to veer (in the northern hemisphere). Finally, the transport is given by the sum of a steady Ekman transport at right angle to the wind plus an anticyclonic rotation with the same amplitude around inertial circles. For a particle moving with the average velocity for the layer, the result gives a cycloidal path as expected (for example, [2]).

One of the illustrations for the above cycloid trajectory is introduced by Sverdrup [4] and by Hidaka [5]. This is obtained as a rotating currents of period one-half pendulum day observed in Baltic and represented by a progressive vector diagram for the period, Augst 17 to August 24 in 1933, and by a central vector diagram between 6h and 20h on August 21 (according to Gustafson and Kullenberg) The measurements were undertaen between the coast of Sweden and the island of Gotland in a locality where the depth to the bottom was a little over 100m. On August 17 in 1933, when the measurements began, a well-defined stratification of the water was found. From the surface to a depth of about 24m the water had a nearly constant density, but between 24 and 30m a slow increase continued toward the bottom. The most striking example is shown in Figure 1.

The cycloidal trajectory pattern were confirmed by Pollard and Millard in 1970 [6], by Kundu in 1976 [7], and by Käse and Olbers in 1979 [8], after a modified equation is introduced. That is,

$$(\partial / \partial t)[U_E,\ V_E] - f[V_E,\ -U_E] = -r[U_E,\ V_E] + (1/\rho)[X_S,\ Y_S] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

where, the notation r is a decay constant (or Rayleigh friction). This form of friction was used Airy(1845) in his canal theory of tides.

The inertia motion in the above sections is for model of a ocean water layer in a range of 10m to 100m thick for 5 inertia cycles corresponding to 4 days [4]..

5. TURBULENCE AND KELVIN-HELMHOLTZ BILLOWS

Bell [9] introduced a model for seeing the decay of inertia oscillations in the mixed layer in 1978. Turbulent motions advected by the mixed-layer currents cause motions of the base of the mixed layer that radiate energy in the form of internal waves at a rate that gives $(1/r)$ of order 3 – 4 days. The layer also act as a significant source of internal waves with frequencies of order N and wave numbers of order NH_{MIX}/U_E, U_E/H_{MIX} being taken as a typical value of the current at the base of the mixed layer.

The presence of inertia oscillations in the mixed layer of the ocean represents also a possible source of mechanical energy that can be used to entrain water from below the mixed layer, they cause a large shear at the base of the mixed layer that can produce turbulent mixing in the form of turbulent Kelvin-Helmholtz billows such as those observed in the laboratory and in a lake by Thorpe in 1973 [10] and in 1977 [11].

6. PLANETARY INERTIA MOTION

Whipple [12] developed a theory of inertia motion of air particle in a planetary scale on the rotating earth of low latitude in 1917. Sasaki [13] had obtained seven solutions in a advanced model of inertia motion in a planetary scale. Shono [14] digested Sasaki model of inertia motion of air particles in 1954. Sasaki obtained an inertia motion on a polar orbital path in the solutions.

The author [15] presented a note on satellite thermal monitoring of ocean water front formation referring to satellite thermal monitoring of an intruding of Bering Sea water into the Arctic Sea in order to see a link of the ocean waters in the north Pacific, the Arctic Sea, and the north Atlantic. For this work, it was taken as reference when Perovich and Richter-Menge published the loss of sea ice in Arctic in 2009 [16].

Marzke's works ([17] and [18]) are effective references as much as those works appeared in Stommel's text [1] and Sverdrup's publication [4] for the author in this work. The other observation data obtained in the past were also taken as the author's references though no detail is noted in this work.

The author could not find any published materials which noted on inertia motion after Whipple [12] except the theoretical solution of inertia motion in a global scale solved by Sasaki [13]. So that, the author decided to introduce his dynamical understanding on the inertia motion with a global scale surely be existing. The author would not introduce many related physical processes obtained by the scientific observations. Nevertheless, no detail is described in this work for completing this work in a simple form.

7. CONCLUSIONS

A linealized equation of motion is analyzed in order to see the Ekman transport whether observable or not. This problem is closely related to inertia motion of ocean water. Some examples in the past are reviewed to realize a wind-induced inertia motion which can be reduced to form an illustration of trajectory which agrees well to the simplified theoretical model. A brief note is given for problem on mixed layer and for turbulent Kelvin-Helmholtz billows. It is stressed to note about an inertia motion of water particle with a polar orbital motion which could take part of a link of the north Pacific, the Arctic, and the north Atlantic. It may supported to consider a polar orbital inertia circulation of the ocean waters on the bases of the theoretical model and the satellite thermal monitoring of the ice front in the Arctic.

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Satellite Monitoring of the Ocean in Relation to Structure of the North Atlantic

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Abstract- Ocean front which can be monitored by the existing satellites, is a glimpse of the two water masses in the ocean. In this work, a basic problem about the ocean front in relation to the density of the ocean water. The typical ocean water motion is geostrophic under the effect of the earth's rotation. The ocean water is essentially stratified in densimetric stratification. The density of the ocean water is determined by salinity, temperature and depth under the ocean surface. In brief, the water is specified by a function of salinity, temperature and depth. For demonstrate the waters in the ocean surface layer, intermediate layer and deep water layer (abyssal layer). For the author's convenience, a special reference is taken for the structure of the North Atlantic.

1. INTRODUCTION

Ocean front which can be monitored by satellite, is a glimpse of the two water masses in the ocean. In order to realize ocean front evolution, it is essential to see about density of ocean water as a function of salinity, temperature and water depth. A special reference is taken for the structure of the North Atlantic, in this work, for the author's convenience.

2. EQUATION OF MOTION

Ocean front evolution is generally induced between the two ocean waters where the two kinds of ocean water motions are found on the one side and on the other side. This ocean front evolution can be monitored by the satellite.

The ocean front is on the ocean surface as a part of the interface of the two ocean water masses. Ocean water is specified by density as a function of salinity, temperature and water depth.

In the ocean, a forcing of F generates a motion of the ocean water mass m to move with an acceleration a, that is,

$$F = ma \quad \text{.......................................} (1)$$

When a corresponding displacement of the water is r, then, it can be written as follow,,

$$a = [d/dt(dr/dt)]\text{, and} \quad v = [dv/dt] \quad \text{for} \quad v = dr/dt\text{, ...} (2)$$

then, equation of motion for the mass ρ of an unit volume can be written as,

$$F = \rho\ (dv/dt)\ . \quad \text{.......................................} (3)$$

When the above ρ is taken as density as a function of salinity s, temperature t and depth D at a position r, then, the above equation is rewritten as,

$$F = [d(\rho v)dt]/dt \quad \text{for } \rho = \rho\,(s, t, D) \quad \text{.......................} (4)$$

Now, the above equation is rewritten as follows, that is.

$$F = \rho\, dv/dt + v\, d\rho/dt \quad \text{..........(5)}$$

As for a case of $d\rho/dt = 0$ (the condition of the mass conservation), the equation can be taken as the equation of motion for the ocean water with in terms of the pressure gradient, the effect of the earth's rotation, and the stress. Generally, the stress should be a tensor though it is assumed here a vector could be replaced for a convenience.

Many scientists have had reduced the solution for the equation of motion under some given conditions in space and in time.

Strictly, the equation of motion is a nonlinear equation. Nevertheless, there have been many kinds of solutions for the linear equation or for the nonlinear equation in an approximated expression. Some of them are expressed in a form of an asymptotic solution.

3. DOUBLE DIFFUSION EQUATION

The double diffusion equation for ρ (s, t; D), can be written as

$$d\rho/dt = \partial\rho/\partial t + v\nabla\rho = D, \text{ and } \quad D = -\nabla\rho + \nabla(\kappa\nabla\rho), \quad \text{..........(6)}$$

under some specific condition of the ocean water motions. Generally,, κ is a tensor nevertheless it is taken as a diffusion coefficient, for a convenience. The values of κ for s and for t are not same to each other. Diffusion of salinity is a process for simply saline contents nevertheless thermal diffusion is a process of fluid motion of a water mass as a heat carrier.

In the ocean, the water motions after the effect of viscosity, are so complicated that as if it were a dye-streak rather than a diffusion processes. The observed results during the ocean expeditions had been introduced first to note a specified ocean water masses, for example, Defant [1], Sverdrup et al.[2], and, Dietrich[3]. Although, the diffusion process modeling was developed by Taylor for describe a smoke in the atmospheric surface layer. The diffusion does not mean the molecular diffusion but the eddy diffusion or turbulent diffusion. Any one of the ocean waters is not isotropic and not uniform. Nevertheless, the concept of the eddy diffusion is convenient at discussing a macroscopic process in the ocean as well as in the atmospheric layer.

4. EQUATION FOR DENSITY

In the ocean, the water density is determined by salinity and temperatureeven in any case holding above diffusion equation.

When the ocean water in a conservative system, the equation for conservation of ρ can be written as, for example, in a rectangular co-ordinate system,

$$\partial\rho/\partial t + u[\partial\rho/\partial x] + v[\partial\rho/\partial y] + w[\partial\rho/\partial z] = A, \quad \text{..........(7)}$$

or, in a cylindrical co-ordinate system,

$$\partial\rho/\partial t + u[\partial\rho/\partial r] + (v/r)[\partial\rho/\partial\theta] + w[\partial\rho/\partial z] = A. \quad \text{..........(8)}$$

Referring to the above equation, several specific tendencies can be seen in a form of a mathematical expression.

(A) When any one of the velocity components is trivial to be possible to neglect, then,

$$\partial\rho/\partial t = A, \quad \text{..........(9)}$$

now, the solution is reduced to write as

ρ =Ao exp(pt), or, (ρ = Ao + A_1 t, as an approximation for small value of t).(10)

(B) When a very slow motion with a small horizontal speed (no radial component),

$(v/r)[\partial \rho / \partial \theta] = A$, ...(11)

then, the solution is writen as follows,

$\rho = \oint (A/v) r \, d\theta$, ...(12)

(C) When the motion is very slow vertical motion (no redial component),

$w(\partial \rho / \partial z) = A$, ...(13)

then, the solution is written as,

$\rho = \int (A/w) \, dz$, ...(14)

These three solutions might be helpful at considering the water motions just around an interface between the stratified water motion in a small column in the ocean.

When these cases are happened just in the ocean subsurface, the satellite might monitor the trends of the density variation pattern which can be specified boldly.

5. S-T DIAGRAM

In order to specific property of the ocean waters, it has been widely used a S-T diagram with a sigma-t in the field of oceanography. The sigma-t (σ t) is a parameter for an index of the density of the ocean water. This sigma-t is defined as the difference of the ocean water density and the fresh water density. This difference has a dependency of salinity and temperature. For a convenience, one of the illustrations is introduced in Figure 1 [2]. In Figure 1, no data were included for the surface layer between the ocean surface layer about 200m thick which is taken to be understood as a wind generated mixing layer[4].

Looking at the illustration in Figure 1, it is easily found that the following which has not clearly described by the ocean scientists. That is,

1) the Mediterranean out flow (G) spreads to form an intermediate layer in the sub-surface areas covering (E) to the north, (S) to the south and (M) to the mid ocean area. The intermediate water is well stratified stable layer between the surface layer and the deep layer with transitional layers as the interfaces between the surface layer and the intermediate layer, and between the intermediate layer and the deep layer.
2) The Mediterranean out flow must have been pooled for a long years (say, more than ten thousand years) to form the stable intermediate layer by the thermohaline exchange at meeting the water of the primitive North Atlantic ocean water.
3) The intermediate water must have a faint flow in a thermohaline stable balance.
4) In the interfaces, the diffusion coefficient of salinity can be taken to be proportional to the diffusion coefficient for temperature.
5) The Gulf Strean extension in the area at the south of Greenland © shows cooled well to form a stable stratification. This area is just neighbor of the over turn area of the Gulf Stream water [5]. Nevertheless, the S-T diagram tells us nothing about the water

transport at the over turn from the surface layer to the deep layer [2].

6) The origin of the Gulf Stream must be in the area (S). The track of the Gulf Stream can be along a line through the areas (W), (H), (g), and (C).
7) The Arctic surface water (P) has a contact with the Mediterranean water (E), though the diffusion coefficients of salinity and of temperature in the two interfaces are different from those in the areas (E), (G), and (S), but looks to be similar to that in the area (M) at the south of Iceland.
8) The deep water layers have a common thermohaline property in the S-T diagram. This shows that the strong effect of the Arctic Sea water (C) to the waters in the areas (E), (G), (S), (W), (H), (g), and (M). A water transport in the area of the over turn, meets to the Arctic Sea water (P) and (C) in the deep layer to form a kick of curve in the S-T diagram. This fact supports that the author's proposal of the meridional ocean inertia circulation in a global scale with a polar orbital path [6, 7, 8].

6. CONCLUSIONS

The ocean front evolution is a glimpse of the ocean water circulation in the satellite thermal monitoring. The author proposed a meridional ocean inertia circulation in a global scale with a polar orbital path. Reviewing the observed results obtained during the Expeditions in the early stage of the 1900s, and referring the Marzke's recent work about over turn of the Gulf Steram extension, the author found that both of the Expedition data and the Marzke's over turn teory support the existence of the meridional ocean inertia circulation in a global scale with a polar orbital path which had ever been reduced in a mathematical model.

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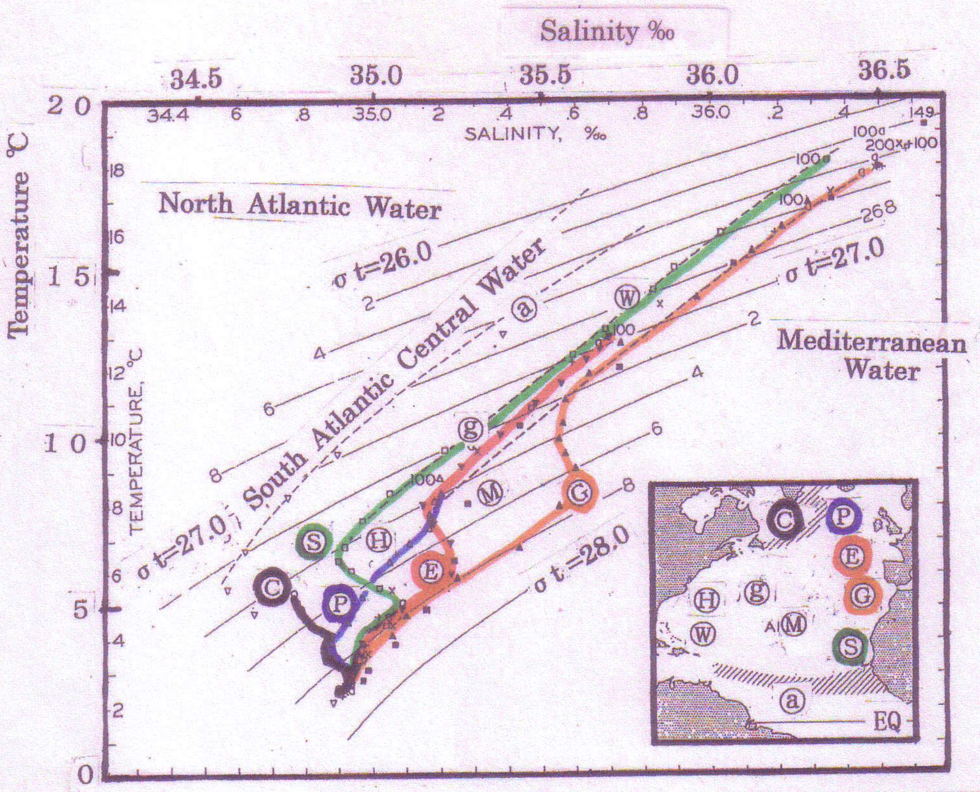

Figure 1 Double diffusion pattern of S-T diagram in the North Atlantic

1) Mark (G)-[Orange line] for Mediterranean water in Atlantic,
2) Mark (E)-[Red line] for water in the north area of Gibraltar,
3) Mark (S)-[Green line] for water in the south area of Gibraltar,
4) Mark (C)-[Black line] for water in the south area of Greenland,
5) Mark (P)-[Thin line] for water in the south area of Iceland.
6) The other marks- refer to the inset map.

[modified from Sverdrup et al., 1942]

MONITORING OF MEDDIES IN THE NORTH ATLANTIC

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Abstract- This work concerns on mid-ocean eddies in the North Atlantic. Eddies in the ocean are frequently found as a result of an undulation of the ocean front. The author notes about a meddy formed by contact of the Gulf Stream water and the Mediterranean water in the area around the Azores. Then, the author notices about the ocean front formed by the two water masses with his hydrodynamic understanding of problems.

1. Introduction

The author introduces a problems on mid-ocean eddies in the ocean. In the NW Pacific, the eddy formed after undulation of the ocean front in the ocean current extension of the Kuroshio as one of the western boundary intensified ocean currents. In the North Atlantic, researches and surveys related to the eddy, named as "mid-ocean eddy" were left to be continued beyond the year of 2000 for realizing the meddy in a scope of hydrodynamics.

First, a review note is introduced for a primary understanding what is eddy in the ocean. Then, an ocean front evolution is considered as a key to realize ocean eddy formation. In this case, the ocean front formed between the two waters in the North Atlantic, i.e., the water in the Gulf Stream extention and the Mediterranean water in the Atlantic.

Present status of the related reseach on meddy must be aimed to see whether the Gulf Stream crosses the Atlantic mid-ocean ridge and to find the interaction of the interested two waters in the ocean. Some remarks could be given for a more advanced research in the related fields to the oceanography.

2. Review Note

Eddy in the ocean had been found around the Japanese Islands in the NW Pacific in the early age of 1900s. Robinson [1] published his "Eddies in Marine Science" to show local scale eddies observed in the ocean and to notice "mid-ocean eddies" in relation to biological processes. He introduced Armi's preliminary hydrographic data report including transient tracers, which was appeared in 1981. Research papers on Meddy had been reported to descibe the physical pattern.

In the year of 2008, the author had a chance to know a project for ocean research with observation promoting by the University of Azores (the leader- Professor Anna Martine). The research group under the leader is working to see ocean pattern in the surface layer, covering the process of the meddies and of the ocean front, by using the survey ships and the satellite monitoring.

Marchuk has evaluated highly in 2008 by EGU for his long-time life work on the overturn process of the ocean water in the south of Greenland area.

3. Mediterranean Water Outflow into Atlantic

A shear flow field model is considered for helping our understanding of eddy evolution as shown in Figure 1(A). This can be taken as a simplified model of Gibraltar. When the Mediterranean water flows out into the Atlantic water, an ocean front is formed between the two waters, for example, as shown in Figure 1(B).

The front evolution can be detected by the satellite monitoring. The pattern of the front on the sea surface varies in time and space.

Hydrodynamics tells us that the pattern of the front on the sea surface can be a glimpse of the two waters contact in motion.

4. Salinity and Temperature

Sverdrup et al. [2] introduced a typical illustrations of the temperature and salinity vertical sections through the Gibraltar. These look to be illustrating a stable stratification of the North Atlantic water and the Mediterranean water nevertheless the budget of the Mediterranean Sea tells us that the inflow from the Atlantic is 1,750,000m^3/sec, and the outflow to the Atlantic is 1,680,000m^3/sec respectively. The minor factors are the budget of the Black Sea, precipitation and evaporation, and, runoff. The above budget is referred to Schott. In this case, the average velocity of the total inflow is evaluated to be ca 100 cm/sec (or 2 knot). For a convenience for our understand, the illustration of the oceanographic patterns of salinity, temperature along 36°N is shown in a modified form of G.Schott in 1942 referring to the figure introduced by Dietrich [3], that is, Figure 1. Looking at the Gibraltar in Figure 1, the flow of the upper layer (surface to 200m deep) is driven as a geostrophic tidal flow to and fro the Mediterranean, and, the flow of the lower (200m to 500m under the sea surface) is taken as a thermo-haline water motion.

In order to clarify the relation of salinity, temperature and density, the S-T diagam with a parameter of sigma-t (where, sigma-t=Dstx10^{-3}, for Dst=[sea water density minus fresh water density]), the S-T diagram is obtained by the author referring to the data obtained by this time on the bases of the oceanographic data obtained during the expedition in the early age of 1900s.

Looking at Figure 2, it can be seen that the water M flow out of the Mediteranean into the Atlantic to be modified as the water T in a shape of tongue. The upper part of the tongue is in an inversion state, so that a densimetric unstable condition is settled, though the lower part is in a ordinal and stable state.

On the upper surface of the tongue T, a physical processes of thermal energy exchange and of salinity potential adjustment though the saline exchange must be seen in order to form a stable state even after the intrusion of the water tongue. During the intrusion, the water M exchanges thermal energy and salinity for densimetric adjustment.

Some part of the upper surface water of the tongue T forms a small droplet by the buoyant effect caused by the density difference if the two waters above and under the surface of the tongue. The buoyancy make to accelerate to move the droplet up to the balanced state to intrude and mix up in the intermediate water in the Atlantic..

5. Conclusions

In a case of the Mediterranean water out flow into the Atlantic water, an ocean front is formed between the two waters. The ocean front can be monitored by the satellites though it is necessary to see three dimensional structures of salinity, temperature and density in a scope of hydrodynamics on the rotating earth.

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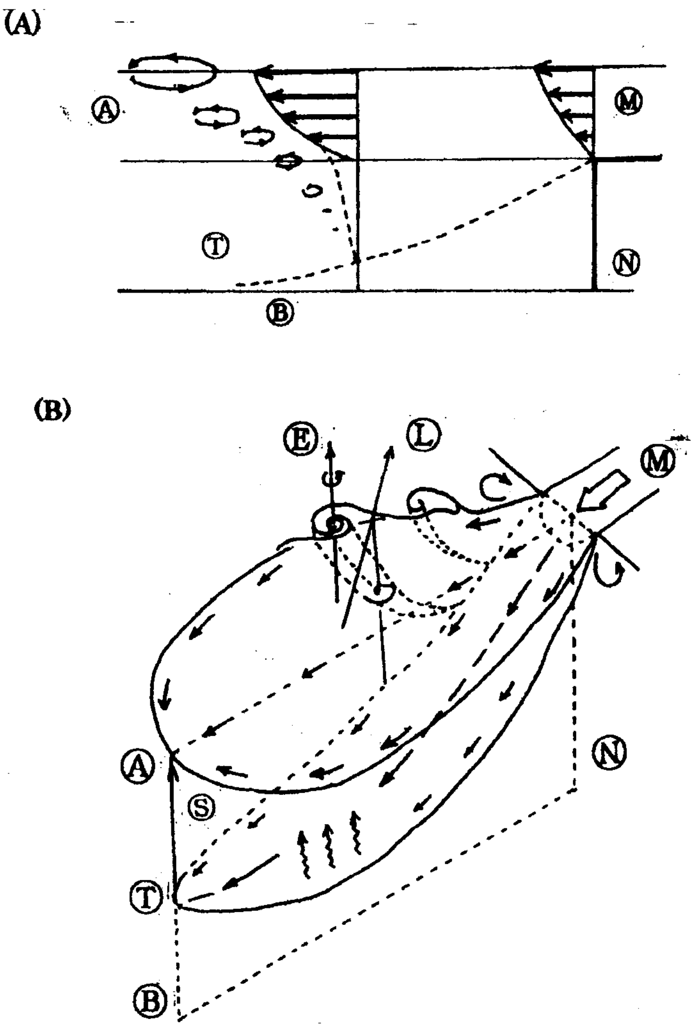
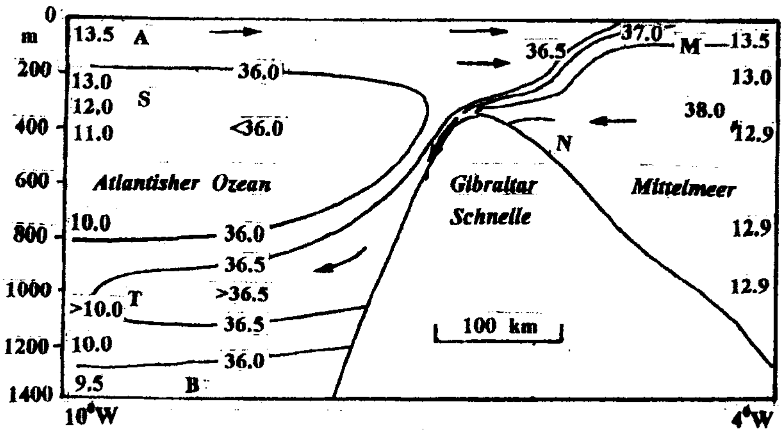


Figure 1 Schematic model for ocean eddy evolution

(A) Ocean eddy evolution in a shear flow field.
- (1) An outflow from M to A in the surface layer,
- (2) A dense down-flow from M to T in deep,
- (3) A tongue shaped interface between M and T,
- (4) A reference in deep at B and/or at N.

(B) A model structure of an ocean eddy in a field [cf. (A)].
- (1) An outflow from mark M to mark A,
- (2) A down-flow along mark M to mark T in deep,
- (3) A tongue shaped interface between M and T,
- (4) A reference in deep from B to N,
- (5) An intermediate water layer S between marks T and A,
- (6) A reference in deep for a horizontal line from B to N,
- (7) An eddy evolution found on the ocean front
  Formed between the outflow water M and the ocean water,
- (8) Mark L for a log line on the ocean surface for a eddy survey.

(A)



(B)

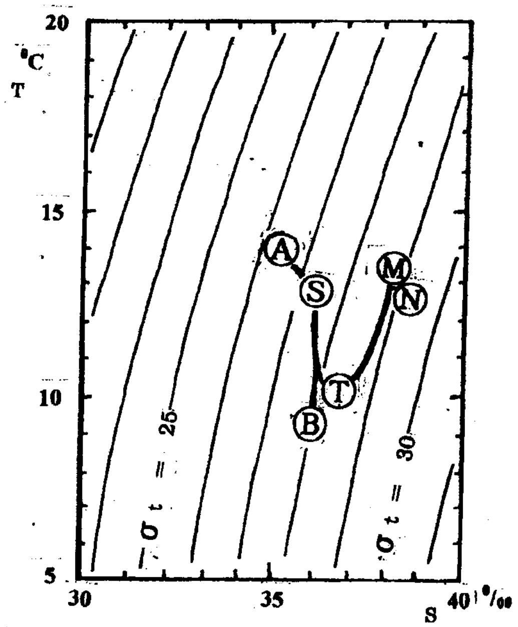


Figure 2 A shear flow field around the Gibraltar Strait.

[Refer to G.Schott(1942) and G.Dietrich(1957)]

(A) A vertical section between the Mediterranean Sea and the Atlantic,

(1) Marks for M, N, B, T, S, and A are corresponding to those found in Figure 1 (B),

(2) The Atlantic Ocean for the notated Atlantischer Ozean,

(3) The Mediterranean Sea for the notated Mittelmeer,

(4) The Gibraltar Strait for the notated Gibraltar Schnelle.

(B) S-T diagram.

(1) Notations S and T for Salinity and Temperature,

(2) A densimetric parameter sigma-t (σ t) is in the S-T diagram, where, sigma-t=[difference of density of ocean water and of fresh water]x10^3,

(3) Marks for M, N, T, B, S, and A should be referred to those in (A).

APPENDIX

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