POLAR ORBITAL OCEAN CIRCULATION

SHIGEHISA NAKAMURA

2009 MAY 1

PREFACE

This work concerns on a possible process found by the satellite thermal monitoring of the earth surface in a global scale.

In these years, the satellites for monitoring the earth has had launched for monitoring the earth surface process. Some of them are for practical application in public services.

In this work, the author concentrates his interest to a polar orbital ocean circulation. First, a glance of the recent information and trend of the research works in the field of geophysical aspects, especially, in the field of oceanography.

By this time, the human activity had been limited in the sea water zones facing the coastal zones in the recent half century. In the first half of the last century, the earth as a planet in the solar system had been a strong interest for the natural scientist. Nevertheless, the scientists seems to be forced to concentrate their contribution in the man-made processes found in the natural processes on the earth for these years.

The accumulated data and contributions by this time now a key for finding some processes which have been seen easily around the human activity.

One of the human interests is to see the natural processes in a descriptive aspect as a first step. Next to this, those interests might be concentrated in how to see what mechanism could be possible to appear the interested processes in nature. Human activity has been active to utilize the fruits of the scientific findings. Though they have to aware of what is their affects to the environments around the human activity.

Any one of the dynamical processes in nature could be formulated at present to realize in a scope of science. A solution of dynamic process might make us to see what is the nature on the earth.

At present, the satellites have been launched in order to monitor not only for the earth surface but the space outside of the earth. Now, we have to see what processes are seen on the earth as a planet.

For this purpose, the satellite data should be utilized after developing the advanced techniques, for example, applying electro magnetics. Such an application might lead us to see what is true processes on the earth.

In this work, a specific example of the research works is introduced for finding a key to consider the future of the human activity.

Lastly, the author has to notice that this research work was started as a scientific project in Kyoto University in 1960 after Professor Shoitiro Hayami as a geophysical scientist. He constructed the first offshore oceanographic tower in the Northwestern Pacific. This Tower has been contributive for helping not only the oceaograophic reseach but the other related research fields. This Tower is effective even at present.

Director (Retired), Sirahama Oceanographic Observatory
Kyoto University

2009 May 1

CONTENTS

ORIGINAL PAPERS

1. PHENOMENOLOGICAL ASPECT

OCEAN FRONT IN RELATION TO OVERTURN OF OCEAN CIRCULATION IN THE NORTH ATLANTIC

(This work lead to suggests that the most aged ocean water is in the deep sea of the Northwest Pacific, and a possible phenomenological pattern to show a Pacific-Antarctic-Atlantic Link)

1. PHENOMENOLOGICAL ASPECT
CEAN FRONT IN RELATION TO OVERTURN OF OCEAN CIRCULATION IN THE NORTH ATLANTIC

Abstract

This work is an extensive work of satellite thermal monitoring of ocean front evolution. The author has learned the recent contribution for the global ocean circulation. This lead to introduce a model is possible for the exhausted ocean water in a basin of the NW Pacific in relation to the down flows in the North Atlantic. This down flows surely an index of the ocean climate not only in the North Atlantic but in the Pacific. Then, an aging of the global circulation could be related to the ocean front evolution of the northwestern Pacific in a global scale. Several notices are given for the related ocean processes of ocean tides in the equatorial zone of the Pacific and of the ocean thermal leakage at the Bering Strait to the Arctic Sea It can be accepted an existing of a meridional link of Pacific-Arctic-Atlantic (PAA-Link) in the climate of the deep ocean circulation.

Introduction

A possible model of ocean front evolution in a global scale is studied in relation to ocean climate in the North Atlantic. This model could be a helpful on for realizing a ocean front evolution process directly monitored in the northwestern Pacific. The recent contributions on the three dimensional structure of the global ocean circulation is showing us that the ocean water in the surface layer is taken to be mainly governed by the meteorological effects on the sea surface, especially by the wind stress. Nevertheless, the scientists have found the thermohaline ocean circulation should be a more reasonable at considering on what was the actual ocean circulation system in the global scale. The deep water motions have been taken to be faint and maintain a quasi steady so that the deep water motion is affecting a negligible effect to the sea surface ocean water motion.

A recent oceanographic contribution has been obtained by the advanced instrumentations. The advanced instrumentations made us to see a more detail of the ocean structures. The launched satellites have given the data of the ocean surface but of the undersea state.

However, we have to see a three dimensional structure of the global ocean circulation now. At this time, it can be considered what interaction is between the surface layer and deep layer in the ocean.

The author here introduces a possible model for ocean front evolution monitored directly in relation to the deep ocean flow which is formed by the down flow in the North Atlantic.

Historical Data and Satellite Monitoring

In order to introduce the author's model, it is necessary to note that a possible model of ocean front evolution has to be studied in relation to ocean climate in the North Atlantic. For this, the satellite monitoring and the oceanographic observations are taken as the references.

The deutsche oceanographic expedition [1] must be the first scientific work, even though there might be a plenty knowledge obtained during the pioneer works by the sails for many years. A glance of the vertical pattern of the oceanographic factors had been seen after the expedition. Since then, they have undertaken various kinds of surveys by use of the ships or boats for finding the ocean structure. There have been many data sets of the oceanographic observations obtained for several hundred years. Even though, the data was in a form of discrete files so that a faint understanding of the systematic insight on the ocean was obtained (for example, Sverdrup et al.,1942[2] and, Dietrich, 1957[3]).

In these several ten years, the satellites have been launched to monitor the earth surface. The recent advanced system of the satellite monitoring informs us a more detailed finding. Nevertheless, the electromagnetic waves can only informs the sea surface state but what are undersea.

Combining these data sets obtained on the sea directly and the satellite data for these years, a bold understanding of the three dimensional understanding could be constructed.

What is found by analyses of the data has given an understanding not only on the sea surface pattern but the deep sea area. Then, we had the time to consider that it is possible to construct a three dimensional structure of the ocean circulation in a global scale.

Double Diffusion and Ocean Front

In order to see an ocean front evolution, it is necessary to remind what physical process is on the interested ocean front which is on the ocean surface though a subsurface interface between the coastal and ocean water is formed.

The ocean front and the ocean subsurface interface is formed by a different two waters as noted above. The two waters interact their motions each other so that equation of motion for the waters around the ocean front should be described as that is done for a densimeric water motion.

Equation of motion for each of the waters can be described as follows:

$$\partial u/\partial t + u\nabla u = -(g/\rho)\nabla h + \nabla[\mu \nabla u], \quad \cdots\cdots(1)$$

where, assumed field for the field of water velocity u under the water surface h in the frame of time t and an arbitrary space governed by the earth's gravity g for the water of density ρ of viscosity μ. The notation ∇ denotes special gradient. The numerals of ρ and μ for the coastal water and for the ocean water should be specified, for example, as those expressed in a given suffices. As for the coastal water, notation is $\rho = \rho_c$ and $\mu = \mu_c$, and as for the ocean water, $\rho = \rho_o$ and $\mu = \mu_o$ respectively.

In the ocean water and the coastal water, each density is not uniform though a macroscopic expression is used by several equivalent indices for a convenience instead of the exact material indices as those indices for specific water in a scope of basic physics.

As is already known, there are many kinds of the dissolved materials in the ocean water and the coastal water. Several dissolved materials are in a form of ions and the other are in a form of suspended fine particles. Even though, the water motion in the ocean is mainly determined the specific dissolved materials, i.e., the salinity. The others are indices for local specifying factors.

A more important factor is the water temperature which has closely related to the dependency of the water density.

Then, the water motion in the sea should be analyzed with a consideration of densimetric stratified fluid which is determined by temperature and salinity. That is to say, the density of the sea water is determined approximately the two factors noted above. So that, the density can be expressed as a function of temperature T (Kelvin) and salinity (unit per mille) S "in situ" in practice, for example, $\rho = \rho$ (S, T).

The bathymetric condition in the ocean is also an important factor at considering the deep water motion in a stratified layer. In this case, the density is determined by an additional depth factor because the compressibility of the ocean water is effective to see the vertical structure of the sea water. This means that the density of the sea water should be a function of temperature T, salinity S and water depth D (meter), i.e., $\rho = \rho$ (S, T, D).

The two factors T and S of the sea water, both of the coastal water and the ocean water, are diffusive property respectively. Then, a diffusion equation should be introduced at the analyses of the ocean water motion, especially around the ocean front.

It can be expressed the diffusion equation for the ocean water as follows:

$$[\partial T/\partial t,\ \partial S/\partial t] + u[\nabla T, \nabla S] = -[\nabla \kappa_T (\nabla T)\ ,\ \nabla \kappa_S(\nabla S)]. \quad \cdots\cdots\cdots\cdots\cdots(2)$$

where, the notation κ is diffusion parameter with suffices T and S for temperature and salinity respectively.

Diffusion of thermal energy is not to be diffusion of salinity, so that the numeral index of κ for T is not same to that for S. This salinity is a simplified form of the index used widely in the field of oceanography. Exactly, the sea water is a solution of many solvents essentially though the symbolic index S may be useful at extending the formulation of the diffusion process as well as the other physical, chemical or biological process. In these years, a more convenient index is introduced for biological processes in the ocean after defining index for concentration of Chlorophill-a as a representative of the other minor factors. Optical satellite monitoring and remote sensing have been cast for these several ten years in order to find a biological process in relation to a dynamics of ocean flow.

Down Flow of Ocean Water

As is well understood, the meridional ocean circulation system is effective to see the global ocean circulation as a three dimensional process, even though it is yet primitive. This process could be possible to consider the two layers of the ocean, i.e., the surface layer and the deep layer with the down flows surface to the deep in Labrador Sea and Nordic Sea.

In the ocean water circulation updated, the deep water flow is formed by the ocean water of the down flow in the North Atlantic. There might be a key of several minor down flows just around the Antarctic coastal zones (for example, Kuhlbrot et al.[4]). Marotzke[5, 6] has already noted on "the Atlantic Meridional Overturning Circulation" in 1991 and 1997.

The down flow in the North Atlantic forms a deep water flow along the western part of the Atlantic to get to the circum polar deep flow which direct to east to form a upwelling in the Indian Ocean, and direct to more east to intrude into the South Pacific.

In the South Pacific, an upwelling off Peru contributes the surface flow to the west. This flow in the tropical zone strongly affects to the ocean climate in the northwestern Pacific.

A branch of the circum polar deep flow passing off the south of Australia and New Zealand, crosses the equator to get to the Philippines Basin to be stored as an exhausted water. This water might be the most aged ocean water in the world. Amount of this storage must be increase to raise the sea level in the Basin.

It must be possible to see what age is the oldest deep ocean water in the Basin if the sampling could be successful or a remote sensing of the radio-isotopic monitoring for a specific element. For example, the natural radio-isotope of K might be a good index because its decay time is 1.277 x 10^9 year for ^{40}K (β^-decay, electron capture, or β^+decay). In this case, the reference should be ^{39}K found in natural condition in the deep sea water.

Aged Deep Water Effect to Ocean Front Evolution

As noted above, the down flow in the North Atlantic suggesting to get to the Philippine Basin of the northwestern Pacific through the Southern Circum Polar Current. Some of the recent reports tell us that the oldest water has been found in the deep sea of the Philippine Basin after aging of the dissolved oxygen. The water from the North Atlantic might have got to the Basin after dissipating the original dissolved oxygen. This oldest ocean water might increase and be stored there to raise the sea level of the Basin in a long year period. The author here considers that this water in the tropical zone forms a stable deep layer to swell up the sea surface and to raise the sea level in the tropical zone. This could affect the ocean front evolution in the northwestern Pacific which had been monitored well by the recent satellites. This effect of the oldest deep sea water to the ocean front evolution might be found in a spacial undulation and in a timely variation.

With our knowledge on the potential of the water motion on the earth, increase of the old water in the northwestern Pacific can be effective to spread the surface ocean water to intensify degree of convergence on the ocean front to result an ocean front evolution activated around the spreading water mass. This might be a cause of no intermediate eddies in the offshore side of the ocean front in the northwestern Pacific. Nevertheless, the details to this process must be clarified by utilizing a more advanced instrumentation and a more advanced numerical model in near future.

As it has been well understood, the ocean front evolution process in the northwestern Pacific is not so simple in spacial undulation of its pattern and in timely variations of its form as seen on the sea surface.

Considering some other factors possibly related to the ocean front evolution, one of the factors controlling the ocean front evolution process in a long time scale than the age of the oldest water could be the deep water mass transported from the Atlantic.

Then, the author tends to introduce a conceptual model on the basis of what stated as above. This model is now a hypothetical one but realistic when the data of the sea level and ocean surface flow obtained for these one hundred years and the satellite monitoring of the ocean front evolution.

The author here feels it necessary to notice that any numerical model can not give us any answer to the interested process of the ocean front evolution because numerical computation is an approximated technique for a related dynamical theory but a solution of a theory which is constructed on the bases of the dynamical background. Numerical processing for an interested process is simply a replaced approximation in a manipulation technique as that the numerical model gives a realistic solution equivalent to the actual ocean processes.

An expression of differential equation is formed in a dynamical background with an assumption and under some specifying conditions. Generally, this equation is in a form of nonlinear. A linear equation has been used for an approximated form in convenience. It is only for some restrict case that the exact solution can be obtained for the nonlinear case of the equation. Mathematical techniques does not necessarily promise an exact solution for the interested differential equation constructed on the bases of dynamics.

At present, the author feels that it forces an introduction of numerical model in convenience for his display of the possible ocean front evolution as a result of the effect of the old water swelling in the Philippines Basin.

In near future, an advanced mathematical technique might be an effective for the purpose of the problem introduced in this work.

On the other hand, the other advanced remote sensing techniques might be developed well for realizing what process is fact even when a-model is solved mathematically.

Recently, in the early stage of the year of 2008, the 21st century, the EU project of the JASON-2 mission is started for the expected earth surface monitoring.

What is important here is to see what process is actually effective at considering the mechanism of the ocean front evolution in relation to the ocean climate in the North Atlantic.

Effects of Ocean Tides

Considering the global ocean circulation, some of the scientists are anxious to evaluate water mass transport across the equatorial zone to the other hemisphere. This problem might be rather minor problem in the global ocean circulation. As we have had learned already by this time, it is clear that the ocean tides might be little contributive factors only for energy exchange of the ocean water masses in the northern and southern hemisphere. Several straits around the islands of Indonesia and Papua New Guinea are in the equatorial zone of the western Pacific. These straits are connecting several basins with sea area of about 4000 meters, so that it is hard to consider any significant water mass exchange and mixing in the sea area in the equatorial zone. Nevertheless, the author feels it unfortunate that there is no up-dated data but a poor data of ocean observation in the interested equatorial zone even at present.

There has been introduced a concept of "tidal residual current" for a problem on coastal processes but "tidal residual sea level" in the last quarter of the twenty century. This concept is not consistent to the phenomena of periodic tides found not only in the ocean but in the atmosphere and on the earth.

The author has understanding of that the tidal residual current is simply defined as that for convenience of a issue to a citizen notice to describe the water mass displacement in a coastal zone in 24hours. Hence, this "residual" does not have any dynamical meaning.

Essentially, the ocean tides are consists many constituents of solar and lunar tides. The ocean tides are a resultant process of these constituents so that the ocean tide process is a resultant process of the corresponding periodical processes essentially.

Bering Sea and Arctic Sea

Adding to the above, the author has to notice about a thermohaline leakage of the Bering Sea to the Arctic Sea through the Bering Straight. This must be the most contributive process for the September sea ice extent change in the Arctic Sea as a natural process.

What the author noticed above could be understood looking at a satellite thermal pattern of the sea surface around the Bering Strait, even though the pattern must be a resolution of around a 5km or 10km scale in a period of September ice extent in the Arctic Sea. The pattern on the sea surface shows a thermal tongue which is suggesting that the sea water in the Bering Sea is intruding into the Arctic Sea through the Bering Sea. The pattern is composed by a data set of a satellite thermal monitoring of the sea surface after a data which was processed for making a global satellite thermal pattern on the sea surface in a resolution of a 5km or 10 km scale. This satellite thermal pattern tells us that a leakage of the Bering Sea water into the Arctic Sea at least in September every year.

The above global satellite thermal pattern forces to aware of us that the satellite thermal monitoring informing an intrusion of the Bering Sea linked to the Pacific into the Arctic Sea through the Bering Strait. When the open sea is found in the Arctic Sea, the surface water is easily controlled by an atmospheric effect in a form of wind dynamical action or by a thermal effect in a form of cooling on the sea surface just around a local area of the Arctic Sea where the Bering Sea.

Then, the sea surface of the Arctic Sea could easily get to the North Atlantic. When the ice sheet is covering the surface water of the Arctic Sea, the ice sheet acts as a isolator of any atmospheric cooling during the cold season. This might make it possible to aintain a water leakage of the Bering Sea into the Arctic Sea.

This means that the global satellite monitoring has given a linkage of the sea waters of the down flow of cold sea water to form a deep current in the North Atlantic flowing as a Antarctic circum current in the deep layer, and a part of this Antarctic circum current might turn to get to a terminal in a deeper layer of the northwestern Pacific. A compiling water of this deeper layer could be a trigger to raise the sea level of the interested area in the Pacific, to affect for the ocean front evolution, and to affect for the water motion in the Bering Sea. This linkage must be not so strong at comparing to that of the circum-polar current induced by the atmospheric effects in the surface layer around the Antarctic Sea. This can be named as a meridional link of Pacific-Arctic-Atlantic (in short, as "PAA-Link")

Then, it can be understood that two kinds of ocean current circulation is existing in a global scope. This fact has been found by the satellite monitoring of the sea surface thermal pattern since the first satellite mission of the earth surface.

Next step of the satellite thermal monitoring of the sea surface might be to see its evolution for a long tome period in a global scale.

Since 1990s, it has been raised that a consistent trend of the man-made activity may be the decrease the September sea ice extent in the Arctic Sea as noted in the period between

1900 to 2100, for example, by Stroeve et al.[7] in Geophysical Research Letters (Vol.34,2007). This is introduced in the publication by Carlson and Giorannoni [8].

Nevertheless, the author has to notice here that the global processes have the history of about 4500,000,000 years though the significant man-made processes have been raised their attentions for these several ten years. We have to be careful at considering the future of the global processes with consideration in a proper time scale.

Conclusions

The author introduced a problem of ocean front evolution in relation to the ocean climate in the North Atlantic where the down flow of the ocean water of the surface layer moving to the deep layer to form a vertical circulation in the global ocean.

Referring to see what is found in a satellite thermal monitoring of global ocean circulation after the author's work for updating the global ocean surface thermal pattern, it can be accepted an existence of a meridional link of Pacific-Arctic-Atlantic

The EU project of the JASON-2 mission and the other operating satellites are surely effective for advanced works in the following hundreds years in relation to processes introduced by the author as noted as above.

The author wishes to have an advanced mathematical technique for solving the equation in order to realize much more about the ocean front evolution in a scope of dynamics.

An advance in the remote sensing techniques is also expected in near future for promoting the interested problem to realize what should be the actual process in the global ocean circulation.

References

[1]Wust,G.G., Bohnecke und H.H.F.Meyer 1932 Ozeanographische Methoden und Instrumente, Wissenschaft Ergebniss der Deutsche Atlatische Expedition "Meteor" 1925-1927, Vol.4, No.1, Berlin, 1932.

[2]Sverdrup,H.U., M.W.Johnson, and R.H.Fleming 1942 The Oceans, Prntice-Hall,Inc., Englewood Cliffs, N.J., 1087p.

[3]Dietrich,G. 1957 Allgemeine Meereskunde, Gebruder Borntraeger, Berlin, 492p.

[4]Kuhlbrot,T., A.Greisel, M.Montoya, A.Levermann, M.Hofmann, and S.Rahmstorf 2007 On the driving processes of the Atlantic meridional overturn circulation, Reviews of Geophysics, Vol.45, RG2001, doi 10.1029/2004RG000166, pp.1-32.

[5]Marotzke,J. 1997 Boundary mixing and the dynamics of the three-dimensional thermohaline circulation, Journal oof Physical Oceanography, Vol.27, pp.1713-1728

[6]Marotzke,J. and J.Willebrand 1991 Multiple equilibria of global thermohaline circulation, Journal of Physical Oceanography, Vol.21, pp.1372-1385.

[7]Stroeve,J., Holland,M.M., Meiner,W., Scarbros,T., and Serreze,M.. 2007 Arctic Sea ice decrease: greater than forecast, Geophysical Research Letter, Vol.34, L09591.

[8]Carlson,C.A., and S.J.Giorannoni 2009 Annual Review of Marine Science, Vol.1, 466p.

2. DYNAMICAL ASPECT

OCEAN FRONT IN THE NORTHWEST PACIFIC AND BERING SEA WATER INTRUDING INTO THE ATLANTIC SEA

(This work is concentrated to an interest to introduce a linealized dynamical model in order to see that one of the solutions shows an inertia motion of ocean water after reviewing the specific oceanographic and geophysical contributions)

2. DYNAMICAL ASPECT
OCEAN FRONT IN THE NORTHWEST PACIFIC AND BERING SEA WATER INTRUDING INTO THE ANTARCTIC SEA

S. Nakamura
Kyoto University, Kyoto, Japan

Abstract

In this work, the author introduces a simplified model for a dynamical understanding of the intruding Bering Sea water to form an ocean thermal front in the Arctic Sea. First, some notes are given about the recent reports of the phenomenological processes around the Bering Strait, the Bering Sea and the Arctic Sea. Referring to what is our knowledge on the ocean front formation in the area of the Arctic zone, a dynamical illustration is introduced for having a key to see what part is caused by the natural process and what is the way to distinguish the ma-made effect out of the information in the satellite thermal monitoring.

Introduction

The author introduces a simplified model for a dynamical understanding of the intruding Bering Sea water to form an ocean thermal front in the Arctic Sea For a convenience, recent reported contents are introduced to see what processes are found in these ten years. Then, a recent work on the global ocean circulation is introduce in order to help at considering on the Bering Sea water intrusion into the Arctic Sea on the bases of the satellite thermal monitoring for not only seeing the natural process but distinguishing the man-made disturbances in the global process of the ocean circulation. A model might help us to have a dynamical understanding of the intrusion in the interested sea area.

Update Information of Antarctic

The author has had several reports on satellite thermal monitoring of ocean front evolution in a mid latitude zone. It was the site of the Northwest Pacific so that satellite thermal mentoring had been undertaken after directly receiving the satellite signal and processing the signal for obtaining a series of the ocean front evolution by utilizing a desk top personal computer. What is the point must be that the ocean thermal front can be found as a maximum of thermal gradient on the sea surface in the obtained pattern after processing the satellite data.

In this work, an example of ocean front in the Arctic Sea formed by an intrusion of the Bering Sea water. This intrusion might have been appeared many times in some other scientific publications. For example, Shimada et al. [1] in 2006 noticed on the Pacific Ocean inflow as an effective factor for influence on catastrophic reduction of sea ice cover. Stroeve et al. [2] in 2007 have noted on the Arctic Sea ice decrease, that was greater than forecast. Stroeve et al. [3] in 2008 noted about Arctic sea ice content plummets in the year of 2007. Gasaard et al. [4] in 2008 noted the Arctic trans-polar drift during dramatic sea ice retreat. These notes on phenomenological process seem to suggest the author to promote a research on the specific process in the Antarctic Sea in a scope of hydrodynamics.

Global Ocean Circulation

The author found in this time a review on the driving processes of the Atlantic meridional overturn circulation [5] by Kuhlbrot et al. This should be evaluated after finding the contributions by Marotzke and Willebrand [6] and Marotzke [7]. These works are descriptive works that notices simply on the phenomenological process in fact.

Nevertheless, what they have written were invaluable at understanding what processes are found in fact in the area covering not only the Atlantic but the ocean area of a world-wide scale.

Now, the author is tending to consider the ocean front formed by the intruding Bering Sea in the Antarctic in a global scale.

Link of the Pacific-Antarctic-Atlantic

Referring to the reports introduced as above and the information about satellite thermal monitoring of the ocean surface in a global scale, the author produced a modified map of the deep ocean water circulation as found in Figure 1.

In Figure 1, arrows indicate deep ocean water circulation with a starting point just off the Newfoundland (blue colored arrows), and the red mark corresponds to the ocean front formed by the Bering Sea water intrusion into the Arctic Sea.

It is already found a recent trend of the September sea ice extent in the Arctic Sea [8]. In the cold season in every year, the Arctic sea surface area is covered by the frozen sea ice. Sea ice of one year might melt away in every summer season but old sea ice group maintain to cover the sea surface of the Arctic Sea. At the bottom of the old sea ice, salt trapped in the ice is squeezed with time elapse. When the cold wind blows on the sea surface opened in the worm season, the sea surface is easily cooled down to be a higher density of sea water. In addition, the sea ice contains salts as named it in tem of "**brine**". This sea ice tends to squeeze out the salts of the ice content. Then, the salinity of the sea water just under the old sea ice tends to be dense, and the sea ice tends to be an ice of more purified frozen water with less salt contents. These processes in the Arctic Sea might be one of the important factors to determine the salinity and temperature of the waters in the surface layer in the Arctic Sea.

A Dynamical Model

As for the upper layer of the ocean, the wind-induced current system is understood to be actual pattern in fact. In the ages of Ekman [9], the Coriolis parameter $f=2\omega\sin\phi$ was assumed to be a constant. Henry Stommel [10] and Munk [11] introduced a f-plane model for the westward intensification of wind-driven ocean currents.

As for thermohaline circulation, a mathematical model was hard to construct for a long time, though some of the scientists have had challenged to have a mathematical solution as an approximated solution.

Now, the author has to introduce several contributions in the field of meteorology. Shono

[12] had given us his lecture about horizontal inertia motion not only for a local air mass of a small scale but also for a global process in a large scale. As for the motion in the tropical zone was analyzed by Whipple in 1917 (published in Philosophical Magazine, Vol.33, pp.457-471). In 1950, Sasaki analyzed a more general form of the aimed solution for inertia motion in a global scale which was reduced under the conditions of conservation of kinetic energy and conservation of absolute angular momentum for a case of no atmospheric pressure gradient (published in Geophysical Notes, Tokyo University, Vol.3, No.32). In the author's present work, this could be read as that is, "of no sea water pressure gradient".

After Sasaki's solution, the author may notice that the expected orbit of the water mass is determined by the several factors under some assumptions. The author here introduces only one example of a polar orbital motion as a circulation as shown in Figure 2.

A simple hydrodynamic model is introduced to show that horizontal inertia motion of the sea water is on a polar orbital path. This polar orbital motion seems boldly supporting a link of the deep sea water flow from the Atlantic to Arctic through Pacific.

With what about noticed above, the author tends to consider it to be expected an existence of a link between the Pacific, the Bering Sea, the Arctic Sea and the Atlantic.

Then, the global ocean circulation may be formed by the wind-induced ocean current in the upper layer, the southern circumpolar current, the deep sea water flow starting at an cold area in the North Atlantic to get to the mid of the Pacific after flowing south of the deep of the Indian Ocean and off the Australia.

There are left many problems to be solved successively after introducing any new techniques.

At the same time, a time series should be considered for satellite thermal monitoring in order to see the long term variations and in order to find a proper forecasting system of the global ocean circulation as a total.

Conclusions

The author introduced first a brief review note for the satellite thermal monitoring of the intruding Bering Sea water as a key to formation of an ocean front in the Arctic Sea.

The open sea area of the Arctic Sea in summer is easily affected by the cooling effect caused by the atmospheric winds. In addition, the young sea ice melts in every year to make an open sea and the old ice grows to cover the sea surface of the Arctic Sea. This ice cover is effective as a thermal isolator for the sea water under the old ice pack. The old sea ice shows to affect the ice of quality to be more purified as squeezing the trapped salt in the ice. The squeezed salt go down to diffuse into the sea water. These effects control the density and temperature of the sea water under the ice cover in the Arctic Sea.

A simple hydrodynamic model is introduced to show that the horizontal inertia motion of the sea water is on a polar orbital path. This polar orbital motion is boldly similar to the deep sea water flow in the ocean.

With the above notices, the author tends to consider it to be expected an existence of a link between the Pacific, the Bering Sea, the Arctic Sea and the Atlantic.

References

[1]Shimada,K.,T.Kamoshima,M.Itoh,S.Nishino,E.Carmack,F.McLaughlin,S.Zimmermann, and A.Prognutinsky 2006 Pacific ocean inflow: Influence on catastrophe reduction of sea ice cover in the Arctic Ocean, Geophysical Research Letters, Vol.33, L08605, doi: 10.1029/2005GL025624.

[2]Stroeve,S., M.Sereze, S.Drobot, S.Gearheard, M.Holland, J.Maslanik, W.Mehler, and T.Scambos 2008 Arctic Sea ice content plummets in 2007, EOS, Transaction of American Geophysical Union, Vol.89, No.2, p.13-14.

[3]Stroeve,J., Holland,M.M., Meiner,W. Scarbros,T., and Serreze:M. 2007 Arctic Sea ice decrease: greater than forecast, Geophysical Research Letters, Vol.34, L09591.

[4]Gasaard,J.C., et al. 2008 ExploringArctic trans-polar drift during dramatic sea ice retreat, EOS, Transaction of American Geophysical Union, Vol.89, No.3, pp.21-22.

[5]Kuhlbrot,T., Greisel,A., Montoya,M., Levermann,A., Hoffmann,M., and S.Rahmstorf 2007 On the driving processes of the Atlantic meridonal overturn ciculation, Reviews of Geophysics, Vol.45, RG2001, doi:10.1029/2004RG000166, pp.1-32.

[6]Marzke,J., and J.Willebrand 1991 Multiple equibria of global thermohaline circulation, Journal of Physical Oceanography, Vol.21, pp.1372-1385.

[7]Marzke,J. 1997 Boundary mixing and the dynamics of the three-dimensional thermohaline circulation, Journal of Physical Oceanography, Vol.21, pp.1372-1385.

[8]Perovich,D.K., and J.A.Richter-Menge 2009 Loss of Sea Ice in the Arctic, Annual Review of Marine Sciences 2009, Vol.1, pp.417-441.

[9]Ekman,V.W. on the influence of the earth's rotation on ocean-currents, Arkiv fur Mathematik, Astronomy och Fysik, Bund.2, No.11, Stockholm, 53p.

[10]Stommel,H. 1948 The westward intensification of wind-driven ocean currents, Transaction of American Geophysical Union, Vol.29, pp.202-206.

[11]Munk,W.H. 1950 On the wind-riven ocan circulation, Journal of Meteorology, Vol.7, pp.79-93.

[12]Shono,S. 1954 Introduction to Meteorological Dynamics, Iwanami, Tokyo, 425p.

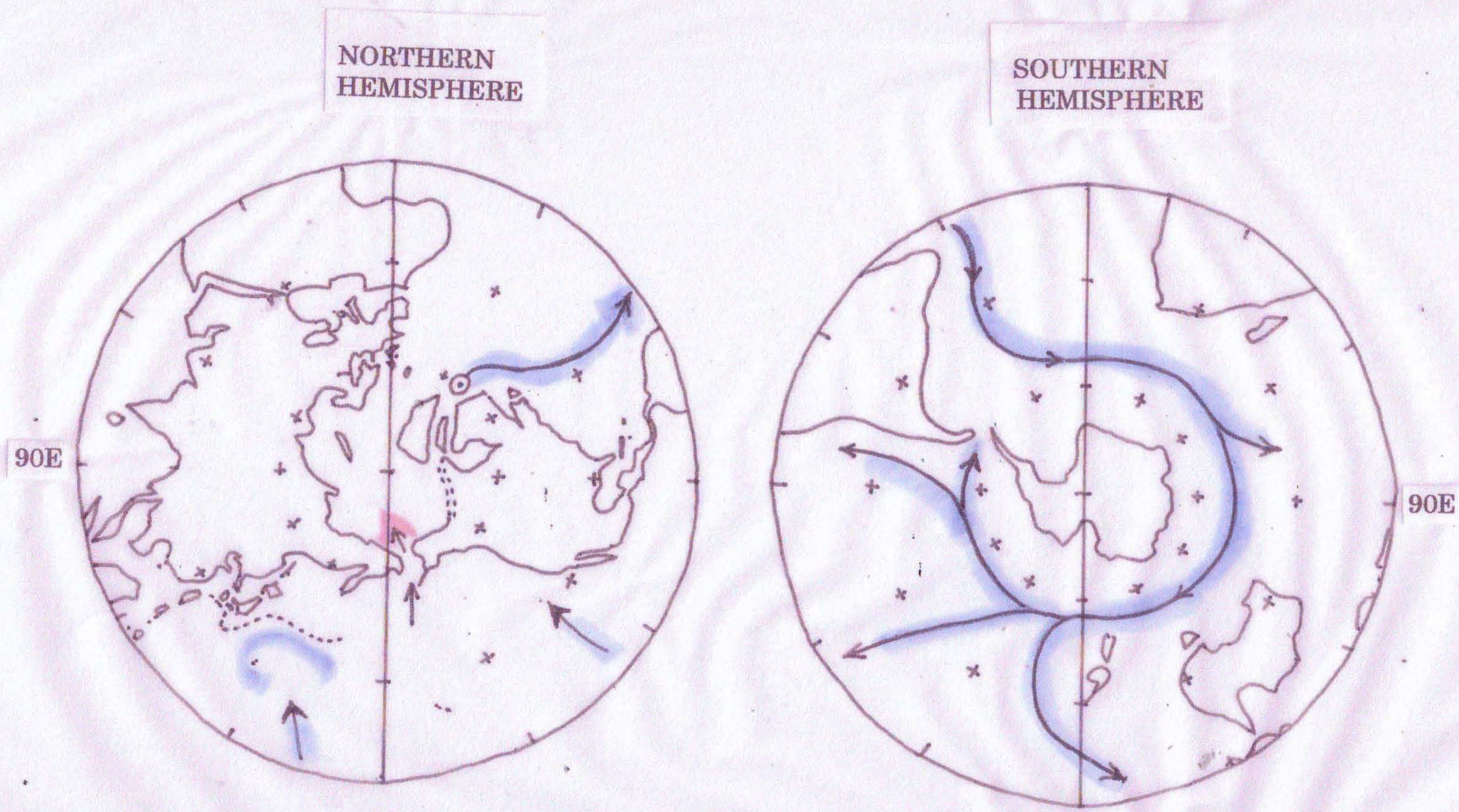

Figure 1 Pacific-Arctic-Atlantic Link in relation of the North Atlantic Meridional overtern circulation.

(1) The warm water of the Bering Sea intruding into the Arctic Sea has been found in an up-dated global sea surface pattern after the satellite thermal monitoring

(2) The Bering Sea as a marginal sea is facing the Pacific

(3) The Arctic Sea is between the Bering See and the Atlantic

(4) The dotted circle is a location of down-flow to form an origin of the deep sea circulation in the Atlantic

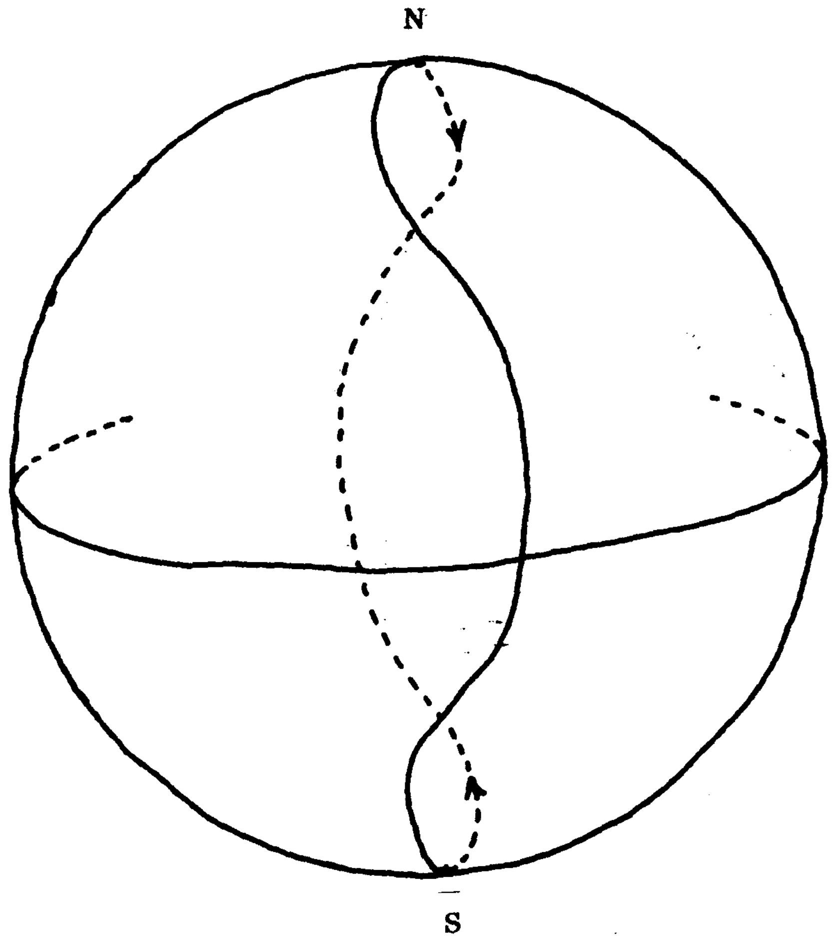

Figure 2 Polar orbital path of an inertial motion
1. Referring to Shono, 1957 [11]
2. Original work by Sasaki, 1960

3. SATELLITE THERMAL MONITORING

(This work introduces an intrusion of the ocean water of the Bering Sea into the Atlantic Sea water through the Bering Strait. Referring to the observed data and the recent researches, this satellite thermal monitoring can support the above dynamical model of a polar orbital circulation in form of a part of the global ocean circulation)

3. SATELLITE THERMAL MONITORING
OSATELLITE DATA SUPPORTING A POLAR ORBITAL OCEAN CIRCULATION

S.Nakamura

Kyoto University

Abstract

This work concerns an ice front evolution in the Arctic Sea referring to the satellite thermal monitoring. There have been presented many charting of the ocean thermal pattern on the sea surface in a global scale. The author here introduces a hydrodynamic understanding of the ice front evolution in the interested sea area. The ice front evolution for the time period between 1980 and 2008 is too short to notice what relation for the ice front is an effect of global climate change. An equation of motion for the sea water around the ice front is introduced in order to realize what dynamical process may support the ice front evolution.

Introduction

There have been introduced many global chart of the sea surface thermal patterns after processing the existing satellite thermal data by this time. The author introduces a dynamical process for a case of the ice front evolution. A special reference is taken for the ice front in the Arctic Sea. In order to show an evaluation of a satellite monitoring of the ice front in the Arctic Sea, a ocean water intrusion from the Bering Sea to the Arctic Sea through the Bering Strait is studied on the basis of fluid dynamics. Then, it is noticed that a solution suggests that a polar orbital ocean circulation as a geophysical fluid dynamics supports the trend of the ice front evolution in the Arctic Sea. For the author's convenience, the September ice front evolution in the period of 1980 to 2008 is taken as a special reference in this work. In order to realize the process of the September ice front evolution, it should be in need to have a set of the satellite thermal monitoring for a long time, for example, more than several hundred years in the interested sea area.

Ice Front Evolution

First, an illustration reduced referring to the satellite data, for example, a case of [1] is introduced the ice front evolution during 1997 to 2008 for the season of September.

The Arctic Sea is covered by a sea ice sheet in the cold season, for example, in December, January and February. So that, the author considers it better to concentrate his interest in a September ice front evolution in the Arctic Sea. The September ice front evolution in the Arctic Sea can be found by a mapping of the ice front location in a several years interval monitoring (for example, in 1980, in 2005 and in 2007) as shown in Figure 1. This makes us easy to see what process is found in the September ice evolution.

Nevertheless, this time interval of 17 years is too short to see the global trend of the September ice front in the Arctic Sea. The author has to notice here the global processes on the earth should be considered in a time scale of more than several thousand years for a problem on climate change of the earth.

Looking at Figure 1, it is easily seen that the specific patterns in the September ice front evolution is the sea water intrusion from the Bering Sea into the Arctic Sea through the Bering Strait. This is clearly found in the chart of the polar zone where the satellites have had monitored on the earth surface.

In these years, most of the scientists are tending to call its pattern as a typical example of the global earth warming effect though this process must be continued for a long time.

Formulation of Inertial Motion

The equation of motion for the ocean water on the rotating earth is decribed in a form as shown in a following form, i.e.,

$$(dv_r/dt) - f'v_\lambda - (v_\lambda^2 + v_\phi^2)/r = -g - (1/\rho)(\partial p/\partial r), \quad \text{.......(1)}$$

$$(dv_\lambda/dt) - fv_\phi - f'v_r + (v_\lambda v_r) - [(v_\lambda v_\phi)/r]\tan\phi = -(1/\rho)(1/r\cos\phi)(\partial p/\partial \lambda), \quad \text{.......(2)}$$

$$(dv_\phi/dt) + fv_\lambda + (v_\phi v_r)/r + (v_\lambda^2)\tan\phi = -(1/\rho)(1/r)(\partial p/\partial \phi). \quad \text{.......(3)}$$

where, the origin of the co-ordinate is at the center of the earth, the notations (r, λ, ϕ) are for the radial axis, the longitudinal axis and latitudinal axis, and the notations of v and p are for velocity and pressure respectively. Each of the substitutions (r, λ, ϕ) denotes the axis component respectively. The notation r in this case is the radius o the earth. The density of the sea water is denoted by ρ. The effects of the earth's rotation are expressed by $f=2\omega\sin\phi$ and $f' = 2\omega\cos\phi$ with the notation ω for the earth's angular velocity of rotation.

When a case of no pressure gradient on the sea surface is seen, the term of $(\partial p/\partial \lambda)$ in (2) and the term $(\partial p/\partial \phi)$ in (3) are vanish and to be zero value respectively, and the formulation can be described more simple form [2].

With consideration of no pressure gradient in the equation of motion, the following form can be reduced to describe as

$$v_r(dv_r/dt) + v_\lambda(dv_\lambda/dt) + v_\phi(dv_\phi/dt) = -[g + (1/\rho)(\partial p/\partial r)]v_r. \quad \text{.......(4)}$$

In a case of horizontal water motion($v_r = 0$), the above equation can be expressed in an integrated form, i.e.,

$$(1/2)[v_\lambda^2 + v_\phi^2] = \text{constant} = (1/2)v_i^2. \quad \text{.......(5)}$$

This tells us that the kinetic energy is conservative. In this case, absolute angular momentum is also conservative, so that,

$$r\cos\phi(v_\lambda + r\omega\cos\phi) = M. \quad \text{.......(6)}$$

The path of the sea water motion can be obtained from (5) and (6).

When an angle θ_t between the orbit and the x axis(a zonal axis in a cartesian co-ordinate on the sea surface) is defined, then, we have

$v_\lambda = v_i \cos\theta_t$ ....(7)

Substituting the above (7) into (6), then, it can be reduced the following formulation for the earth's radius a, i.e.,

$a v_i \cos\phi \cos\theta_t + a^2 \omega \cos^2\phi = M$ ....(8)

This expression shows the relation between ϕ and θ_t, and the orbital pattern of the water motion can be obtained. In 1950, Yoshikazu Sasaki had solved for several orbital motions.

Polar Orbital Inertia Motion

Now, one of the solutions can be the polar orbital inertia motion. Introducing several parameters, an approximated solution can be obtained to demonstrate several patterns can be possible motion of the interested sea waters. Some bold illustration gives us that one of the several solutions may be actively supporting what process found around the Arctic September ice front evolution. This process may be a scale of longer time than the global climate changing process, because the sea water inertia motion can not be easily changed or affected to induce a variation like the atmospheric inertia motion.

The path as one of the solutions supports the satellite thermal monitoring of the Arctic September ice front evolution in pattern.

A more detailed study should be promoted for clarifying what this polar orbital water motion though it is clearly expected that there is a polar orbital inertial motion link to the global ocean circulation.

Conclusions

In this work, an Arctic September ice front is introduced first as a result of the satellite thermal monitoring of the ice front evolution. Then, a simplified linearized model is introduced for the purpose of seeing what factor is essential as a driving trigger of the ice front evolution. The author is considering a meridional motion of the sea water could be a part of the actual sea water motion in the Arctic Sea as the interested sea area. This motion is well supported by a dynamical solution of a polar orbital ocean circulation, which could take part of the three dimensional ocean circulation after a more advanced study in future.

References

[1]Perovich,D.K., and J.A.Richter-Menge 2009 Loss of sea ice in the Arctic, Annual Review of Marine Science, Vol.1, No,1, pp.417-441.
[2]Shono,S. 1954 Introduction to Meteorological Dynamics, Iwanami, Tokyo, 425p.

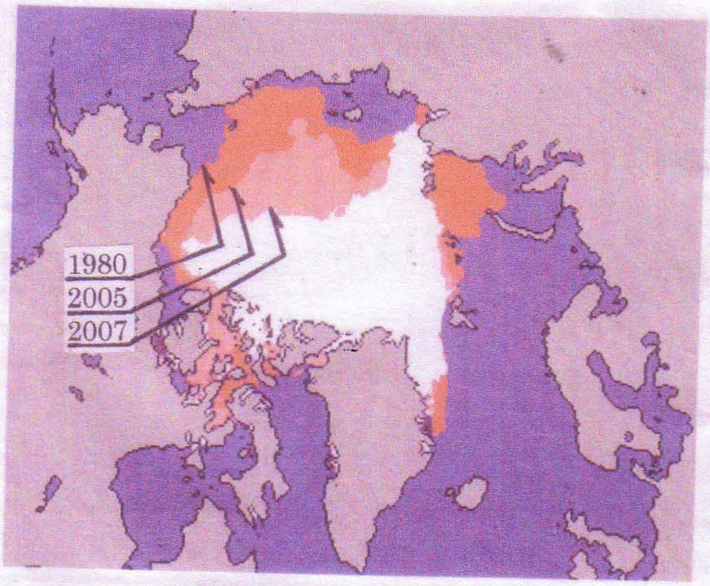

Figure 1 Arctic September ice-front for 1980, 2005 and 2007
(cf. Perovich and Richter-Menge, 2009)

APPPENDICES

Monitoring of Satellite Thermal Pattern of an Ocean Front as a Hydrodynamic Convergence

Shigehisa Nakamura
Kyoto University, Kyoto, Japan

Abstract— This is an over view of an ocean front as a hydrodynamic convergence. The water motion on the earth surface may have a conversion process and a diversion process. In this work a case of ocean process as a conversion process is the author's interest. On the bases of the knowledge obtained by monitoring of satellite thermal pattern of an ocean front, a notice on a hydrodynamic convergence is given for more advanced understanding of the ocean front as found on the sea surface.

1. INTRODUCTION

An over view of an ocean front is introduced as a problem of convergence in the field of "hydrodynamics". Hydrodynamic includes problem of convergence and divergence though the ocean scientist has recently shown on a global problem of convergence in the ocean [1]. As for the ocean front, the author introduces some overview with consideration of the factor "convergence" in this work.

This work concerns an over view of an ocean front as a hydrodynamic convergence. The author has noted the ocean front formed by two waters, i.e., a coastal and ocean waters to be found as a line on the sea surface. This ocean front can be well monitored by using a satellite. This technique has helped the author's finding of the specific properties of an ocean front on the sea surface. By this time, it was discussed mainly about several specific patterns of an ocean front, for example, in the northwestern Pacific. Similar pattern can be found in the Atlantic (around the Gulf Stream) or in the South Pacific (as the western boundary flow off the eastern boundary of Australia). After the author's monitoring of satellite thermal pattern of the ocean front in the northwestern Pacific, it is clarified that the front has a close relation to the western boundary current named as "Kuroshio". The front pattern is significantly governed by the costal configuration and varies its spacial pattern with the time elapse. The author has first introduced several cases that including some specific pattern of the ocean front at a shot reduced from the signals directly received by a system of an antenna and a software for the data processing. Successively, several case of timely change process of the ocean surface front has been obtained during a continuous satellite monitoring of the sea surface in the foot print covering the interested ocean front. This monitoring has given a key to the author for helping to develop a model of ocean front evolution on the sea surface referring to his understanding of hydrodynamics. Adding to the above, it was found that a satellite thermal plateau and a satellite thermal pinnacle can be understood as the specific cases a physical processes after an application of Stefan-Boltzmann's radiation theory. A satellite thermal pinnacle could be a set of concave facets as a part of the sea surface waves concentrating at the related pixels in the monitoring. A satellite thermal plateau could be formed by an ensemble of the set considered above for the pinnacle. The author has to take it necessary to relate these processes to the meteorological processes on the sea surface. Several cases of the interested processes were well related to an effect of a set of wind induced waves radiated out of a distant storm (more than one thousand kilometer far from the interested area) even in the satellite's foot print covering. Following the author's satellite monitoring of the ocean front evolution, it is clarified that the front is an example of a line where the waters converge to maintain the ocean front.

The author introduces an overview of the ocean front as a problem on convergent.

2. A KEY TO CONVERGENCE IN OCEAN

First, the author has to note a key to convergence in the ocean [1]. Now, the knowledge of hydrodynamics leads us to see where the convergent and divergent areas are existing in the ocean, and to help our dynamical understanding of the motion of the global ocean. An understanding of an ocean front might be a way to get a trigger for seeing the convergent line as the ocean front on the sea surface. One of the ideas to this problem might be to consider a global circulation of the ocean waters.

That is to say, one of the most recent reviews on the global ocean circulation is noted a pattern of surface ocean circulation combined to a deep ocean circulation. It is now understood as that a significant convergent is seen in the area between Green Land and New Found Land on the sea surface at the north arctic zone in the Atlantic. This convergence might be governed by the transport of the tropical water by Gulf Stream and by the effect of latitudinal cooling of the water at meeting the Arctic water. This could be understood as that of a specific example of the ocean front formed by two waters of the Arctic water and of the tropical waters. This convergence is connected to an area of water sinking down to form a deep water circulation. An estimated age of the ocean water tells us that the oldest deep water is at the mid of the North Pacific. This suggests us the ocean surface in the North Pacific must be the area of divergence. The author now is facing to solve a local problem in relation to a global process of the ocean circulation referring to the distribution of the ocean fronts as the convergent zones in the ocean.

3. OCEAN CURRENT

Pioneer work on the ocean current must be developed by Ekman [2]. In order to see the ocean current off the northwestern Pacific, Suda [3] had his energetics of the ocean current. Sverdrup et al. [4] noted his overview on "dynamics of ocean currents" in 1942. As for "the Gulf Stream", Stomme [5] had given an overview. Following these works, the ocean current could be taken as a geostrophic current. There has no attention had been no concept of "ocean front" which is formed by a contact of the coastal and ocean waters.

in fact, the ocean front is just neighbor the ocean current. The ocean current is between the coastal water and the ocean water. The author dare write that the ocean front has well found after launching a satellite for monitoring the ocean surface.

4. SATELLITE MONITORING OF OCEAN FRONT

As for the ocean front, satellite monitoring is an effective to see a thermal pattern time to time. The recent advance of electronic techniques have been helpful for finding the ocean front evolution as a physical process.

By this time, it had been discussed mainly about the variation of the ocean flow pattern for a quick report in a purpose in hydrographic practice.

On the other hand, Grimsaw and Yi [6] developed their mathematical theory on evolution of a potential vorticity front over a topographic slope. Adding to the above, Viera and Grimshaw [7] discussed on topographic forcing of mesoscale phenomea in the ocean, for example, filamentations, vortex formations and detachment.

Under the above noted satge, Kyoto University had developed a research project to use satellite for monitoring ocean processes. The author had take part of this project to start in 1980s. A simple system of an antenna and data processing function for a personal computer, is introduced for monitoring the ocean front evolution referring to the signals directly received at a station settled on the coast facing the northwestern pacific.

5. OCEAN FRONT EVOLUTION

The author has found that the ocean front is approximately same location to the axis of the ocean current. This makes us it easy to see the ocean current variations referring to the real time ocean front evolutions which are reduced after processing the directly received satellite signals as the satellite passing time just above the station settled on the coast.

Since the research project started, several interesting processes on the sea surface have been found. One of the contributive results must be satellite thermal monitoring of storm flood spreading around Kuroshio flow as the ocean current [8].

Successively, Nakamura [9, 10] has presented his notice on shear flow effect to Kuroshio meandering in the northwestern pacific.

6. SATELLITE THERMAL PLATEAU AND PINNACLE

Monitoring of the satellite thermal ocean front, the author found satellite thermal plateau and pinnacle in mid of the Pacific [for example, 11]. This pinnacle was found under the normal operation of the monitoring so that it could be realized as one of the physical processes.

It was realized that the satellite thermal plateau was an effect of the wind induced wave group which was radiated out of the distant storm zone. In this case, the location of the storm (a storm growing to Typhoon in the Pacific) was more than 1000 km far from the monitoring station. The meteorological factors support that the satellite thermal plateau was coincides well to the swell propagating area between the storm and the station facing the ocean.

In the cold season of the Asian monsoon area, the satellite thermal plateau has been seen at the northwestery when the atmospheric cold front is passing just neighbor the station. That time, wind stress is a cause to induce a wind induced wave group off the coast of the down wind area on the sea.

7. APPLICATION OF STEFAN-BOLTZMANN'S RADIATION THEORY

A physical background of the above noted process of the satellite thermal plateau and pinnacle requires a set of concave wave facets with a focus just neighbor the sensor mounted on the satellite. This is a necessary condition. So that it is necessary in order to identify the process relating to the ocean surface waves.

Nevertheless, the other factor must be introduced to satisfy a required sufficient condition. For this, an application of Stefan-Boltsmann radiation theory with an assumption of the ocean surface as a black body. When the radiation theory is applied to the concave wave facets noted above, the satellite thermal plateau and pinnacle can be understood in the scope of physics. Although, the author has to note that no reference data of waves is found for the satellite thermal pinnacle yet.

8. GLIMPSE OF OCEAN CIRCULATION

As stated above, ocean front is a line formed at meeting the coastal water and ocean water. The line on the sea surface as an ocean front is in a process of evolution, though the process is not well understood in a scope of geophysical dynamics.

Before the ocean front evolution is discussed, the scientists had have leaned that an ocean current is exist in a belt zone between the coastal water and ocean water.

A history of the ocean expeditions undertaken by the research ship "Meteor" was the first project covering the most area of the ocean in the world. The modern ocean surveys and the systematic ocean observation by the ships and boats under the international co-operative project have been undertaken to compile bathymetric pattern of the ocean waters. Nevertheless, the specific ocean front has started in these years after the satellite operation for some monitoring of the ocean front evolution.

The scientists know well that the ocean has a three dimensional structure. The understanding of the updated ocean pattern might be seen, for example, what is described by Kuhlbrot et al. [1]. Then, the sink of the ocean in the world is in the arctic area near the Atlantic. The tropical warm warm water is transported in the western part of the northern Atlantic, and the Atlantic surface water is going down to form a deep sea current. This deep sea current be a current to pass along the western part of the Atlantic. In the deep layer of the Indian Ocean, this current is nearly parallel to the south circum polar current in the surface layer. The Atlantic deep water get to the south of the Pacific dissipating its dissolved oxygen, and flow across the equator to enter the deep basin of the northwestern Pacific. The deep water in the basin of this area in the Pacific is understood the oldest at present. When the transportation of the Atlantic surface layer is continued for a long time, the deep water mass in the Pacific basin must increase, and this increase of the deep water could be a trigger of a large scale upwelling of the upper warm water in the Pacific subtropical water. This upwelling let to spread the warm water to the coastal zone. Then, the coastal water meeting to the Pacific warm water may form a line of fluid convergent, i.e., the Kuroshio front found in the northwestern Pacific, for example.

The minor Kuroshio flow variations might be governed by a condition of the tropical waters as the source of Kuroshio to affect a climatologic effect. Another trigger effective to climate might be the upwelling off the Peru, that is, named as "El Nino".

What the author noted above, it can be seen that there has been no interest for divergence of the ocean water, even though this divergence is important as much as the convergence in the ocean in a global scale. Now, the ocean front evolution is a glimpse of the ocean circulation even when the pattern is occasionally distorted by the meteorological effect on the ocean surface area.

9. GLOBAL UNDERSTANDING OF OCEAN FRONT EVOLUTION

With what the author has noted above, it can be seen that the ocean front evolution is a simple convergent line, and only a glimpse of the ocean front evolution should be closely related to the global process of the ocean circulation.

10. CONCLUSION

An overview of the research on ocean front evolution is briefly introduced. This is a simple ocean front evolution though the author takes it to be a glimpse of the ocean circulation of a three dimensional process in a global scale. In the related history, the initial stage of the related research had looked to be trivial for the human activity. Research on the ocean current has had helped our understanding about what is the ocean just around the area of human activity. Monitoring of satellite thermal pattern of the ocean front evolution has effective to see what process is actually appearing on the sea surface. The compiled survey data and the satellite monitoring are more effective to realize a three dimensional process of the ocean circulation. Increase of our experience, knowledge, and systematic survey of the ocean surly lead to give us a key for the important information about the global ocean circulation which is effective even to a glimpse of the variation of the circulation.

REFERENCES

1. Kuhlbrot, T., A. Griesel, M. Montoya, A. Levermann, M. Hofmann, and S. Rahmstof, "On the driving processes of the Atlantic meridional overturing circulation," *Reviews of Geophysics*, Vol. 45, No. 2004RG000166, 1–32, 2007.
2. Ekman, V. W., "On the influence of the earth's rotation on ocean currents," *Arckiv fur Mathematik Astronomik och Fysik*, Vol. 2, No. 11, 1905–06, Kungsreich, Svenska Vetter, Akademy, Stockholm, 1905.
3. Suda, K., "On the dissipation of energy in the ocean current (2nd paper)," *Geophysical Magazine*, Vol. 10, 131–243, Tokyo, 1936.
4. Svedrup, H. U., M. W. Johnson, and R. H. Fleming, *The Oceans*, 1087, Prentice-Hall, Inc., Englewood, New Jergey, 1942.
5. Stommel, H., *The Gulf Stream*, 202, University of California Press, 1958.
6. Grimshaw, R. and Z. Yi, "Evolution of a potential vorticity over a topographic slope," *Journal of Physical Oceanography*, Vol. 21, 1240–1255, 1991.
7. Viera, F. and R. Grimshaw, "Topographic forcintg of mesoscale phenomena: filamentations, vortex formations and detachment," *Journal of Physical Oceannography*, Vol. 24, 1433–1448, 1994.
8. Nakamura, S., "Satellite thermal monitoring of storm flood spreading around Kuroshio flow," *Bulletin of the Disaster Prevention Research Institute*, Vol. 43, 31–39, Kyoto University, 1993.
9. Nakamura, S., "Shear flow effect to Kuroshio meandering in the northwestern Pacific," *Hydrodynamics*, 939–944, edited by A. T. Chwang, J. H. W. Lee, and D. Y. C. Leung, Hong Kong, 1996.
10. Nakamura, S., "A dynamical understanding of Kuroshio front," *Hydrodynamics*, 449–453, edited by H. Kim, S. H. Lee, and S. J. Lee, Seoul, 1998.
11. Nakamura, S., "An example of observed thermal structure of sea surface at an offshore tower," *La mer — Bulletin*, Vol. 35, 125–126, Societe franco-japonaise d'oceangraphie, 1997.

Monitoring of Satellite Thermal Pattern of a Drifting Ocean Front

S. Nakamura
Kyoto University, Japan

Abstract— This is a note to a drifting ocean front which had been observed during a monitoring of an interested satellite thermal pattern. The pattern is obtained after processing a satellite signal directly received at a station. The author notes a typical case of the ocean front estimated out of the line found as a spacial maximum of thermal gradient on the sea surface. Spacial thermal pattern of the sea surface temperature found in the satellite is usually in drifting. It is now necessary what had been taken as an ocean front found by satellite monitoring. The pattern of the ocean front reduced from the direct measurement of the ocean surface in-situ should be considered in relation to the satellite thermal pattern of a drifting ocean front for effective data utilization. What is noted above is in need for the next step of the research of global ocean circulation in relation to the global warming effect.

1. INTRODUCTION

This work concerns about a problem of drifting ocean front. The author has been studied on satellite thermal pattern of a ocean front evolution as a part of the research project of Kyoto University. After his works on the satellite thermal pattern as an approximate ocean front, it is necessary to see what drifting pattern of the ocean front could be possible in a scope of hydrodynamics. The author has thought it necessary to note now about a problem of the ocean front which is taken as a maximum thermal gradient on the sea surface in the foot print of the satellite monitoring sensor. For this purpose, the author refers to the data which has had obtained by receiving directly the interested satellite signal at the satellite passing time above his station. The author feels it also necessary to note about the ocean front pattern obtained referring to the data in-situ obtained by the survey ships.

This work is the first note to problem on drifting ocean front. What are noted in this text must be in consideration at evaluating the global ocean circulation governed by the climate change interaction.

2. OCEAN CURRENT AROUND OCEAN FRONT

It has been well understood that the ocean current on the sea surface is only a part of the global ocean circulation. This circulation should be understood as a three dimensional (3D) process now. Nevertheless, the fact shows that the upper layer of the ocean has been seen after the air-sea interaction on the sea surface under the earth's gravity field.

The ocean current in the surface layer is a densimetric property and strongly controlled by the earth's rotation, and it has been taken as that the ocean current is geostrophic. Several mathematical models had developed in order to demonstrate the intensified western boundary current. The pattern of this current has been found ever by the ships' survey, for example, as the "Gulf Stream" in the Atlantic or as the "Kuroshio" in the NW Pacific. In the area off the eastern Australia, a similar intensified western boundary current has been found.

The ocean geostrophic current noted above is governed by the sea water density which is a function of salinity and water temperature. The other minor factors is considered to be not so effective for current pattern, though compressibility is effective for the sea water in the deeper part under the surface layer.

3. OCEAN THERMAL FRONT

The ocean thermal front is formed by meeting of the waters in the coastal zone and in the ocean. This means that the geostrophic current in the NW Pacific is an intensified western boundary current. This current forms a part of "wind-induced circulation" in the upper layer. In this work, a little consideration is pay for the water in the deeper part of the ocean.

As is known well for the ocean thermal pattern, the axis of the ocean current in the NW Pacific is located just neighbor of the border of the two waters. The border is called as the "ocean thermal front" for convenience. The ocean thermal front can be easily monitored by an interested satellite. The ocean thermal front is defined as the line formed by the thermal maximum gradient on the ocean surface. This front can be monitored by the satellite.

Pattern of an ocean thermal front can be generally undulated. This front changes its spacial and timely form as seen in the satellite monitored pattern. For example, this pattern could be described boldly by a sinusoidal pattern on the ocean surface as seen A in Figure 1. In some drifting of this front might be looked as if it were distorted a pattern shown in the right side of A in Figure 1. There might be an unidentified forcing to the front.

4. PATTERN OF DRIFTING OCEAN THERMAL FRONT

A distorted pattern of the front is assumed to be shown as seen in B of Figure 1, for the author's convenience. The cold and warm water masses, for example, is assumed to form a front on the ocean surface. Then, thermal patterns along the transect M, N, P, Q, and R, can be shown as C in Figure 1. As far as we concern the data in-situ observed by a ship, the thermal pattern in C should be distorted if a drifting affecting the thermal pattern in B of Figure 1. In fact, it takes a certain time for ship's observation along the line of M, for example. The pattern for M is a step pattern demonstrating thermal gap at the location of the ocean thermal front. The pattern for R looks to be same to the pattern for M. Though, the pattern N, P, or, Q is a little difference in pattern along the corresponding line (cf. D in Figure 1).

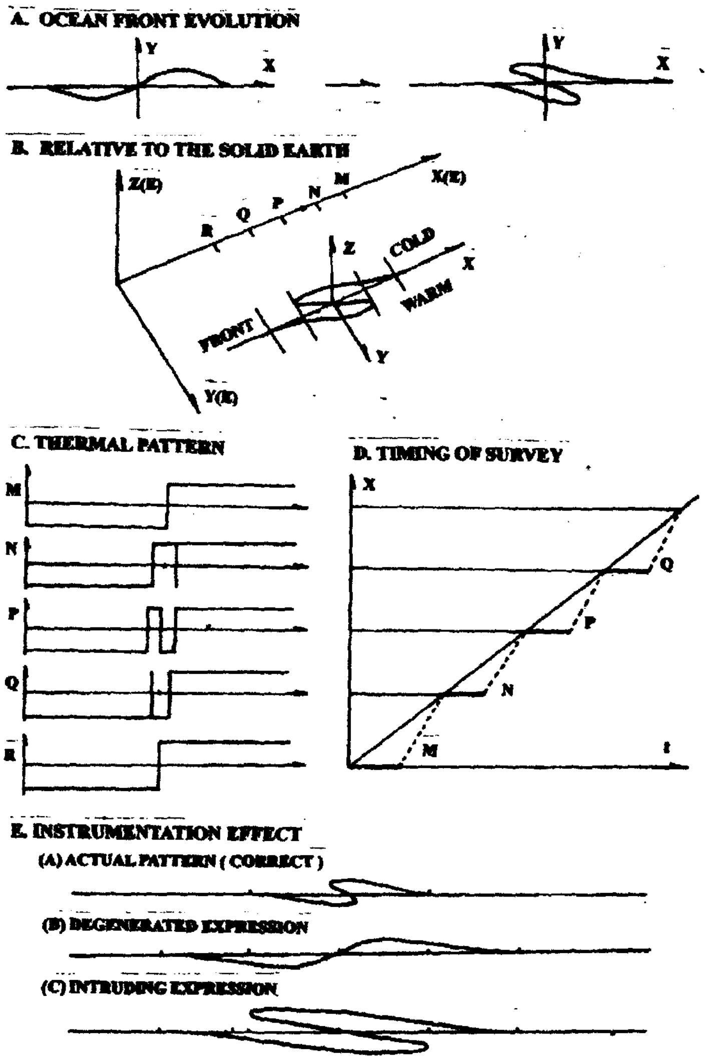

Figure 1: Evolution of a drifting ocean front.

The author has understanding that a limited data only for the lines as the transects suggests hardly to find a thermal pattern as assumed in B of Figure 1.

5. OBSERVATION BY FLOATING SURVEY SHIPS

In a case of the observation in-situ by survey ships, it takes a certain time to obtain the data, for example, along the line M starting at a time on a day to get to the other end of the line M at several hours or more. On the other hand, a satellite monitoring might have the necessary data of the sea surface thermal pattern in the area covering the zone from the line M to the line R in several minutes, for example.

In a several minutes monitoring, any drifting effect of the ocean thermal front might be not so significant. Nevertheless, a time interval of several hours for completing an operation of observation by ship in-situ has an inevitable drifting effect in the operation. Now, it must be aware of that any one of the survey ships are floating and drifting. So that, positioning of any survey ship does not mean the positioning of the actual observation at the time.

The author, here, has to notice that the operation ambiguity might be in the data so that it is necessary for us to be careful at reading the several data sets in the interested area of the ocean covering the drifting ocean front.

6. INSTRUMENTATION ON BOARD FOR OPERATION

The author has to remark to positioning and timing for an operation of instrumentation. In fact, a survey ship can get a data from the sea surface to the sea floor. Even though, it is hard to identify the exact positioning of the location for operation under the sea surface referring to the precise positioning of the survey ship.

For example, assume that an actual ocean thermal pattern is (A) of E in Figure 1. Drifting effect might give us a data for another solution. One of the possible cases might be as is (B) of E in Figure 1. The other one might be as is the case (C) of E in Figure 1.

7. CONCLUSIONS

A problem of drifting ocean front is studied referring to the result of monitoring of satellite thermal pattern of an ocean thermal front. A note on ocean current is given in relation to the ocean thermal pattern. This makes us to refer to the satellite data for his monitoring of satellite thermal pattern of a drifting ocean front. An ocean front distorts after an shearing effect to the ocean front formed between the two water masses. The ocean front has been taken as one of the related indices for understanding the ocean currents around the front.

The ocean current is taken to be geostrophic. Geostrophic ocean current in the gravity field is governed by the gradient of water density. This is mainly determined by the two factors of salinity and water temperature. The interested ocean current should be understood in a scope of geophysical hydrodynamics. Generally, the ocean front is evolving time to time so that its pattern is not simple as the author's model. Though, it is important for us to realize ocean current after a model.

Some specific thermal pattern along a section crossing the front might be well demonstrated by a model. Even though, the author uses to trust a satellite thermal pattern on the ocean surface to be true if the data in-situ at or in any part or point is well identified.

The author raised a problem of ocean surface thermal pattern in-situ obtained by the survey ships. Ambiguity of positioning in the ocean along a survey line might be caused by drift effect of the ocean thermal front.

Essentially the satellite thermal pattern should be compared to the data on the sea surface. Nevertheless, the author has to notice about an "instrumentation effect". This effect controls the accuracy of the data obtained on the sea surface.

An actual pattern might be obtained under a certain survey condition for a correct pattern. Drifting effect of the ocean thermal pattern causes to get a degenerated or intruding pattern. It is conditional what pattern is correctly founded in the survey data on the ocean surface. Adding to the above, the author has to notice that the ocean structure under the sea surface could give a key to monitoring the drifting ocean thermal front by electromagnetic waves application. The key must be effective to see the global warming control system.

Monitoring of Satellite Thermal Pattern of Ocean Front in Relation to a Double Diffusion Process

S. Nakamura
Kyoto University, Japan

Abstract— After monitoring of satellite thermal pattern of an ocean front evolution, the author has had a step to see a double diffusion process on an interface related to an ocean front evolution. This double diffusion process is significant in the ocean, though it is enough to consider a simple diffusion process in the coastal water or in the riverine water. Some note is given to have a key to understand the process under the sea surface even referring to a satellite thermal pattern of an ocean front evolution.

1. INTRODUCTION

This work concerns a problem on monitoring of satellite thermal pattern of an ocean front evolution in relation to a double diffusion process found just around an interested front. As is well understood, this ocean front is formed by a contact of the two waters in the coast and in the offshore zone of the ocean.

Double diffusion process seems to be a specific process though there are many cases just like to the case in the ocean. Exactly, a diffusion process of a mixture of many elements in the natural processes as a multiple diffuse process. For simplicity of the problem here, the author would introduce a simplified case of a specific double diffusion found in the ocean. That is, a double diffusion found just around an ocean front in evolution.

This case could be helpful for the other similar cases found in nature or in some artificial cases. What is introduced here in this work could be a key to solve "double diffusion" in a scope of generalized physical process which could be expressed to realize by application of a mathematical technique.

2. SPECIFIC PROPERTY OF OCEAN WATER

As has been well understood by this time, the ocean water contents in the ocean controls the density of the water. Several ions. of the inorganic elements, the dissolved materials and the suspended materials are the contents of the ocean water. The ocean scientists have had taken conveniently that any ocean water sample could be specified by the two main factors, the salinity and the water temperature. These two factors determine density of the water in the ocean surface layer. As for a case of deep sea, compressibility of the ocean water is important. This means that the motion of the ocean water could be a densimetric motion in the gravity field of the Earth. With the ocean survey for a long time of many years, it has been introduced a double diffusion process as a fluid mechanics during a period of 1990s in a scope of hydrodynamics.

3. DIFFUSION PROCESSES

Each of the salinity and the water temperature has a diffusive property respectively. It is understood that the diffusivities of the two factors, i.e., of salinity and of water temperature.

A formulation for each interested diffusion process is simple. Usually an equation expressed as follow is taken to be a starting to analyze and solve a diffusion process, that is,

$$d(S,T)/dt = \partial(S,T)/\partial t + u\nabla(S,T) = -\nabla(\kappa\nabla(S,T)) \quad (1)$$

where, salinity and temperature are denoted as "S" and "T" in a vector velocity field of ocean water. Timely derivative and spacial derivative are expressed as "d/dt" or "$\partial/\partial t$" and "∇", respectively. A coefficient of diffusion is denoted as "κ".

Mathematical form of the equation is essentially same for each case of S and T. Though there is some difference of the value of κ for S and for T. It should be aware of that salinity is an index of material contents (solvents and supended). So that, "diffusion" of S is a process of some material translation processes. As for the temperature, the "diffusion" of T is for a thermal energy transfer. With this, it should be introduced κ for S and κ for T, respectively.

Nevertheless, actual process in the ocean is not so simple so that it is difficult to see the processes of S and T at the same time at an instant.

Adding to the above, the two diffusion processes interact each other. That is, one of a typical double diffusion process.

At present stage, the scientists in the fields of oceanography have never had any idea for applying several contributions on double diffusion in the fields of fluid mechanics.

4. PHENOMENOLOGICAL NOTICES

Essentially, this difference of the two factors raises some problem of double diffusion in a scope of fluid mechanics. Dynamics of ocean front evolution has been studied as a simple process of the water density. In ocean, density of the water in the ocean is easily defined by the two factors at formulating water motion in the ocean under the earth's gravity field.

An ocean front is evolving at any time and at any location. The author has had introduced a model for an ocean front evolution for a purpose of his realizing what thermal pattern found on the sea surface after monitoring by using his simple system for directly receiving a satellite signal at a time just passing above his station settled on the coast facing ocean.

In the author's experience, it is easy to monitor thermal pattern on the sea surface when a satellite monitoring technique is applied and it is hard to find salinity distribution even on the ocean surface after any available sensor mounted on a satellite. Salinity observation is possible if a sensor has a much higher resolution. Then, the author has to consider another available technique to see the ocean front evolution.

The author considers fortunate or unfortunate when the most effective factor for monitoring the ocean surface thermal pattern is to apply a satellite monitoring of a real time signal.

5. SATELLITE THERMAL MONITORING

Boldly, a thermal factor is the most effective for finding the ocean front evolution which is found between the coastal water and ocean water. A case of the monitored thermal patterns monitored in an area of the NW Pacific in practice, could be seen by a simple model with an understanding of classic hydrodynamics, though to the details it must be referred to an advanced contributions in geophysical hydrodynamics. Another specific example is an eddy and a front monitored in the area of the NE Atlantic. Formulation of the water motion may be simple in form when one factor may be enough to consideration. In some specific cases, information of salinity is important for analyzing salt finger or salt lens in relation to the Mediterranean outflow. Nevertheless, the author has to note here no existing satellites is for the author's purpose of detecting any structure of the water motion under the ocean surface even around an interface as the extension of the ocean front on the ocean surface. What is noted above is left to be discussed in future in relation to any process found in the global ocean circulation in order to obtain a key to global warming control system.

6. OCEAN FRONT EVOLUTION

As stated above, we have to work to contribute for our dynamical understanding of ocean. For our present understanding of this problem, it is strongly expected to have an advanced technique for monitoring the ocean surface.

At present, a combined system is available for the author's purpose and our promotion for the much more advanced understanding of the ocean.

Now, the author feels it necessary to introduce you an outline of oceanography which might help us to find a key to promote our research work in the world.

In Figure 1, a simplified illustration is introduced. At the top (A), a specific example of the ocean front evolution is shown. Warm and cold ocean waters forms an ocean front which is evolving.

Thermal pattern along a transect ("P to Q" and "S to R") of a survey ship is shown in a simplified form. In case of A in Figure 1, the evolution process might be as shown as an adiabatic process (see B in Figure 1). Nevertheless, actual pattern obtained by observation is affected by conduction and double diffusion processes to find a pattern (see C in Figure 1). What noted above is for the ocean surface pattern. This pattern could be realized when a satellite thermal pattern.

In the case as shown in Figure 1, the locations, P, Q, R, and S, might be plotted on a ST-diagram. In D of Figure 1, the ST-diagram tells us that conduction and diffusion might be important at understanding the ocean to the details. In Figure 1 (see D), a parameter σ t (sigma-t) shows

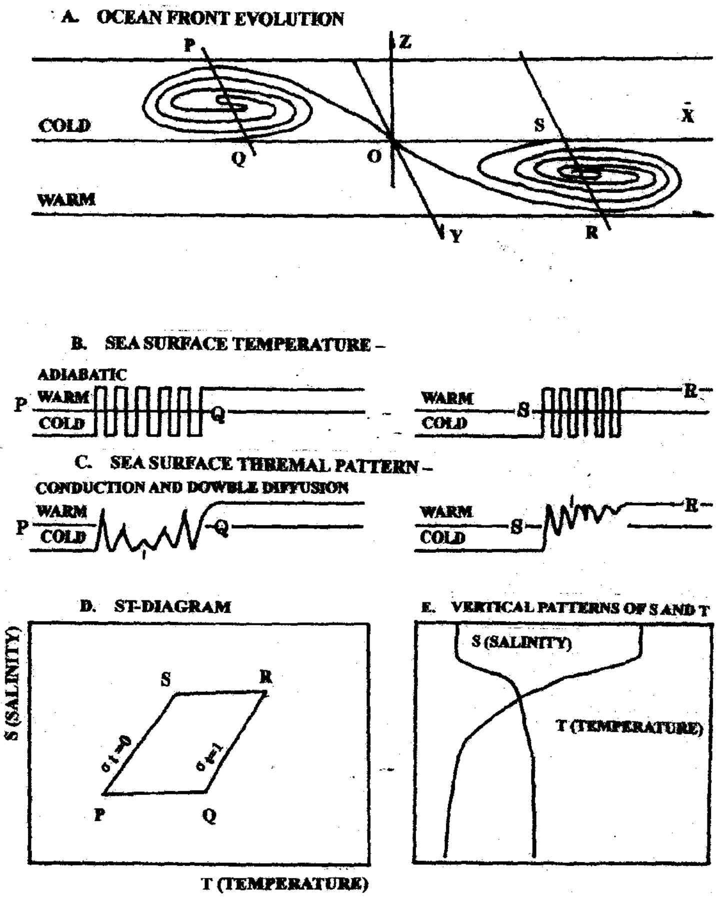

Figure 1: Double diffusion process during an ocean front evolution.

isopicnal line. When sigma-t=0 for cold water and sigma-t = 1 for warm water, an water particle at P have various paths to get to R in the area even in the square formed by PQRS. In order to see what path is actually found, a dynamical model should be developed in order to predict what path is for the minimum energy loss of a interested water particle moving, for example, from P to R. In order to get a proper dynamical model, an advanced formulation should be found for in practical applications.

However, the ocean has a three dimensional structure. The structure is not so simple. In the surface layer of the ocean (for example, a case of mid-latitude zone), vertical structure of salinity and temperature could be demonstrated as shown in E of Figure 1. This shows a simplified example of some specific observation.

7. CONCLUSIONS

In this work, the author has introduced a double diffusion problem as a key to obtain an advanced understanding of the ocean. For this purpose, it is effective to utilize the satellite thermal pattern of real time which is reduced by a personal computer system which helps to receive directly the interested satellite signal in need.

INTERNATIONAL ACTIVITY – Shigehisa Nakamura 2009May 1

1. 71Aug01-71Aug19 IUGG General Assembly, Moscow, USSR
2. 72Aprx1-72Aprx2 Congress on Ocean Development, Keidanren, Tokyo#
3. 74Jan25-74Feb03 IUGG Tsunami Symposium, Wellington, NZ
4. 77Mar21-77Apr01 IUGG Tsunami Symposium Ensenada, Mexico
5. 78Jun10-78Oct10 *Visiting Senior Fellow, Hawaii Univ., HIG, Hon, HI
6. 79Aug24-79Sep05 Pacific Science Congress, Khabarovsk, USSR
7. 80Jul26-81Jan21 *Visiting Scientist, CSIRO Perth(Div.LRM), Australia
8. 82Aug15-82Aug22 Tsunami Soc., Honolulu, Hawaii, USA
9. 83Aug13-83Aug28 IUGG General Asembly, Hamburg, West Germany
10. 84Dec09-84Dec15 Seminar/Workshop on Preparedness for Geologic Disasters in Southeast Asia and the Pacific Region, Manila, Philippines
11. 85Aug03-85Aug09 Joint Assembly IAMAP/IAPSO, Honolulu, HI, USA
12. 87Aug16-87Aug24 IUGG General Assembly, Vancouver, Canada
13. 88Mar18-88Mar25 EuropeanGeopysicalSociety(EGS) General Assembly, Bologna, Italy
14. 88Nov14-88Nov21 NOAA Int.Conf.on Tidal Hydrodynamics(NBS/NIST) Gaithersburg, MD, USA
15. 91Aug17-91Aug24 IUGG General Assembly, Wien, Austria
16. 91Sep20-91Oct05 Int.Workshop 'Waves and Vortices in the Ocean and their Laboratory Analogues, Vladibostok, Russia
17. 92Apr06-92Apr10 EGS General Assembly, Edinburg, UK
18. 92Jun01-92-Jun05 Pacific Congress on Marine Science and Technology, (PACON), Kona, Hawaii, USA
19. 93Jun13-93Jun18 PACON93 China Symposium, Beijing, China
20. 94Jul02-94Jul09 PACON94, Townsville, Queensland, Australia
21. 94Sep20-94Sep27 InternationalSymposium on Marine Positioning 1994 (INSMAP94), Hannover, Germany
22. 95Apr02-95Apr09 EGS General Assembly, Hamburg, Germany
23. 95Jun05-95Jun10 Int.Workshop 'Boundary Effects in Stratified and/or Rotating Fluids', Sankt-Peterburg(Pushkin-Tsarskoi Selo), Russia
24. 95Aug09-95Aug14 IAPSO(IUGG) General Assembly, Hon, HI, USA
25. 96Mar04-96Mar10 Oceanology International 96, Brighton, UK
26. 96Jun17-96Jun23 PACON96, Honolulu, Hawaii, USA
27. 96Jul20-96Jul26 AGU-WPGM'96, Brisbane, Australia

28. 96Aug12-96Aug18 Pacific Ocean Remote Sensing Conf.(PORSEC96), Victoria, BC, Canada
29. 97May10-97May14 Oceanology International 97 Pacific Rim, Singapore
30. 97Jun30-97Jul04 Joint Assembly IAMAS/IAPSO, Melbourn, Australia
31. 98Jul21-98Jul24 AGU-WPGM'98, Taipei, Taiwan
32. 98Jul27-98Jul31 PORSEC98, Quindao, China
33. 98Oct12-98Oct15 ICHD98, Seoul, Korea
34. 99Mar22-99Mar26 PIERS1999, Taipei, Taiwan
35. 99Jul19-99Jul24 IUGG99 General Assembly, Birmingham, UK
36. 00Mar25-00Apr01 ISRE(Int.Sym.Remote Sensing Env.), Cape Town, SA
37. 00Dec03-00Dec08 PORSEC2000, Panaji, Goa, India
38. 01Jul08-01Jul12 PACON2001(Jul8-11), Burlingame, Calif., USA
39. 01Jul15-01Jul19 IAMAS2001(Jul.10-18), Innsbruck, Austria
40. 02Feb11-02Feb15 AGU-Ocean Sciences 2002, Honolulu, Hawaii, USA*
41. 02Jul01-02Jul05 PIERS2002, Cambridge, MA, USA
42. 02Jul21-02Jul26 PACON2002, Makuhari, Chiba#
43. 03Jun30-03Jul11 IUGG2003, Sapporo, Hokkaido#
44. 03Oct12-03Oct16 PIERS2003, Honolulu, Hawaii, USA
45. 03Nov30-03Dec03 PACON2003, Kaoshiung, Taiwan
46. 04May30-04Jun04 PACON2004, Honolulu, Hawaii, USA
47. 04Aug15-04Aug21 ICTAM2004, Warsaw, Poland
48. 04Aug28-04Aug31 PIERS2004, Nanjing, China
49. 05May23-05May27 AGU Joint Assembly, New Orleans, LA, USA*
50. 05Aug23-05Aug26 PIERS2005, Hangzhou, China
51. 06Mar26-06Mar31 PIERS2006, Cambridge, MA, USA
52. 06Jul24-06Jul27 AGU-WPGM, Beijing, China*
53. 07Mar26-07Mar30 PIERS2007, Beijing, China
54. 07Aug27-08Aug30 PIERS2007, Prague, Czech
55. 08Mar24-08Mar28 PIERS2008, Hangzhou, China
56. 08Apr13-08Apr18 EGU2008 General Assembly, Vienna, Austria
57. 09Mar23-09Mar27 PIERS2009, Beijing, China
58. 09Apr19-09Apr24 EGU2009, General Assembly, Vienna, Austria
59. 10Mar22-10Mar26 PIERS2010, Xian, China

2009 May 1

Autobiography and Curriculum Vitae

Name: **Shigehisa Nakamura, Mr..**
Birth: 1933/ Nagasaki, Japan
Address: Famille Vila-A104, Minato, Tanabe, Wakayama, 646-0031 Japan
Tel/Fax: +81-739-25-5691
Email address: schnak09@power.odn.ne.jp

Education

1958 Batchelor of Science, Faculty of Science(Geophysics-Geoelectromagnetism), Kyoto University, Japan
1960 Master of Science, School of Geophysics(Physical Oceanography), Kyoto University, Japan
1963 Finished Doctor Course, School of Geophysics(Physical Oceanography), Kyoto University, Japan [Candidate of PhD as Doctor of Science]
1976 Doctor of Engineering-Civil and Ocean Engineering(PhD), Kyoto University

Affiliation

1963-1997- Disaster Prevention Research Institute, Kyoto University, Japan
1978 - Visiting Senior Fellow, Hawaii University at Manoa, Honolulu, HI, USA
1980-1981- Visiting scientist, CSIRO at Perth, Western Australia, Australia
1992-1996- Director, Shirahama Oceanographic Observatory, Kyoto University

1988-Life Member, American Geophysical Union, Washington, USA
1992- Fellow, Royal meteorological Society, UK
2004- Fellow, PACON International, Honolulu, Hawaii, USA
2007- Fellow, Electromagnetics Academy, Cambridge, Massachusetts, USA
2008-Gratis Member, European Geoscience Union

Prize and Honours:

1983- Prix de la Franco-Japonaise Societe de Oceanographie, Tokyo, Japan

Published materials: Academic papers in Scientific Journals, Proceedings, and others
Scientific Books(Japanese and/English) including "e-Books"
[search Nakamura through the following window, please
->>http:www.piers.org
and/or
->>http://repository.kulib.kyoto-u.ac.jp/dspace]

Recent Interests: Satellite monitoring for earth science, Electromagnetism, Ocean Sciences, Radiations, Natural Hazards, Civil Engineering

I, as Shigehisa Nakamura, declare that my curriculum vitae are correct as seen above.

Shigehisa Nakamura

Documentation Notes

Author: Shigehisa Nakamura
Affiliation: Kyoto University [Retired]
Contact address: Famille Villa-A104, Minato-674-2, Tanabe 646-0031 Japan

Publication Data:
Title: Polar Orbital Ocean Circulation
Author: Shigehisa Nakamura
Tel/Fax: +81-739-25-5691

Keywords: Ocean, Inertia Motion, Bering Sea, Antarctic Sea, Atlantic,
Polar Orbital Ocean Circulation, Atlantic Meridional Overtern,
Ocean Front, Ice Front.

Publisher: Shigehisa Nakamura
Published Date: 2009 May 1