EEOC
Earth Environment Observation Committee

NASDA
NATIONAL SPACE DEVELOPMENT AGENCY OF JAPAN

1995 ADEOS/NSCAT Science Working Team Meeting

Organized by
Earth Environment Observation Committee (EEOC)
National Space Development Agency of Japan (NASDA)

November 29 - December 1, 1995
Miyako Hotel
Kyoto, Japan

NASA-CR-204940

LAMONT-DOHERTY EARTH OBSERVATORY of COLUMBIA UNIVERSITY
Palisades, New York 10964

Final Technical Report of NAG 5-1960

TO:	NASA/Goddard Space Flight Center Greenbelt, MD 20771
ATTENTION:	Director
INSTITUTION:	The Trustees of Columbia University in the City of New York 351 Engineering Terrace 500 W.120th Street New York, New York 10027
TITLE:	Four-Dimensional Oceanic and Atmospheric Data Assimilation with Tropical Rainfall Measuring Mission Data
PERIOD:	April 15, 1992-November 30, 1996
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1. SUMMARY OF RESEARCH

An oceanic data assimilation system which allows to utilize the forthcoming Tropical Rainfall Measuring Mission (TRMM) data has been developed and applied to the Pacific Ocean to produce the velocity field. The assimilated data will be indispensable to examine the effects of rainfall and its variability on the structure and circulation of the tropical oceans and to assess the impact of global warming due to the increase of carbon dioxide on the ocean circulation system and the marine pollution caused by oil spill and ocean damping of radionuclide. The data will also provide the verification for the oceanic and ocean-atmosphere coupled general circulation models(GCMs).

The system consists of oceanic GCM, analysis scheme and data. In the system the flow field has been determined to be physically consistent with the observed density field and the sea surface winds derived from the SSM/I data which drive the ocean current. The time integration has been performed for five years until the flow field near the surface attained the steady state starting from the rest ocean with observed temperature and salinity fields, and the SSM/I surface wind velocity.

The resultant flow field showed high producibility of the system. Especially the flow near the ocean surface agreed well with available observed data. The system, for the first time, succeeded to produce the eastward subtropical current which has been discovered in the joint investigation on Kuroshio current (CSK) in the 1960s.

To verify the quality of the flow field a trajectory analysis has been carried out and compared with the Algos buoy data.

BRIEF DESCRIPTION OF THE DATA ASSIMILATION SYSTEM

* Oceanic GCM and analysis scheme--The basic equations are much the same as used for the GCMs, except for the Newtonian damping terms introduced into the prediction equations for the potential temperature and salinity to maintain these fields as observed. The C grid of 2°lat. by 2°long. in horizontal and the 11 vertical levels are applied to the entire Pacific Ocean. At the east and west ocean boundaries the periodic boundary conditions are applied creating fictitious ocean there. The SMAC Method is used to increase the accuracy of mass conservation.
* Data--The JODC temperature and salinity data obtained from 1906 to 1988 are used in the system between Long.100°E. and 60°W. The surface wind data are derived from the SSM/I data by Dr.R. Atlas of NASA/GSFC. The data set contains every 6 hours data from July 1987 to June 1989 on the grid of 2°lat. by 2.5°long. The averaged for the whole period and then interpolated into the 2°lat. by 2°long. grid data are used to force the system.

The sea bottom topography data was based on the General Bathymetric Chart of the Ocean (GEBCO) supplied by the Canadian Hydrographic Service under contract with the International Hydrographic Organization and International Oceanographic Commission of UNESCO.

2. BIBLIOGRAPHIC REFERENCES

Takano, K. and A. Wada, Pacific Ocean flow simulation using a data assimilation system, Proceedings of 1995 ADEOS/NSCAT Science Working Team Meeting in Kyoto, Japan, 275-287, 1995.

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PACIFIC OCEAN FLOW SIMULATION USING A DATA ASSIMILATION SYSTEM

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1. INTRODUCTION

The purpose of this research is to develop an oceanic data assimilation system that enable us to assess the impact of global warming due to the increase of carbon dioxide on the ocean circulation system as well as the marine pollution caused by oil spill and ocean damping of radionuclide. The assimilated data will provide the verification for the ocean and coupled GCMs. The satellite derived surface wind to drive the system is indispensable to the success of this research.

In the meteorological society the four-dimensional data assimilation systems have been extensively developed and the global analyzed data have been widely used as the initial conditions for the numerical weather prediction and the verifications for GCMs to increase the accuracy, and for various observational studies from diurnal to inter annual time scale phenomenon, since the conventional and satellite data of high space and time resolutions have been available through the global networks.

For the oceans as well known the luck of data especially for the velocity presently makes it difficult to perform the assimilation and even construct the global three-dimensional (3-d) fields. The hydrographic data such as the temperature and salinity are relatively available to the velocity data and if these data of several decades were composed the averaged 3-d global distribution of these may be obtained with some accuracy yet leaving the velocity field undetermined. Then the problem is to produce the velocity field by combining the hydrographic data with a data assimilation system and complete physically consistent gridded data set.

In this paper an oceanic data assimilation is performed to produce the 3-d velocity field in the Pacific Ocean. The main concept that the predicted potential temperature and salinity fields relax to the observed fields through the Newtonian damping terms is the same as used in Sarmiento and Bryan (1982) for the North Atlantic, Fujio and Imasato (1991) for the Pacific and Fujio et al. (1992a, 1992b) for the world ocean. However the ocean model and the data used are different. The surface wind derived from the SSM/I data by Dr.R.Atlas of NASA/GSFC are used to drive the system.

2. NUMERICAL MODEL

The basic equations are much the same as used for the general circulation models, except for the Newtonian damping terms introduced into the prediction equations for the potential temperature and salinity to maintain these fields as observed. The damping coefficients are chosen from Sarmiento and Bryan (1982). The C grid of 2°lat. by 2°long. in horizontal and the 11 vertical levels are applied to the entire Pacific Ocean. At the east and west ocean boundaries the periodic boundary conditions are applied creating fictitious ocean there. The SMAC Method is used to increase the accuracy of mass conservation.

3. DATA

The JODC temperature and salinity data obtained from 1906 to 1988 are used in the system between Long.100°E. and 60°W.

The surface wind data are derived from the SSM/I data by Dr. R. Atlas of NASA/GSFC. The data set contains every 6 hours data from July 1987 to June 1989 on the grid of 2°lat. by 2.5°long. The averaged for the whole period and then interpolated into the 2°lat. by 2°long. grid data are used to force the system (Fig.1).

The sea bottom topography data was based on the General Bathymetric Chart of the Ocean (GEBCO) supplied by the Canadian Hydrographic Service under contract with the International Hydrographic Organization and International Oceanographic Commission of UNESCO.

4. RESULTS

The time integration has been performed for five years until the flow field near the surface attained the steady state starting from the rest ocean with observed temperature and salinity fields, and the SSM/I surface wind velocity.

The calculated flow fields at the 35m and 600m levels are shown in Fig.2 and Fig.3, respectively. The flow pattern at the 35m level agrees well with the observed surface flow data. The system has clearly produced the main 3 circulations in the each hemisphere including the tropical currents, the large subtropical gyres and the Antarctic circumpolar current. The system has also produced the Alaskan, the Bering, the western subarctic and the Okhotsk sea gyres in the north Pacific. At the 600m level the equatorial under current is well produced (Fig.3). The most notable result is that for the first time the system has produced the eastward subtropical current between Lat. 20N° and 25°N. which has been discovered in the joint investigation on Kuroshio current (CSK) in the 1960s.

The speeds of currents are relatively smaller than those observed locally (e.g. 50 cm/sec of computed Kuroshio v. 200 cm/sec of observed). These may be attributed to the usage of 2° grid size and as the averaged values in the grid these values may be acceptable.

Between the westward north equatorial current and the eastward equatorial counter current the sharp boundary is not formed as in the observation. This may be also caused by the grid.

The vertical circulation systems including the upwellings in the tropic and the Antarctic Ocean is produced, although the vertical velocity fields from middle to deep ocean are not yet attained the steady state after five years. The good agreement of initial vertical density distribution with after five years one showed that the assimilation was efficiently working.

To verify the quality of the flow field an trajectory analysis has been carried out and compared with the Algos buoy data.

5. CONCLUDING REMARKS

An oceanic data assimilation system has been developed and applied to the Pacific Ocean to produce 3-d flow field. The system consists of ocean GCM, analysis scheme and data. In the system the flow field has been determined to be physically consistent with the observed density field and the sea surface winds derived from the SSM/I data which drive the ocean current. The resultant flow field showed high producibility of the system. Especially the flow near the ocean surface agreed well with available observed data. The system first produced the eastward subtropical current. The detailed analysis and additional observation of the current are needed to verify the result.

The future plans to improve the system include to increase the horizontal (to the 1° grid) and vertical resolutions, to expand the domain to the world ocean, to produce the data set which resolve seasonal and inter annual changes, and to use the NSCAT derived surface wind data.

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Fujio,S.,and N.Imasato, Diagnostic calculation for circulation and water mass movement in the deep Pacific, J.Geophys.Res., 96,759-774,1991.

Fujio,S., T.Kadowaki, and N.Imasato, World ocean circulation diagnostically derived from hydrographic and wind stress fields, 1,The velocity field,J.Geophys.Res.,97,11,163-11,176, 1992a.

Fujio,S., T.Kadowaki, and N.Imasato, World ocean circulation diagnostically derived from hydrographic and wind stress fields, 2,The water movement,J.Geophys.Res.,97,14,439-14,452, 1992b.

Sarmiento,J.L., and K.Bryan, An ocean transport model for the North Atlantic, J.Geophys.Res.,87,394-408,1982.

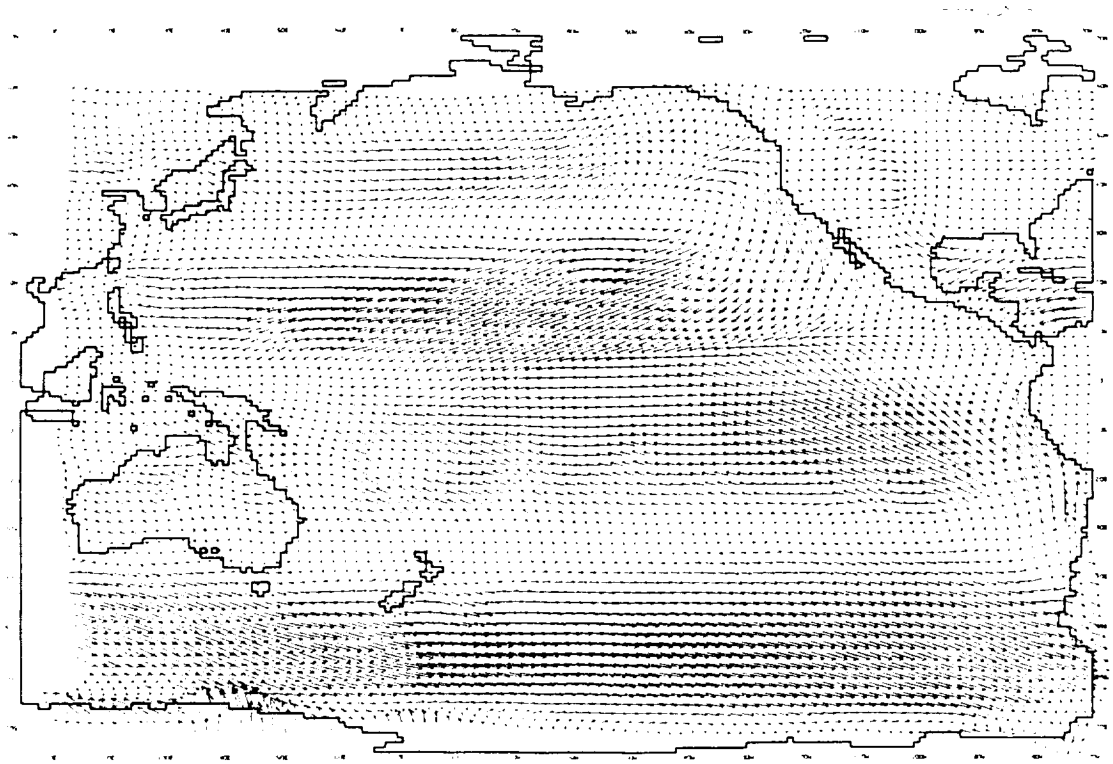


Fig.1   Surface wind velocity
SSM/I by Atlas (July 1987 to June 1989)

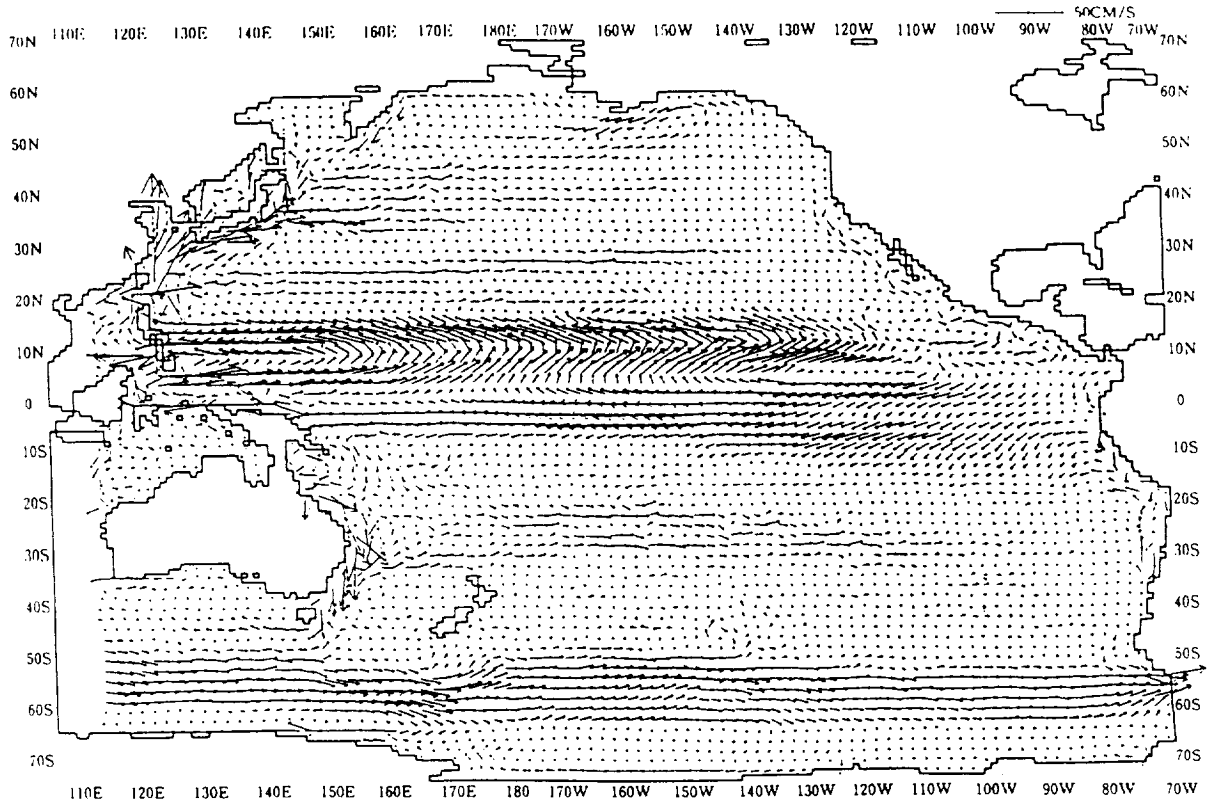


Fig.2 Horizontal flow (2nd layer: 20 - 50m)

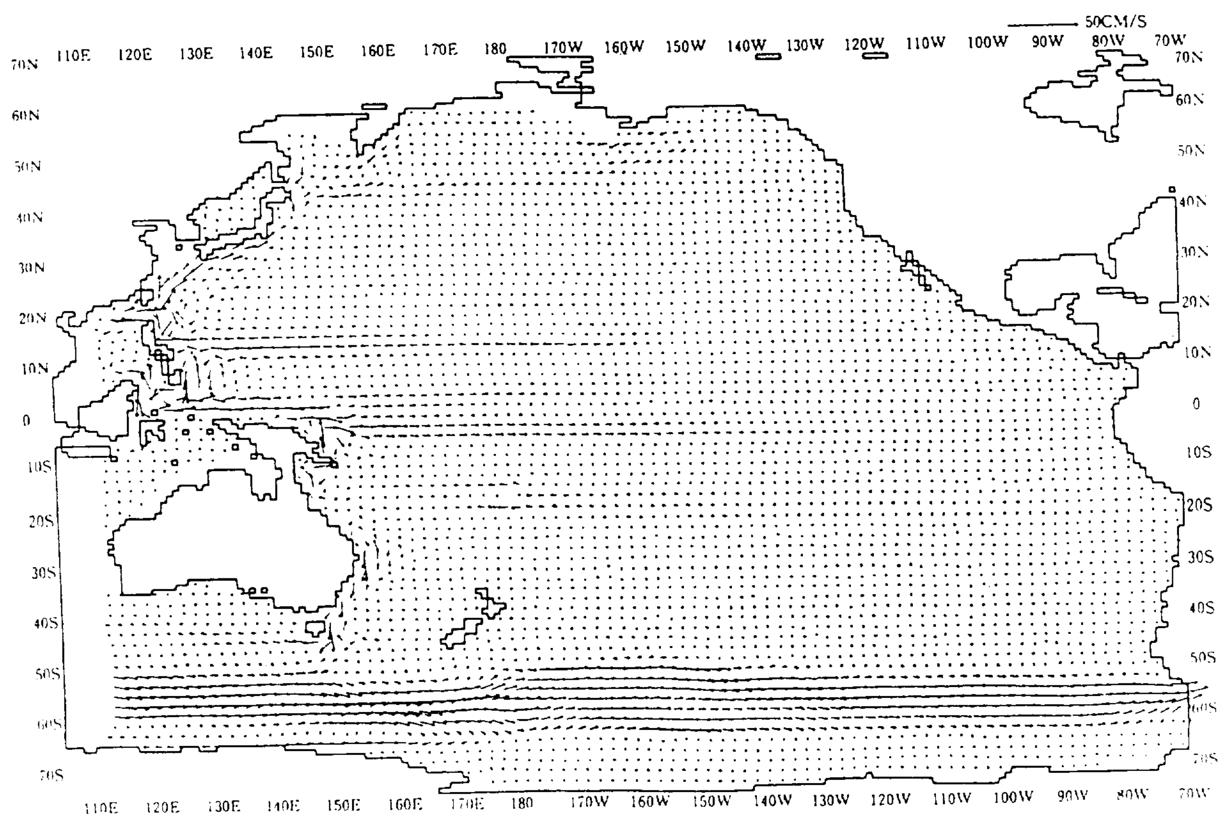


Fig.3 Horizontal flow (6th layer: 400 - 800m)

PACIFIC OCEAN FLOW SIMULATION

1. Introduction

1) An active discussion ------- Global warming caused by increased carbon dioxide

2) Marine pollution ----------- Social attention

3) Role of the ocean ---------- Unclear points
(transport of CO_2, route of pollution)

4) Complete observation networks in a vast ocean requires enormous time and expenses

5) Adoption of data assimilation in the ocean
Sarmiento & Bryan (1982) ---- the Atlantic Ocean
Effect of term γ on ocean circulation

6) Effectiveness of data assimilation & its application to the Pacific Ocean

3. BASIC EQUATIONS, CALCULATING CONDITIONS, BOUNDARY CONDITIONS AND PARAMETERS:

3.1 Basic equations

(1) Coordinate system and assumption —
As a coordinate system, spherical coordinates were used in the horizontal direction. In the vertical direction, hydrostatic approximation was assumed. Also, the rigid lid was assumed as sea surface.

(2) Equation of motion —

$$\frac{\partial u}{\partial t} + \frac{u}{r\cos\phi}\frac{\partial u}{\partial \lambda} + \frac{v}{r}\frac{\partial u}{\partial \phi} + w\frac{\partial u}{\partial r} - \frac{vu}{r}\tan\phi$$
$$= -\frac{1}{\rho r\cos\phi}\frac{\partial p}{\partial \lambda} + A_M\left\{\frac{1}{r^2}\frac{1}{\cos\phi}\frac{\partial}{\partial\phi}\left[\cos\phi\frac{\partial u}{\partial\phi}\right] + \frac{1}{r^2\cos^2\phi}\frac{\partial^2 u}{\partial\lambda^2}\right\}$$
$$+ k_M\frac{1}{r^2}\frac{\partial}{\partial r}\left[r^2\frac{\partial u}{\partial r}\right] + 2\omega v\sin\phi - 2\omega w\cos\phi \qquad (1)$$

$$\frac{\partial v}{\partial t} + \frac{u}{r\cos\phi}\frac{\partial v}{\partial \lambda} + \frac{v}{r}\frac{\partial v}{\partial \phi} + w\frac{\partial u}{\partial r} + \frac{u^2}{r}\tan\phi$$
$$= -\frac{1}{\rho r}\frac{\partial p}{\partial \phi} + A_M\left\{\frac{1}{r^2}\frac{1}{\cos\phi}\frac{\partial}{\partial\phi}\left[\cos\phi\frac{\partial v}{\partial\phi}\right] + \frac{1}{r^2\cos^2\phi}\frac{\partial^2 v}{\partial\lambda^2}\right\}$$
$$+ k_M\frac{1}{r^2}\frac{\partial}{\partial r}\left[r^2\frac{\partial v}{\partial r}\right] - 2\omega u\sin\phi \qquad (2)$$

$$0 = -\frac{1}{\rho}\frac{\partial p}{\partial r} - g \qquad (3)$$

(3) Equation of continuity —

$$\frac{1}{r\cos\phi}\left\{\frac{\partial(u\rho)}{\partial\lambda}+\frac{\partial(\cos\phi\, v\rho)}{\partial\phi}\right\}+\frac{1}{r^2}\frac{\partial(r^2 w\rho)}{\partial r}=0 \tag{4}$$

(4) Equation of [redacted] potential temperature and salinity —

$$\frac{\partial\theta}{\partial t}+\frac{u}{r\cos\phi}\frac{\partial\theta}{\partial\lambda}+\frac{v}{r}\frac{\partial\theta}{\partial\phi}+w\frac{\partial\theta}{\partial r}$$

$$=A_{HH}\frac{1}{r^2}\left\{\frac{1}{\cos^2\phi}\frac{\partial^2\theta}{\partial\lambda^2}+\frac{1}{\cos\phi}\frac{\partial}{\partial\phi}\left[\cos\phi\frac{\partial\theta}{\partial\phi}\right]\right\}$$

$$+A_{HV}\frac{1}{r^2}\frac{\partial}{\partial r}\left[r^2\frac{\partial\theta}{\partial r}\right]+\underline{\gamma(\theta^*-\theta)} \tag{5}$$

$$\frac{\partial S}{\partial t}+\frac{u}{r\cos\phi}\frac{\partial S}{\partial\lambda}+\frac{v}{r}\frac{\partial S}{\partial\phi}+w\frac{\partial S}{\partial r}$$

$$=A_{HH}\frac{1}{r^2}\left\{\frac{1}{\cos^2\phi}\frac{\partial^2 S}{\partial\lambda^2}+\frac{1}{\cos\phi}\frac{\partial}{\partial\phi}\left[\cos\phi\frac{\partial S}{\partial\phi}\right]\right\}$$

$$+A_{HV}\frac{1}{r^2}\frac{\partial}{\partial r}\left[r^2\frac{\partial S}{\partial r}\right]+\underline{\gamma(S^*-S)} \tag{6}$$

(5) Equation of state —

$$\rho=\rho\,(T,\ S,\ p) \tag{7}$$

The equation of the state of international sea water, 1980 (UNESCO), was used.

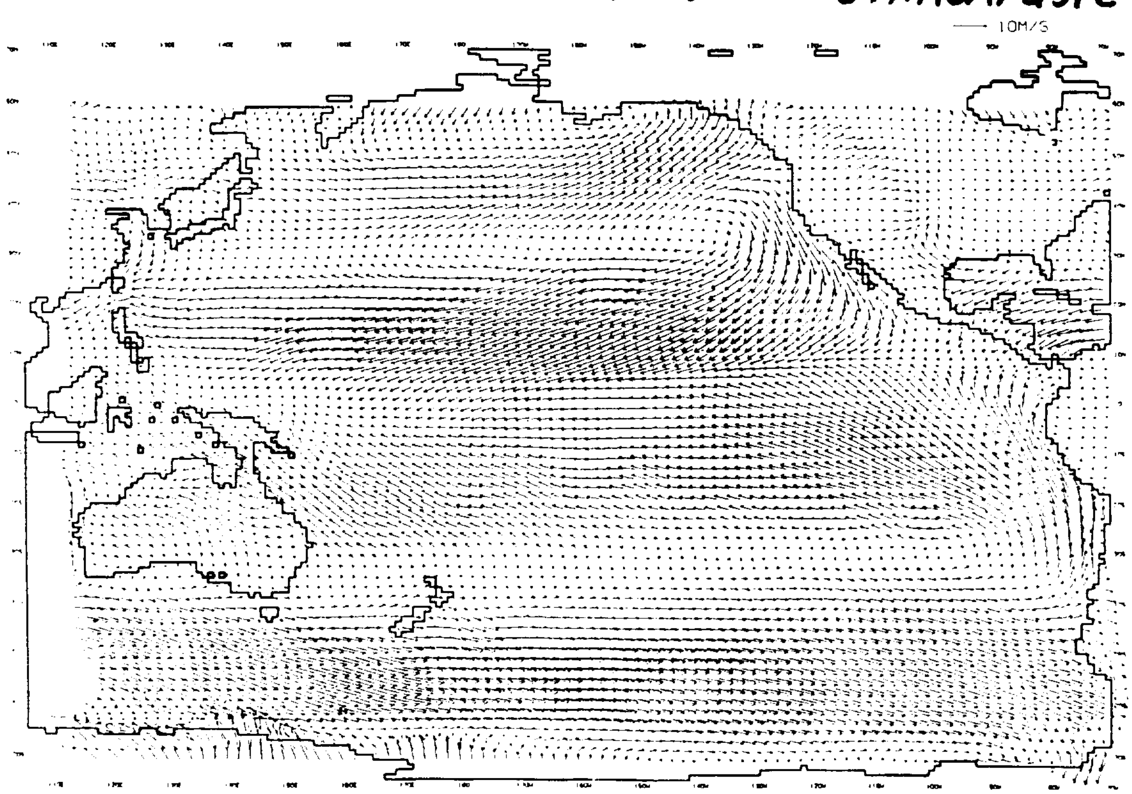
Where,

u, v, w	: Eastward, northward and upward velocity components, respectively
r	: Radius of the earth
ω	: Angular speed of the rotation of the earth
λ	: Longitude
ϕ	: Latitude
p	: Pressure of sea water
ρ	: Density of sea water
A_M	: Coefficient of horizontal eddy viscosity
k_M	: Coefficient of vertical eddy viscosity
A_{HH}	: Coefficient of horizontal eddy diffusion
A_{HV}	: Coefficient of vertical eddy diffusion
T^*, S^*	: Observed values of water temperature and salinity, respectively
T, S	: Calculated values of water temperature and salinity, respectively

Parameter values

Item	Symbol	Value
Horizontel eddy viscosity	A_{MH}	$10^7 cm^2/s$
Vertical eddy viscosity	A_{MV}	$100 cm^2/s$
Horizontal diffusivity	A_{HH}	$10^6 cm^2/s$
Vertical diffusivity	A_{HV}	$10 cm^2/s$
γ term (sea surface)	γ_s	1/50 days ($2.31 \times 10^{-7} S^{-1}$)
γ term (any depth)	γ_D	1/250 days ($4.63 \times 10^{-8} S^{-2}$)
Depth affected by γ term		500m

Surface Wind Velocity by Atlas. NASA/GSFC



July 1987 to June 1989 SSM/I

2. Processing of data used

1) Data sources

Water temperature & salinity data (1906 - 1988) ---------- JODC

Wind data (1987.7 - 1989.6) ---------- NASA

Sea bottom topography ---------- GEBCO

(General Bathymetric Chart of the Oceans)

2) Quality control of data ----------

NOAA Professional Paper 13 (1982)

3) Wind vector data set

A grid of 2° in longitude and latitude

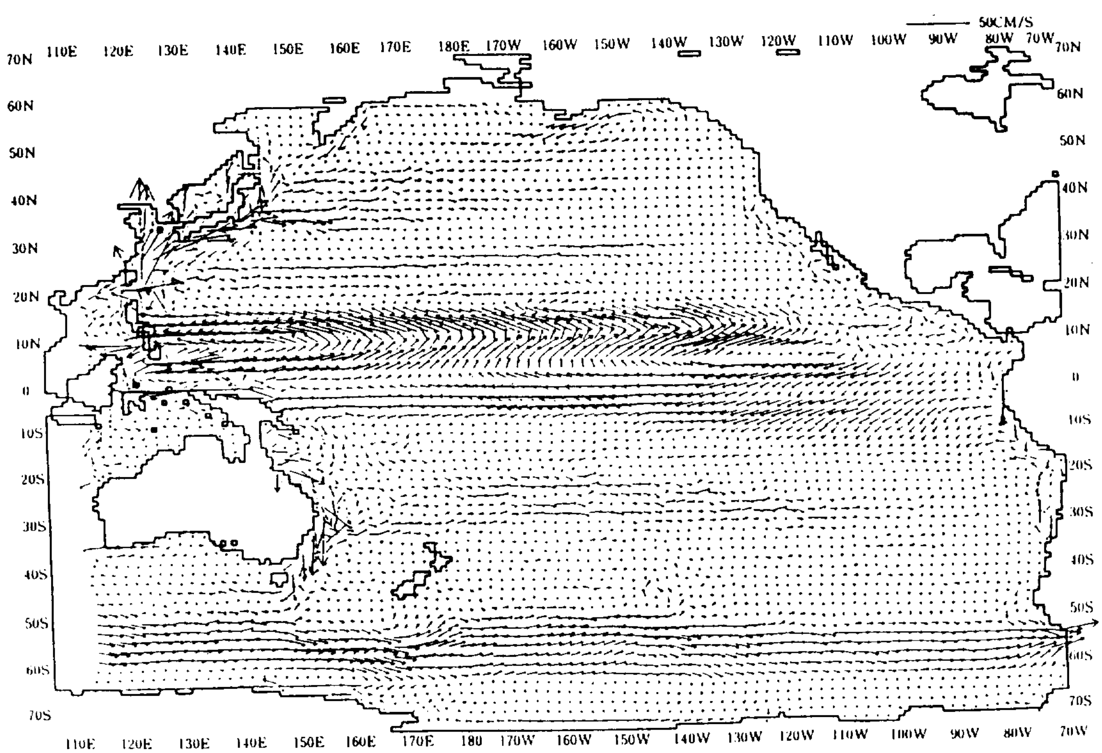
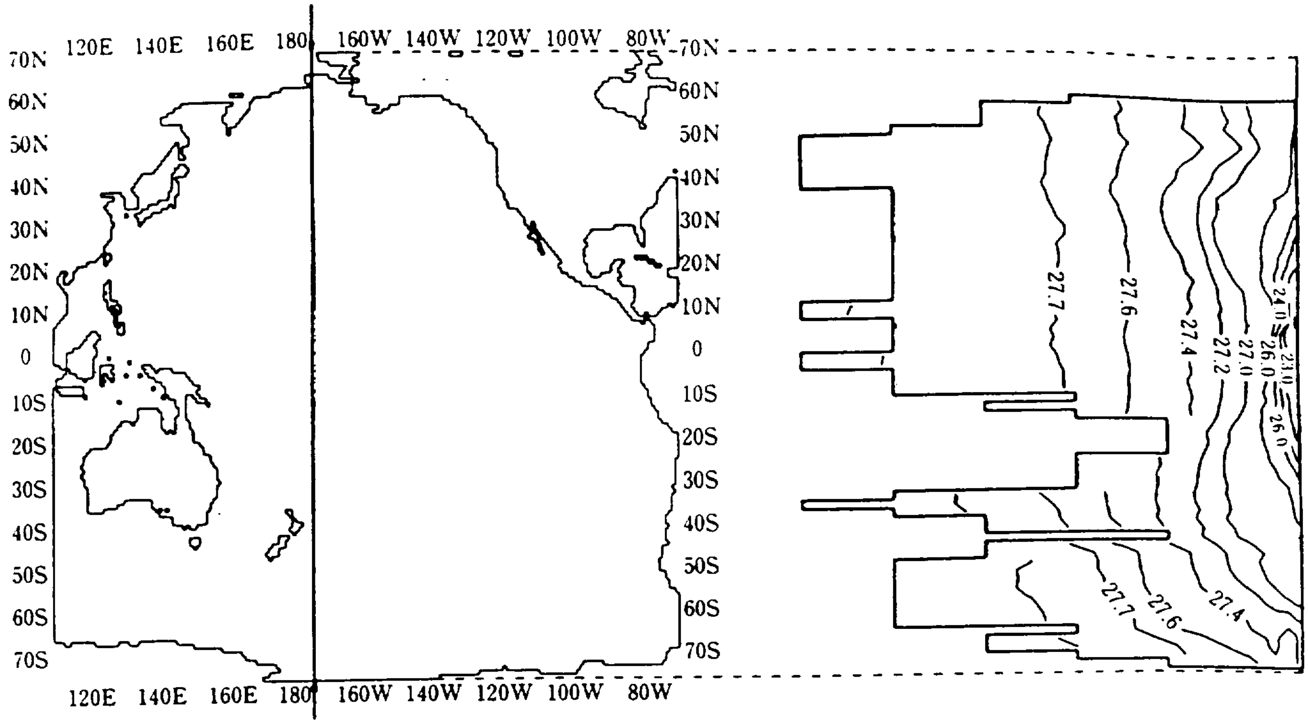
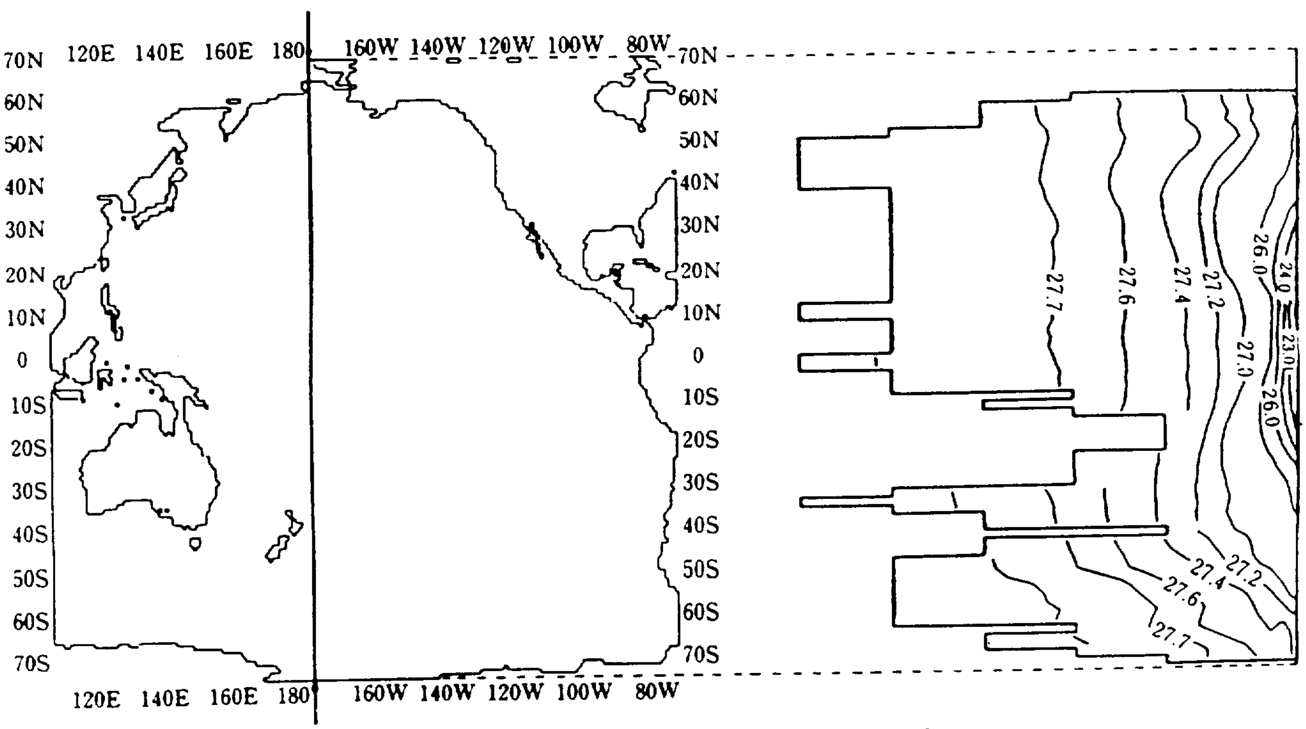


Fig. 4.1.1a Horizontal flow (2nd layer: 20 ~ 50 m)



Initial density field



Density field after assimilation
(5 years later)

Fig. 4.2.1 Comparison of density fields (north and south vertical section : 180° W)

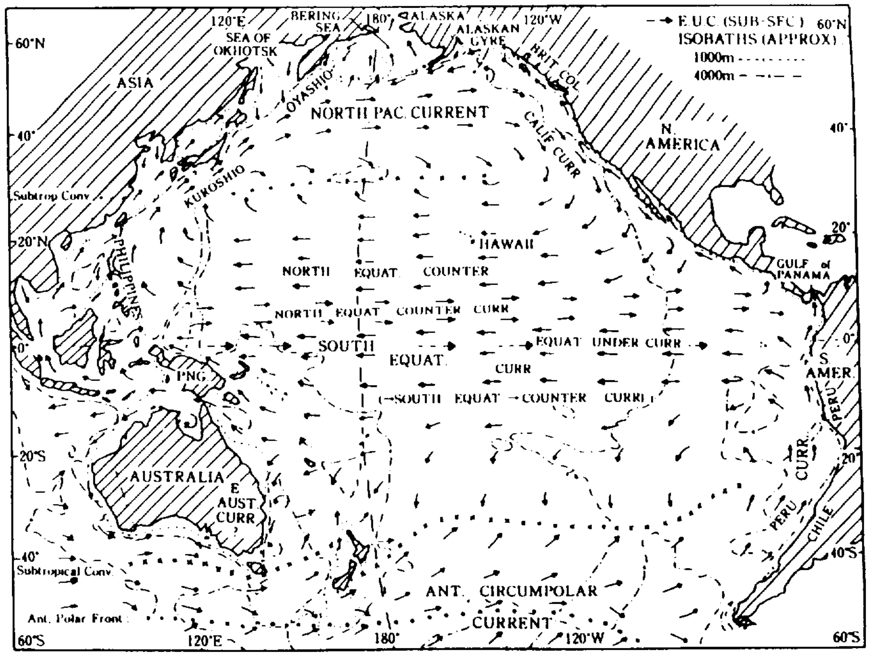
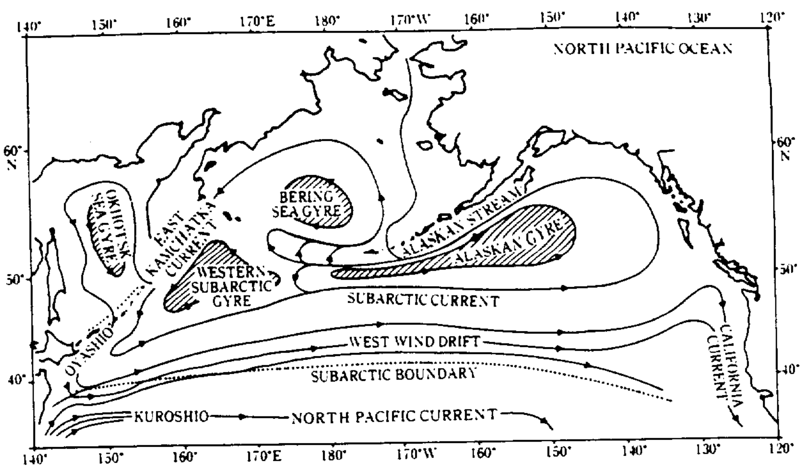
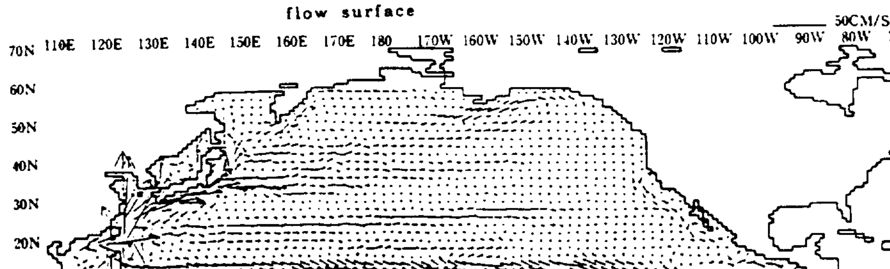


Fig. 4.1.2　Pacific surface-layer circulation map



(A)　Dodimead et al. (1963), surface-layer circulation assuming about 1,000 m as non-flow surface



(B)　Surface-layer (20 ~ 50 m) based on calculated results

Fig. 4.1.3　Comparison of circulations in the North Pacific subarctic zone

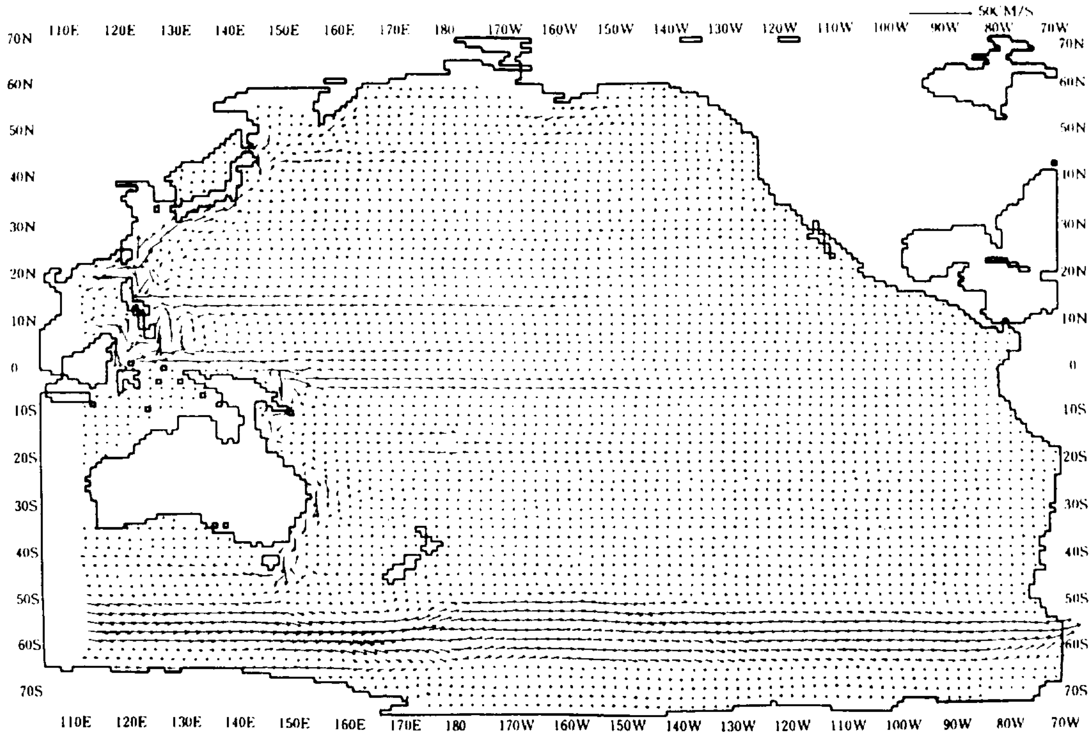


Fig. 4.1.1b Horizontal flow (6th layer: 400 ~ 800 m)

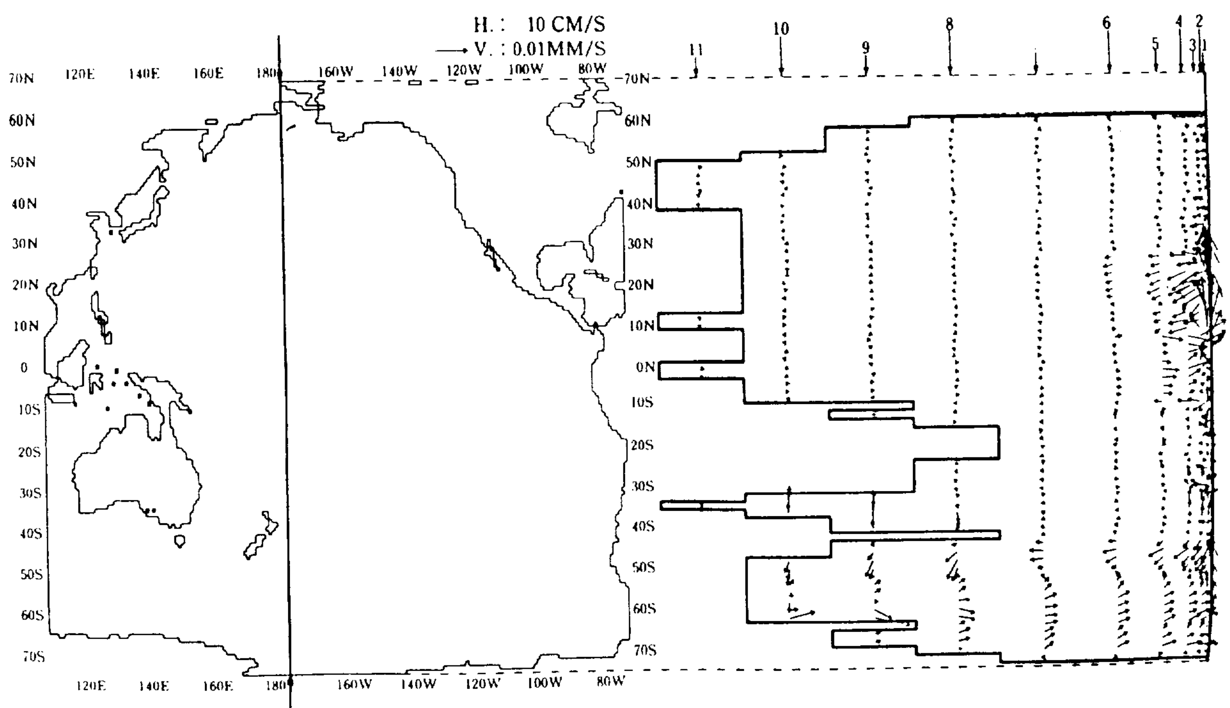


Fig. 4.1.4 Vertical flow (180° meridian section)

(Horizontal flow velocity : vertical flow

velocity = 1 : 10,000)

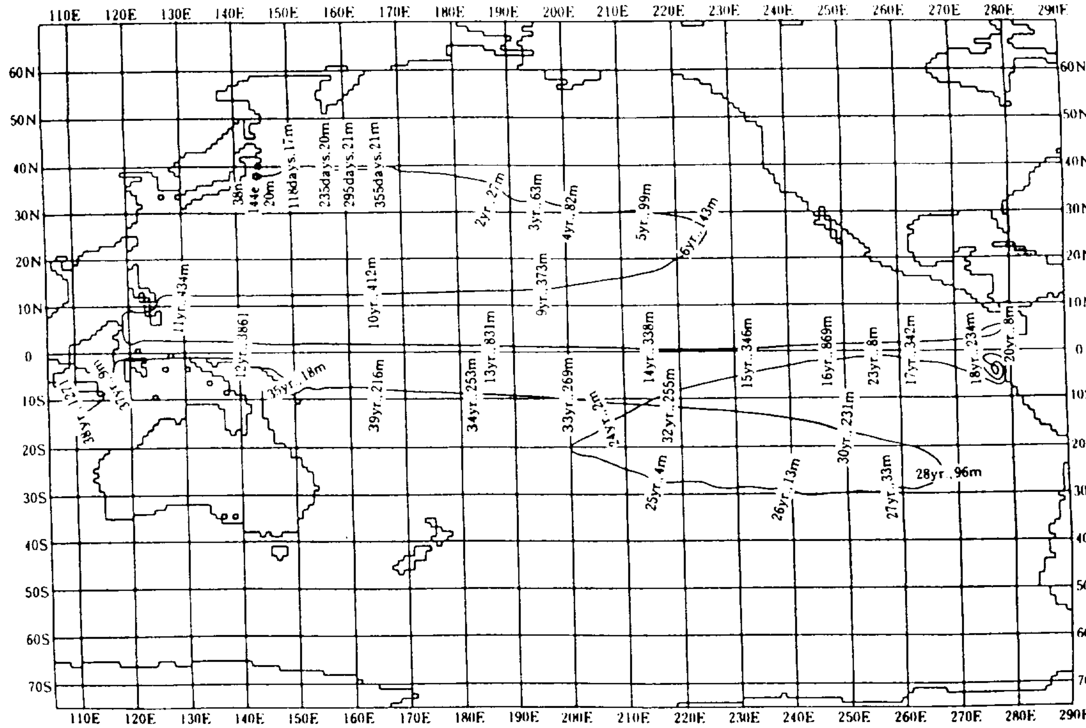


Fig. 4.3.1 Results of particle injection and tracking in the seas around the Kuroshio continuous current (particles are injected in the sea of 20m deep and three-dimensional tracking s performed)

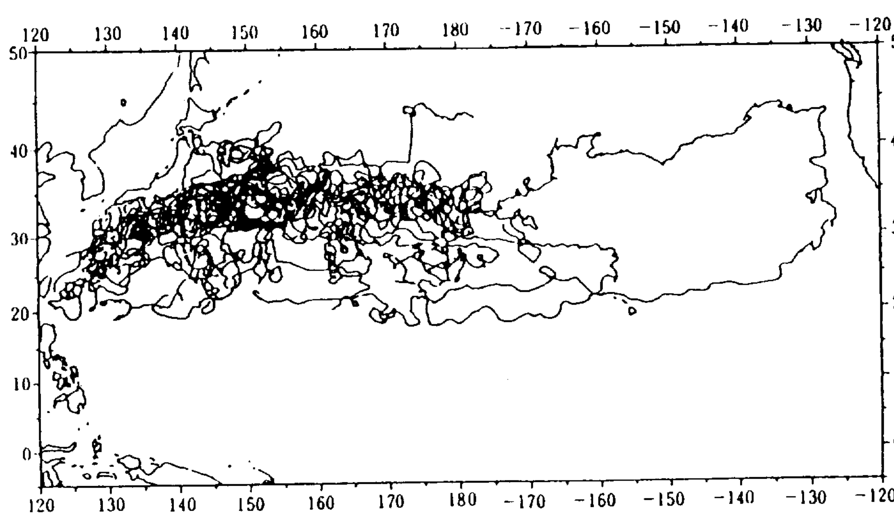


Fig. 4.3.2 Traces of marker buoys released in "Research on Development and Utilization of the Kuroshio Current" (Michita, Ishii, 1992)

PROCEEDINGS OF THE 6TH INTERNATIONAL SYMPOSIUM ON
FLOW MODELING AND TURBULENCE MEASUREMENTS
TALLAHASSEE / FLORIDA / USA / 8-10 SEPTEMBER 1996

Flow Modeling and Turbulence Measurements VI

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OFFPRINT

A.A. BALKEMA / ROTTERDAM / BROOKFIELD / 1996

Pacific Ocean flow simulation using the data assimilation system

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ABSTRACT: Numerical simulations using the data assimilation system were conducted on Pacific Ocean areas to examine the effectiveness of data assimilation on marine fluctuation prediction systems. The result of analysis by this system indicates a very high reproducibility in light of existing information which is currently available on the surface-layer flow.

1. INTRODUCTION

In recent years, an active discussion has been under way on global warming caused by increased carbon dioxide, and there are still many unclear points regarding the role the ocean plays in the transportation of carbon dioxide between the atmosphere and the ocean. Moreover, marine pollution is attracting strong social attention because it has an important influence on the global environment.

On the other hand, in addition to the lack of information on the actual ocean current, the establishment of complete observation networks in a vast ocean requires enormous time and expense, making it difficult to attain such information under the present circumstances.

To cover the lack of these measured values and have a better understanding about the condition of the ocean, various kinds of numerical simulations are presently under way. However, numerical models of the ocean contain various kinds of uncertain elements such as approximation or assumption in basic equations, abbreviation of terms, assumption in boundary conditions, etc., thereby making it difficult to analyze the ocean circulation with a sufficient accuracy. In this manner, under the present circumstances, one possible way to obtain more realistic results is to attain matching while modifying predicted values with observed values.

In this report, the authors discuss the effectiveness of data assimilation and its application as a result of numerical simulations conducted in the Pacific Ocean.

2. PROCESSING OF DATA USED

Concerning the water temperature and salinity data used in the analyses, those obtained in the section of east longitude 100° and west longitude 60° based on the observations made in each layer between 1906 and 1988 by JODC, as well as on the Unified Water-temperature Observations, were used.

The wind data used were based on the observations made by NASA every 6 hours for the 11 month period from July 1988 to June 1989. The data supplied had already been in the grid form of 2° × 2.5° with quality control.

3. BASIC EQUATIONS AND CALCULATING CONDITIONS

3.1 *Basic equations*

As a coordinate system, spherical coordinates were used in the horizontal direction. In the vertical direction, hydrostatic approximation was assumed. Also, the rigid lid was assumed as sea surface.

The technique is taken in such a way that the flow field obtained satisfies, with a sufficient accuracy, the conservation laws of mass, salinity and heat.

3.2 *Calculating conditions*

The entire Pacific Ocean was subjected to calculations. Horizontal calculation meshes were 2° × 2° in longitude and latitude. The layer was vertically divided into 11 layers.

The exchange of heat and salinity with the atmosphere was replaced with T and S fixed in the surface layer, respectively; when the inversion of density occurred, salinity in the inverted layer was mixed momentarily. The mean water depth of a 2° grid is used in sea-bottom topography.

The result of flow was evaluated as steady when change in flow velocity was below 10^{-6}. The equation of judgment is as follows:

$$e_z = \frac{\| X^{n+1} - X^n \|_z}{\| X^{n+1} \|_z} \quad , \quad \| V \|_z = \sqrt{\sum_{ijk} V_{ijk}^2}$$

Where X : u, v, w (velocity component), S (Salinity), T (Water temperature).

4. RESULTS OF FLOW ANALYSIS

The results of analysis indicate a very high reproducibility when compared to the existing data on surface current which we are presently aware of. The results of analysis on water temperature and salinity distribution fields also agree well with the observed values.

The calculated velocities of the Kuroshio current were 30 ~ 40cm/s. The measured velocities of the Kuroshio current, as momentary values, are 100 ~ 200cm/s, but are in the scale of 1/2 ~ 1/4 according to calculations. This may be attributable to a difference between the size of calculation grids (120 mile) and the width of the Kuroshio current zone (60 mile). (Fig. 4.1)

The circulation structure in the top layer agrees very well with the circulation structure of the present information, despite that the calculation time is relatively short (5 years). The eastward subtropical ocean current, which is said to have been discovered in Joint Investigation on Kuroshio Currents (CSK) in the 1960s, is also expressed. This is presumable attributable to the effect of the data assimilation system which can give a density distribution from the beginning of the calculation and maintain this, coupled with the effect of wind, thus indicating that the influence of a realistic density distribution on the equation of motion, that is, the density effect on a large-scale motion, is very important in the calculation process.

In detailed points, however, there are some spots which cannot be expressed. For example, a clear boundary as shown in the existing information is not formed between the tropical northern equatorial ocean current and the equatorial countercurrent which flows eastward in the equatorial windless zone. This is perhaps attributable to the problem of calculation grid intervals in the same way as the scale of Kuroshio current velocity, which can be basically solved by finely-divided grid intervals.

Only when the whole Pacific Ocean is subjected to investigation, the establishment of boundary conditions inevitably comes into question. In the present calculations, processing is carried out using periodic conditions concerning the Antarctic circumpolar sea and no attempt is made at all to set conditions such as the inflow from the Indian Ocean.

The vertical flow observed in the results of calculations is not a conclusive one because vertical division is relatively coarse in the 11th layer, the time elapsed for calculations is 5 years, although the change in the flow velocity e_x with the lapse of time was below 10^{-6}.

However, the vertical density section or water temperature/salinity section is very close to the actual distribution.

Shown in Fig. 4.2 is a comparison between the initial density and the density 5 years later in the density section of the 180° meridian line.

From this figure, it can be judged that the data assimilation system is working very effectively. Density distribution fields in each layer indicate almost the same fields as initial values, and are in agreement at a satisfactory level. In details, however, there are some differences because density inversion occurs from time to time in the calculation process and this inversion is compensated through momentary mixing.

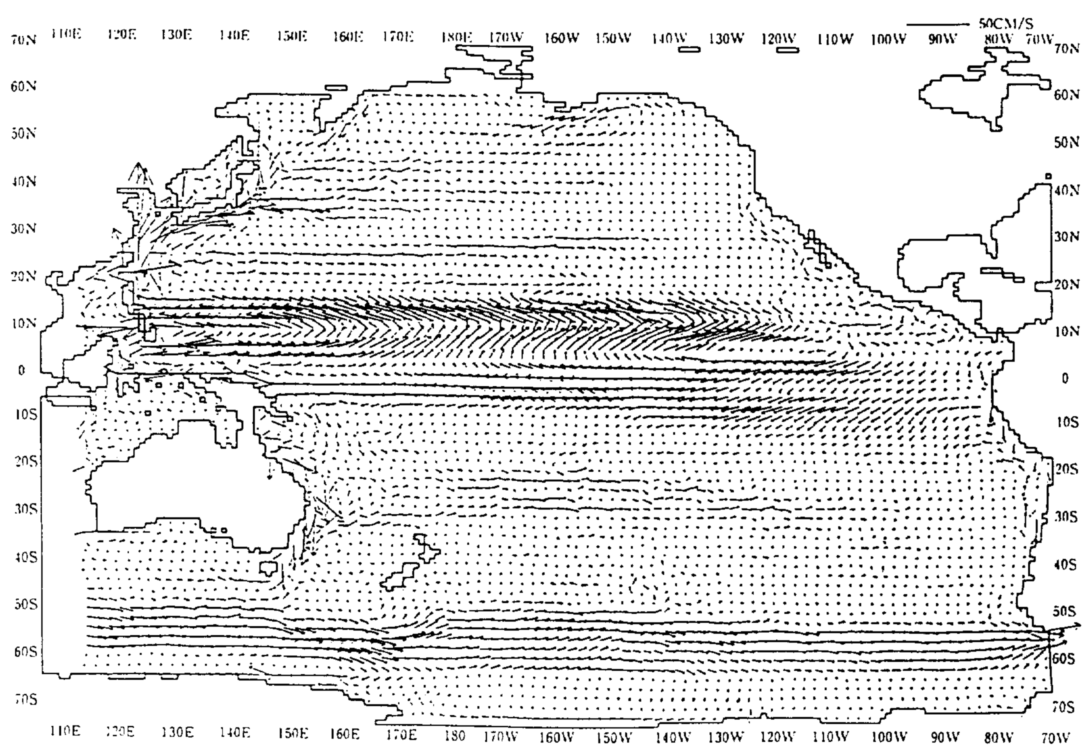
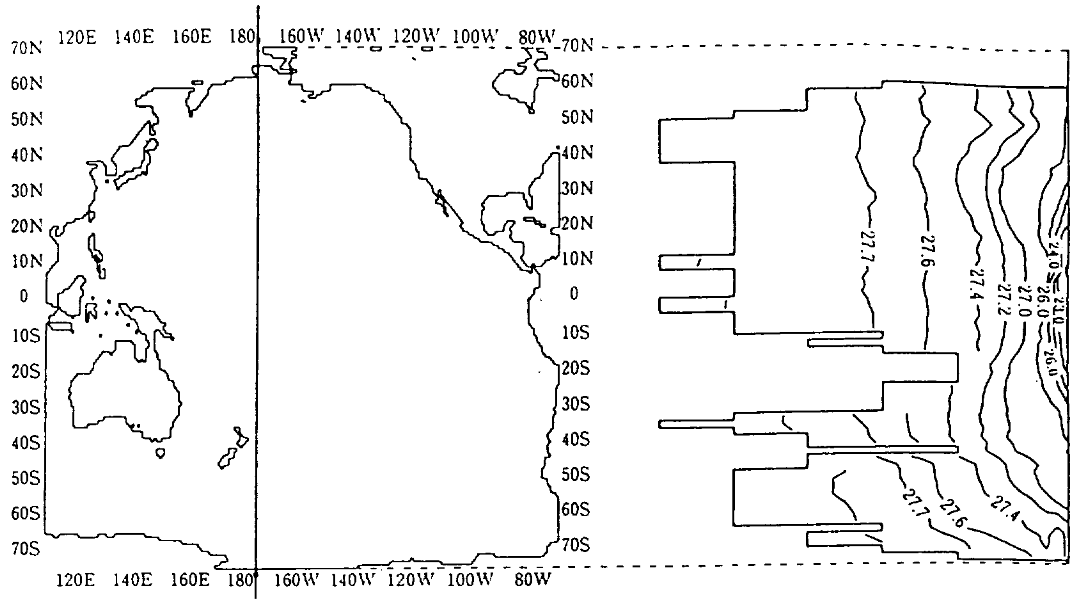
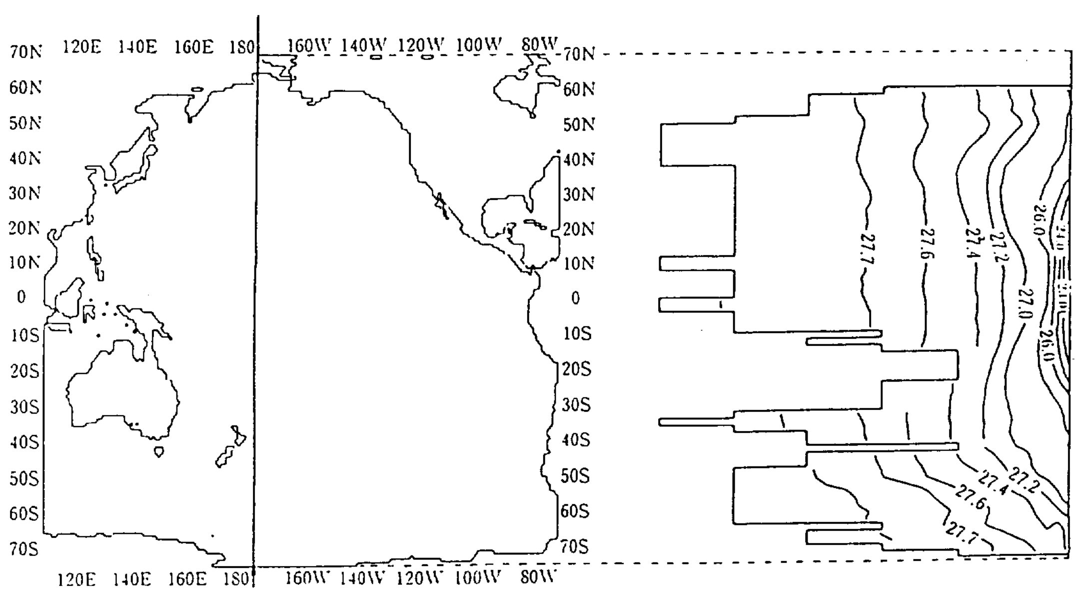


Fig. 4.1 Horizontal flow (2nd layer 20 ~ 50m)



Initial density field



Density field after assimilation (5 years later)

Fig. 4.2 Comparison of density fields
(north and south vertical section: 180° W)

5. TRACKING OF PARTICLES

Particles were injected into the velocity vector field and tracked. Two types of particles were used, i.e., suspended particles which travel in the surface layer alone and water particles which permit sinking and upwelling. (Fig. 5.1)

The results of tracking were compared with Algos-buoy tracking data obtained in Investigation and Research on the Development and Utilization of Kuroshio Current (KER), Joint Investigations in the Western Pacific Seas (WESTPAC) and Joint Research on Atmospheric, Oceanographic and Meteorological Fluctuations in the Pacific Ocean (JAPCS).

Among the Algos-buoy paths indicated by Michita and Ishii (1992), those used in Investigation and Research on the Development and Utilization of Kuroshio Current (KER) are shown in Fig. 5.2.

The paths of both calculated and measured values agree very well in the respective circulation systems, though depths are different. As for their progressive speed, however, the measured tracking data are several times as large as the calculated data even in surface-layer tracking. This is because grid intervals for flow calculations are relatively large and the calculated flow velocity is expressed as the mean velocity between the grids. In consideration of this, therefore, these would be acceptable results.

Also, so as to provide reasons why the calculated paths are smooth, it can be considered that the grid interval is 2° , since an eddy smaller than that cannot be expressed and the flow itself represents the mean flow.

Thus, the results of particle tracking reveal that the circulation system can be reproduced with a considerably high degree of precision on the whole.

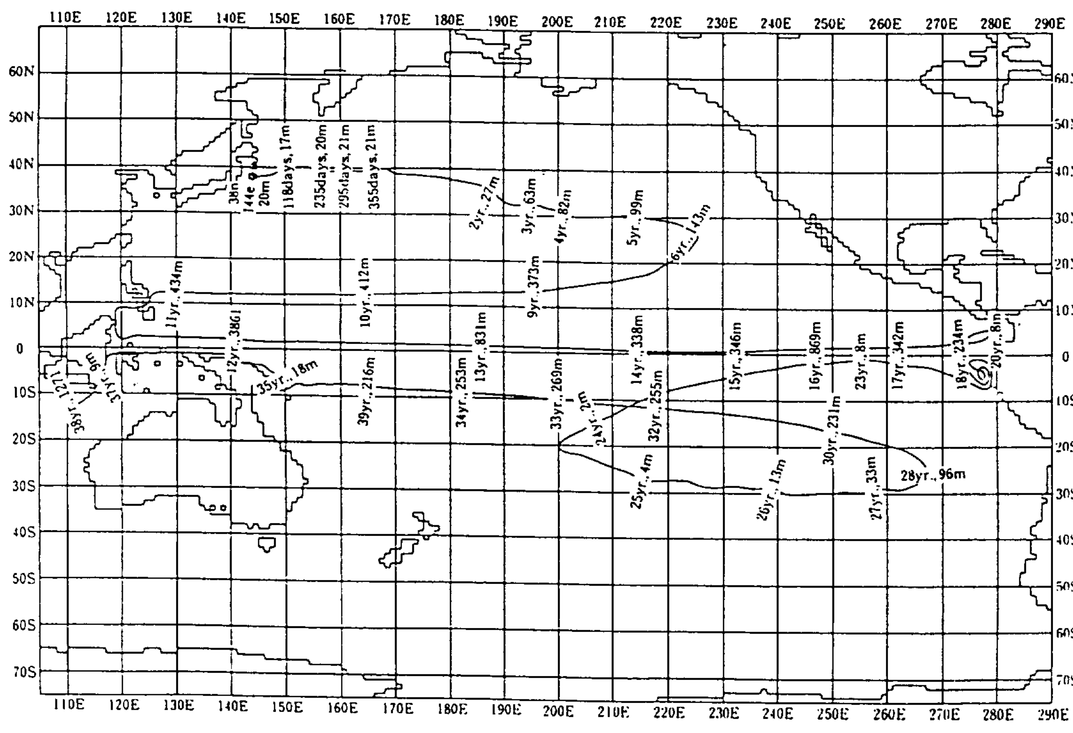


Fig. 5.1 Results of particle injection and tracking in the seas around the Kuroshio continuous current
(perticles are injected in the sea of 20m deep and three-dimensional tracking is performed)

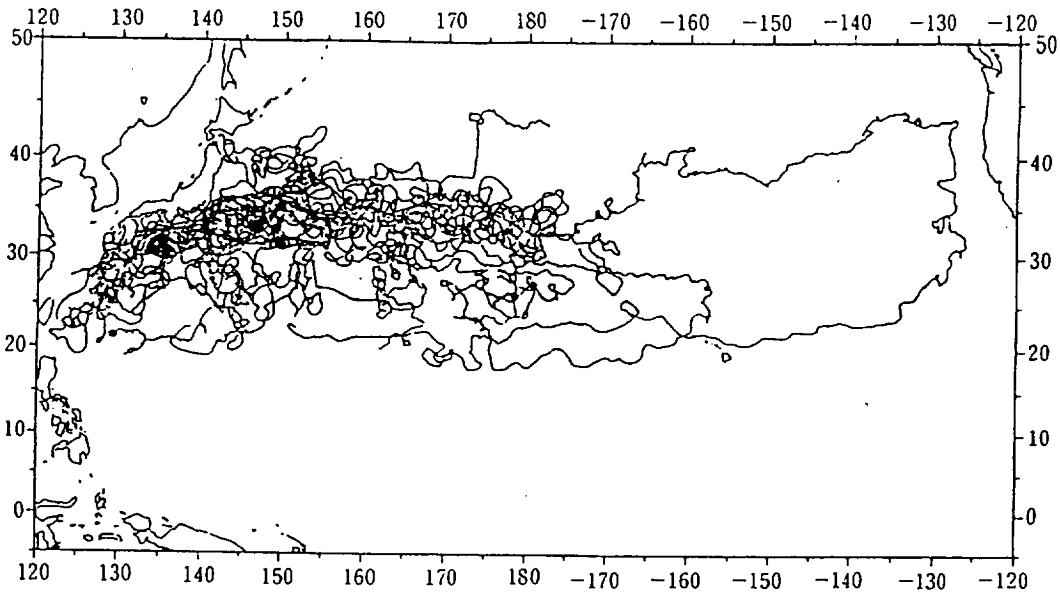


Fig. 5.2 Traces of marker buoys released in "Research on Development and Utilization of the Kuroshio Current" (Michita, Ishii, 1992)

6. SUBJECTS FOR FUTURE RESEARCH

In the present research, the authors could successfully indicate the effectiveness of the data assimilation system constructed. However, the largest problem in numerical modelling in the ocean subjected to prediction is the lack of the absolute amount of observation data and the difficulty of conducting observations. When carrying out simulations including changes with the lapse of time, the supply of periodic data is an indispensable condition. Frankly speaking, however, it is impossible to supply periodic observation data in the whole sea areas at present. Considering such a condition, it can be said that the prediction of marine fluctuations has just started.

The remaining problem, with further improvements made in input conditions (boundary, input) and with mean fields, will be to calculate step by step the fluctuations in each mean field with the object of creating a highly reliable and accurate data set by finely dividing the obtained data, for example, into a 10-year unit, a 5-year unit, a yearly unit and a seasonal unit.

Along with the results of this research, also, the authors hope, among other things, that research will be advanced in the future to encompass the completion of a practical model which can pursue seasonal and monthly changes in 10' meshes in the SAR seas in the North Pacific Ocean.

ACKNOWLEDGMENT

This research was carried out over a period of 4 years from the fiscal year 1990. Thanks are due to the following people who supplied wind data for use in this research; Dr. J.S. Theon, NASA Headquarters, Dr. R. Atlas, NASA Goddard Space Flight Center. This research has been carried out under the financial assistance of the Japan Ships Foundation.

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