PRECEDING PAGE BLANK NOT FILMED

N93-24918

Role of the Ocean in Climate Changes

Sergey K. Gulev

Introduction

The present program aimed at the study of ocean climate change is prepared by a group of scientists from State Oceanographic Institute. Academy of Science of Russia, Academy of Science of Ukraine and Moscow State University. It appears to be a natural evolution of ideas and achievements that have been developed under national and international ocean research projects such as SECTIONS, WOCE, TOGA, JGOFS and others.

During last two decades main efforts were concentrated on quantitative experimental and model description of the ocean's role in the global climate change. In particular, the significance of the energy active zones of the ocean in the ocean-atmosphere interaction processes was defined; the connections between the sea surface temperature (SST) anomalies and the inter annual variations of the global atmosphere circulation were established; the stability of the meridianal ocean thermohaline circulation and it's influence on global climate was carefully concerned about. The derived results have proved the exclusively important role of the North Atlantic as a key feature in formation of the global "conveyor" of interoceanic circulation, which determines the long-period variability of the entire climate system.

All above mentioned plus the possibility of conducting relatively inexpensive field experiments allows to address the North Atlantic as the most suitable site for studies of the Role of the Ocean in Climate Change (ROCC).

The two primary goals are set in the program ROCC.

1. Quantitative description of the Global interoceanic "conveyor" and it's role in formation of the large scale anomalies in the North Atlantic.
   The objectives on the way to this goal are:
   - to get the reliable estimates of year-to-year variations of heat and water exchange between the Atlantic ocean and the atmosphere
   - to establish and understand the physics of long period variations in meridianal heat and fresh water transport (MHT and MFWT) in the Atlantic ocean
   - to analyze the general mechanisms, that form the MHT and MFWT in low latitudes (Ekman flux), middle latitudes (western boundary currents) and high latitudes (deep convection) of the North Atlantic.
   - to establish and to give quantitative description of the realization of global changes in SST, surface salinity, sea level and sea ice data.

2. Development of the observational system pointed at tracing the climate changes in the North Atlantic.
   This goal merges the following objectives:
   - to find the proper sites that form the inter annual variations of MHT
   - to study the deep circulation in the "key" points
   - to develop the circulation models reflecting the principle features of interoceanic circulation
   - to define global and local response of the atmosphere circulation to large scale processes in the Atlantic ocean.

Ocean and the Climate

The forecasting of the climate changes is probably one of the most important problems of our time. In spite of the sufficient knowledge about the processes going on in main components of the climate system, complete and adequate description of the mechanisms governing the state of the system and it's variations seems to be hardly possible. This is mostly due to the high complexity of the climate system - great number of components and complex system of feedback.

The variations of the climate system is obviously determined by different factors on different time and space scales. The ocean with it's tremendous heat capacity is a sort of a heat accumulator and redistributes, it's inter-relation with other components has to be significant on long time periods. comparable to time scale of ocean characteristics variability. and space scales comparable to scales of individual ocean basins.

It is not yet definitely clear whether the ocean appears to be a passive substance in the between components interaction, or it can induce changes in other components of the climate system (first of all in the atmosphere). The first point of view was evolved by Hasselmann (1974). who used the concept of stochastic climate models. and considered the ocean as inertial climatic subsystem. which was subjected to permanent random atmospheric forcing. It was shown that a complete passive ocean could turn the random high frequency input of the atmosphere into much lower frequencies in SST. The other approach was introduced by Bjerknes (1962). who found and suggested an explanation to close relation between the tendencies in SST behavior and time evolution of North Atlantic atmospheric circulation index. reflecting the surface pressure difference between the Azores High and Icelandic Low. The following studies (Palmer, Sun, 1985; Wallace, Jiang, 1988; Lau, Nath, 1990) proved the existence of the atmospheric response to SST anomalies.

Without neglecting the Hasselman theory. it seems that there are strong evidence of the ocean active role in the long-term variations of the climate system.

Global Ocean "Conveyor"

The physics of interaction states that the only possible way of ocean forcing to atmosphere is by the fluxes of heat and water, that are primarily (from ocean point of view) defined by the SST. Thus in order to study the ocean climatic signal, it is important to define the processes that can form and support the long lasting anomalies of SST. In the paper by Folland et al.(1986) devoted to computation of empirical orthogonal functions (EOF) of global SST record (1901-1980), one of the EOF reflected the space pattern of SST with maximum values in high latitudes in both hemispheres (with different signs) and amplitude variability over a period of approximately 40-50 years. The variability of such a period can be formed only by significant changes in global ocean circulation (GOC).

Schematically GOC can be introduced at the movement of two layer liquid. It is known that due the difference in thermohaline properties the North Atlantic has greater mean density than the North Pacific. The relative level of these two basins differs almost by one meter and the age of the deep waters (estimates based on the radiocarbon data, neglecting the exchange with the upper layers) differs by more than 1500 years. Thus the upper warm water following the level inclination flows from the North Pacific to the North Atlantic, and the underlying cold water flowing in the opposite direction (Broecker, 1974; Lappo, 1984; Gordon. 1985). The overturning of the water occurs in the North Atlantic as a result of the heat loss of the upper water to the cold air which leads cooling Of the water and it's consequent sinking (the effect known as the deep convection) (Fig. 1). The misfunctioning of this water "conveyor", can occur at the period of invasion of the Arctic ocean waters, that have positive buoyancy even at low temperatures, to the North Atlantic. This induces the restructure of ocean circulation. In theoretical studies of Stommel (1961), Rooth (1982) and model experiments of F. Bryan (1986), Manabe, Stouffer (1987) it was shown that both these ocean states can be stable.

On the background of global interoceanic exchange a smaller scale circulation cells also playing an active part in exciting the inter annual variations in the atmospheric characteristics can also be pointed out. The careful study of such mechanism in the North Atlantic was performed by Bjerknes (1964).Bjerknes suggested two regimes of heat in transport in the North Atlantic. The strong zonal circulation of the atmosphere the Northern hemisphere (high values of the zonal circulation index) increases the expenditure of the North Atlantic current, so the ocean carries more heat towards the north (the regions of North Atlantic deep Water formation). The weak zonal circulation decreases the heat transport of the North Atlantic current. at the same time increasing the temperature contrast between the waters of middle and high latitudes of the North Atlantic and meridianal heat transport in the atmosphere.

Extraordinary Features of the North Atlantic

Taking in account the state of development of the ocean observational systems it seems impossible to set a task of studying all the elements of the global interoceanic "conveyor". It is more reasonable to concentrate the attention on the ocean basins where the traces of the "conveyor" are most apparent. The suitable site for these purposes is the Atlantic ocean and especially it's northern part.

Atlantic is the only ocean with two polar sources of deep waters. The North Atlantic is the source for North Atlantic deep water (NADW), but up to 50 -55 N one can spot the signs of Antarctic Bottom Water (ABW) as well.

The role of the Atlantic in the changes of upper water characteristics is demonstrated on Figure 2. where the comparison of Lazier (1980) data from the ocean weather station "B" in the North Atlantic and Kort (1974) data from hydrological section in the North Pacific is shown.

The North Atlantic is characterized by extremely high heat fluxes to the atmosphere. The integral turbulent fluxes from the North Atlantic surface are equal to 7.1*10 W. Thus occupying only 11% of the total World Ocean surface. North Atlantic is responsible for 21% of sensible. 16% of latent and 17% of total heat fluxes. This allows to consider the North Atlantic as the energy active zone of the World Ocean (Gulev, Lappo,1988)

Very important integral parameters reflecting the large-scale interaction are the MHT and MFWT. MHT in the Atlantic has two remarkable features. First of all. It is the northward heat flux in the South Atlantic and trans equatorial heat transport of the same direction that equals to approximately 10 W. This result was derived by Hastenrath (1977.1980) and then confirmed by direct and balance estimates (Bunker, Lamb. 1982; Roemmich. 1984; Wunsch, 1985; Gulev, Lappo. 1986. 1988; Isemer. Hasse. 1990, etc). Secondly, it is non unique regime of MHT in the middle latitudes of the North Atlantic (Gulev, Lappo. Tichonov. 1988). one corresponds to the transit of heat through the middle latitudes, the other to intensive heat loss in the Gulfstream delta area. The latter is demonstrated on Figure 3. where the non dimensional curves of MHT, corresponding to above mentioned regimes are shown. More carefully this phenomena is going to be described further on.

The North Atlantic is very sensitive to variations of MFWT, as well, because it is the place of formation of great amount of deep waters of the ocean. so even little changes in salinity can completely change the conditions of the convection.

Resuming, it is necessary to state that the observational part of the program must be concentrated in the North Atlantic, also all the archives data and incoming data from the ongoing research studies in other ocean basins must be used for purposes of understanding the ocean climate.

Different Aspects of Oceanic Component of Global Climate

In order to solve the problems set by the program ROCC. It is necessary to focus on the characteristics of the ocean that are most important in climate sense. The experimental works in the ocean conducted for this purpose will provide field data for testing and creation of reliable parameterizations in mathematical models and reveal the simple physical relations in the climate system that will serve as the base for climate forecasting. It seems that the major attention must be paid to the meridianal transport and the level of the ocean as the highly informative integral parameters and also to SST and surface salinity anomalies and to variations in heat and water exchange as the direct agents in influencing the atmosphere.

Characteristics of the Ocean-Atmosphere Energy Exchange

Calculation and analyses of heat and radiation fluxes on the ocean-atmosphere boundary in the North Atlantic revealed the extremely uneven pattern of heat exchange and evaluated the dominating share of turbulent sensible and latent heat fluxes variability in total dispersion of heat balance. The latter proved to be 10 times greater than the contribution of radiation balance variations (Gulev, Lappo, Tichnov. 1988). It should be noted that the mean annual distribution of this characteristics are more or less the same in papers of different authors (in sense of extremums location) but the values differ in the range of 20-150% for individual points and less than 50% for zonal means. The most significant differences occur in the middle latitudes for sensible and latent heat and in tropics for radiational fluxes. The knowledge of interannual variations of the exchange processes seems to be inadequate. The attempts to approach this problem are confined by the studies of Bunker (1988) and Gulev, Lappo, Tichonov (1988), who never the less found reliable trends (up to 6-10 W/m) in local areas.

The most important objectives in the study of the interannual variability should be :

- Creation of the basic data set of marine meteorological information. It can be possible under international community efforts to update COADS data which is now criticized for several reasons (interpolation algorithms, wind speed data, etc).
- development of new generation of parameterizations of exchange processes, oriented on large scale interaction and considering the effects of time and space averaging.
- Estimation of interannual variability using the new technologies in long time series analyses with parameterization of phase-amplitude characteristics of seasonal cycle.

Meridianal Heat and Fresh Water Transport

The MHT system in the North Atlantic is zonally divided according to the mechanisms that provide the northward transport of heat. That is why in order to study the whole system, each individual mechanisms must be carefully investigated and the complex of direct and feedback relations between these mechanisms must be determined.

In tropical latitudes of the North Atlantic the main mechanism of interannual and seasonal variations of MHT is the Ekman transport (Bulgakov, Polonsky, 1988, 1990; Efimov. 1989; Levitus. 1987). Interannual variations of Ekman transport have the amplitude of 3-5*10 W and seasonal variations 5-7*10 W. At the same time annual mean MHT on the 20 N varies from 1.5 to 2.5*10 W (Gulev, Lappo, Tichonov, 1988). For the first time the low frequency interannual variations of the SST in the tropical Atlantic ocean were detected by Merle et al. (1979). Later Folland (1986) established the relation between the large-scale heat anomalies in the tropical Atlantic and the Sahel drought.

The relations between the atmosphere dynamics and the heat transport in the tropical Atlantic are also seen in variations of El-Niño South oscillation system (ENSO). When ENSO occurs. the trade winds over Atlantic weaken and that leads to formation of heat anomaly in the ocean which in it's place influences the Hadley circulation. Intensification of the latter increases the trade winds and ocean comes back to it's original condition. Such feedback in the ocean-atmosphere system is more or less reliably determined for anomalous conditions and still needs further detailed quantitative study.

The middle latitudes of the North Atlantic are characterized by the extreme values of heat fluxes on the ocean-atmosphere boundary and by extreme variability of these fluxes. That is why the problem of heat balance in this part of the ocean is very important. As it was shown by Rago, Rossby,(1987) by the analyses of hydrological data, on the zonal section 32 N, the integral MHT is primarily governed by the baroclinic movements, mainly concentrated in the Gulfstream area. Thus the dynamics of the western boundary current plays an exclusive role from the point of view of the MHT variations. This fact is emphasized by the results of Volkova, Gulev. Lappo. (1987) who found that the regions of the maximum ocean-atmosphere interaction coincide with the western boundary currents.

Gulev. Lappo. Tichonov (1988) derived two regimes of MHT characterized by different role of the middle latitudes (Fig. 3). The nondimensional profiles of the MHT (for 18 years period) are clearly separated into two types. The first. corresponds to the active heat loss in the tropical and subtropical zone of the North Atlantic and the heat transit in the middle latitudes. The second, corresponds to the active heat loss in the middle latitudes. From the point of view of the Gulfstream dynamics, in the first case, an intensification of the current must be expected and, in the second case. the weakening of the current or strengthening of the recirculation cell must occur.

The non unique regime of MHT in the middle latitudes , accompanied by the formation of the SST anomalies in the Gulfstream delta area what was shown by Lau. Nath) (1989) analyses of the North Atlantic SST data. In it's turn a strong correlation between SST anomalies and the North Atlantic index exists (Bjerknes, 1964).

The intensive flow of the western boundary currents towards the north is possible only in case of developed deep convection in the high latitudes. which allows to compensate the input of water masses in the upper layers by sinking it redirecting it backward in the deep layers.

It is important to notice. that the study of MHT must go together with consideration of MFWT, especially in the high latitudes. Accounting that the atmosphere of both hemispheres carries the water from the tropical zones towards the poles and the equator. a compensating MFWT must exist in the ocean. in form of low salinity waters movement. All the methods of estimating MFWT have substantial deficiencies. as a result the estimates of different scientists do not coincide even in the direction of the transport (Dobroluybov, 1991). Never the less, there is no doubt that the MFWT in the ocean plays a vital role in the climatic changes of the ocean-atmosphere system by defining the buoyancy flux in the source regions of deep and intermediate water (because the contribution of the salinity anomalies to the density at low temperatures overwhelms the temperature anomalies contribution).

In connection to the studies of the North Atlantic role in the climate variations the following questions concerning the MHT and the MFWT must be an answered:

- What are the real values of cross equatorial MHT in the Atlantic ocean?
- What mechanisms form the mean fluxes and its variability in different latitudinal zones?
- How are the MHT anomalies in the North Atlantic related to the salinity anomalies in the source regions of deep water masses?
- What are the real values of MFWT in the Atlantic ocean and its interannual variations?
- What is the physics of interaction between MHT and MFWT in different latitudes?

SST and Surface Salinity

The SST all by itself is an important parameter of the ocean. More to this, the processes that lead to the climatic variations in the ocean circulation and variations in the upper layer heat storage are reflected in SST. More to this the SST is an important factor in producing the heat and water exchange between the ocean and the atmosphere. From the point of climate. the most interesting feature is not the mean SST fields, but SST anomalies. recently conducted diagnostic studies of large-scale atmospheric processes (Dymnikov, Filin, 1985; Schmits et al., 1987) and model experiments with the general atmosphere circulation models (Palmer, Sun Zhuabo, 1985; Degtayrev, Trostnikov, 1987) have demonstrated strong correlation between the SST anomaly south of Newfoundland and quasi stationary anomalies of atmospheric circulation. This connections is a consequence of eingen oscillations in the atmosphere-upper ocean layer system which can be initiated by stochastic forcing on synoptical scale localized along the storm tracks over the Atlantic ocean (Dymnikov, Tolstykch, 1989).

A special interest, in purpose of analyses of large scale climatic changes, is in studies of seasonal and interannual variability of the frontal zones. The extreme values of heat exchange are associated with the frontal zones, the zones of thermal contrasts. The characteristics of the frontal zones to high extent determine the position of the cyclone storm tracks.

For the high latitudes ,as mentioned above. the most important parameter is the surface salinity. Lazler (1980) analyzed the hydrological data collected on ocean weather station "B", and found good correlation between the time behavior of the surface salinity and integral thermal conditions of the Northern hemisphere atmosphere. The data shows that the violation of the fresh water balance in this region leads to changes in ocean circulation and climate (Broecker, 1990), one of such disturbances occurred in the late 60-s, when a negative salinity anomaly up to -0.1 /oo was formed in Greenland Sea and then moved to the North Atlantic (Dixson et al., 1976). The freshening of the water in the region of convection decreases the depth convection, thus isolating the intermediate and deep waters from interaction with the atmosphere, reducing the production of deep waters and, finally, lessening the water exchange between the high and the low latitudes of the ocean and the ocean's climate warming effect.

The objectives in the studies of SST and surface salinity role in climatic system are:

- The study of mechanisms governing the formation of SST and surface salinity anomalies.
- Definition of different processes contribution to variability of the anomalies on different time and space scale in different regions.
- The study of anomalies statistics. and generation of large scale anomalies by the smaller scales.
- The study of the salinity and SST anomalies influence on the depth of the convection in high latitudes.

Sea Level

The high sensitivity of the sea level to changes in the thermodynamic conditions of the ocean on wide range of time and space scales determined it's significant place in the program.

The analyses of level data proves that sea level variations adequately reflect the time dynamics of the ocean climate system. First of all it is clearly seen from the regularity of the sea level behavior in different parts of the World ocean. The tendency of level increasing is accompanied by the quasi periodic oscillations with time periods of climate variations. It is determined that the sea level oscillations of such period are induced by the anomalies of steric heights and so they are good indication of ocean thermodynamic conditions (Wyrtki, 1974, 1975).

The relation between the characteristics of the thermodynamic conditions and the sea level was found in the low latitudes of the North Atlantic (Blaha, 1984), it allows to use the level data for evaluation of the parameters of thermohaline circulation and as tests for numerical models. The character of level variations in the middle and high latitudes of the North Atlantic mainly reflects the processes of ocean-atmosphere interaction (Reva, 1980, which is the significant mechanism of functioning of the climate system in these latitudes.

The important part of the sea level studies under climatic project is the investigation of the different factors contribution to sea level variations. This factors are steric, barogradient and wind. The relative significance of this factors can sufficiently vary from place to place (Reva, 1987, 1988). More to this, the same factor can play a leading part on one time scale and become unimportant on others (Gill, Niiler, 1973; Demchenko, Poleshaeva. 1987; Lappo, Reva, 1989). All these facts. set a special demands to description of the sea level behavior under simple empirical models and in models of global ocean circulation.-

Data Management Strategy

This question is one of the key parts in successful realization of the program. According to scientific objectives of this program, one may formulate basic principles of data management.

Data Collection

It is necessary to determine data types and it's geographical location. One met stress urgent need of hydrological (up to bottom) measurements. sea level observations. marine meteorology, aerology, and current meter measurements. A vital role must be given to chemical properties of the water and paleooceanographic data (concentration of isotopes in ocean waters and sediments columns. corresponding to recent centuries). North Atlantic has to put in centre of attention. All the data must be tested on compatibility. minding that the data sources are quite different. To approach this problem, it seems reasonable to come up with data set of high reliability. that can serve as a basic one for further estimates.

Data Managing

Climatic studies must be provided with a data managing system. that allows to deal with heterogeneous data reflecting the state of the climate system and gives easy excess (in operative mode) to it to all the scientists engaged in the project. The managing system must incorporate two subsystems: global and regional with less data but high operativeness. The purposes of this two components is principally different.

Data Assimilation

Data assimilation is understood as not only the operative usage of the data set in short-term forecasting schemes. but primarily. as a possibility to use the data in applied and theoretical mate investigations. Here on. computational algorithms and numerical models must be developed. capable of being merged in the data managing system both global and regional. More to this. an urgent need of the development of new methods oriented on dealing with huge volumes of heterogeneous data.

References

Bjerkness. J., 1962: Synoptic survey of the interaction of sea and atmosphere in the North Atlantic. *Geophysica Norvegia,* 24, 3, 115-145

Bjerkness. J., 1964: Atlantic air-sea interaction. *Adv. in Geophys.*, v. 10, 1-82

Bjerkness. J., 1966: A possible response of the atmospheric Hadley circulation to equatorial anomalies of ocean temperature. *Tellus. 18,* 820-829

Broecker. W.S. 1974: Chemical oceanography. N.Y., Harcourt Brace Jovanovich, Inc., 214 pp.

Broecker. W.S., D. M. Peteer. and D. Rind. 1985: Does the ocean-atmosphere system have more than one stable mode of operation? *Nature,* V.315, 21-26

Broecker. W.S. 1990: Salinity history of the Northern North Atlantic during the last deglaciation. *Paleoceanogr.*, v.5. n.4, 459-467.

Bunker, A.F., 1976: Computation of surface energy flux and annual air-sea interaction cycles of the North Atlantic Ocean. *Mon. Wea. Rev.*, v. 104., 1122-1140.

Bunker. A.F., 1980: Trends of variables and energy fluxes over the Atlantic ocean from 1948-1972. *Mon. Wea. Rev.*, v.108, 720-732

Dobrolyubov. S.A., 1991: Estimating the fresh water component of the meridianal transport in the ocean. *Meteorologia and hydrological, 1,* 71-78

Folland. C.K., Palmer T.N., Parker D.E., 1985: Sahel rainfall and worldwide sea temperature. *Nature. 320,* 602-606

Gordon, A.L., 1986: Interocean exchange of thermohaline water. *J. Geophys. Res.*, v.91, 5037-5046

Gulev, S.K., and S.S. Lappo, 1986: Zonal climate of the world ocean: Phase Differences, heat flows, interlatitudal exchange. *Meteorologla and Hydrologia*, n.10, 76-84

Gulev, S.K., S.S. Lappo, and V. A. Tichonov, 1988: year-to-year dynamics in the integral characteristics of the thermal interaction between the atmosphere and the North Atlantic. Izvestia academy of Sciences of the USSR, *Atmosphere and OceanPhysics*, v.24, n.8, 861-872

Hasselmann, K., 1976: Stochastic climate models. part 1: theory. *Tellus*, 28, 6, 473-485

Hastenrath, S., 1980: Heat budget of tropical ocean and atmosphere. *J. Phys. Oceanogr.*, v.10,159-170

Hasterath, S., 1982: On meridianal heat transport in the World Ocean. *J. Phys. Oceanogr.*, v.12, 922-927

Isemer, H-I., and L. Hasse, 1985: The Climate Atlas of the North Atlantic Ocean. Vol. 1.: Observations. springer-verlag, 218 pp.

Isemer, H-I., and L. Hasse, 1987: The Climate Atlas of the North Atlantic Ocean. Vol. 2.: Air-Sea Interactions. Springer-Verlag, 252 pp.

Lamb, P.J., and A.F. Bunker, 1982: The annual march of heat budget of the north and tropical Atlantic ocean. *J. Phys. Oceanogr.*, v.12, 1388-1410

Lappo. S.S., 1984: On the reason of the northern heat advection across the equator in the Atlantic ocean. In: Investigations of the ocean-atmosphere interaction processes. Moscow. Hydrometeoizdat, 125-129

Lazier, J., 1980: Oceanic conditions at ocean Weather Station BRAVO; 1964-1977. *Atmos.-Ocean*, v.18, 227-238

Levitus. S., 1987: Meridianal Ekman heat fluxes for the World Ocean and individual ocean basins. *J. Phys. Oceanogr.*, v.17, 1484-1492

Manabe, S., Stouffer R., 1988: Two stable equilibria of a coupled ocean-atmosphere climate model. *J. of Climate*, V. 1, 841-866

Merle, J., 1980: Seasonal variations of heat storage in the tropical Atlantic ocean. *Oceanol. Acta.*, v.3, 455-463

Palmer, T.N., Sun Zhuabo, 1985: A modeling and observational study of the relationship between sea surface temperature in the north-west Atlantic and atmospheric general circulation. *Quart. J. R. Met. Soc.*, 111, 947-975

Polonsky. A.B., N.B. Bulgakov. 1989: Meridianal heat transport in the Northern tropical Atlantic. report of the Sixth Session of the SCOR-IOC CCCO Atlantic ocean climate studies panel. Kiev. USSR. SCOR-IOC/CCCO-ATL-V13, 31-34

Rago. T.A., and H.T. Rossby. 1987: Heat transport in to the North Atlantic Ocean north of 32 N latitude. *J. Phys. Oceanogr.*, v.17, 854-871

Roemmich. D., 1983: The balance of the geostrophic and Ekman transport in the tropical Atlantic Ocean. *J. Phys. Oceanogr.*, v.13, 1534-1539

Stommel. H., 1980: Asymmetry of Interoceanic freshwater and heat fluxes. Proc. Nat. Acad. Sci., USA. v.77, 2377-Z381

Wallace, J.M., and Q.R. Jiang. 1988: On the observed structure of the interannual variability of the atmosphere/ocean climate system. In: Atmospheric and Ocean Variability. H. Cattle. Editor. Royal Met. Soc., Bracknell. UK, 17-43

Wirtki. K., and L. Uhrich, 1982: On the accuracy of heat storage computation. *J. Phys. Oceanogr.*, v.12, 1411-1416

ROCC Science Working group

Sergey Lappo (chairman)
State Oceanography Institute (Moscow)

Genrich Alexeev
Arctic and Antarctic Institute (St. Petrsburg

Sergey Dobrolubov
Moscow State University (Moscow)

Sergey Gulev
State Oceanography Institute (Moscow)

Sergey Halevsky
Main Geophysical Observatory (St. Petrsburg)

Alexandr Hakshtas
Arctic and Antarctic Institute (St. Petrsburg)

Alexandr Polonsky
Marine Hydrophysical Institute (Sevastopol)

Youri Reva
State Oceanography Institute (Moscow)

Alexey Sokov
State Oceanography Institute (Moscow)

Vladimir Tereschenkov
State Oceanography Institute (Moscow)

Jack Tonkacheev
State Oceanography Institute (Moscow)

Igor Yashayaev
State Oceanography Institute (Moscow)

Igor Zveriaev
State Oceanography Institute (Moscow)

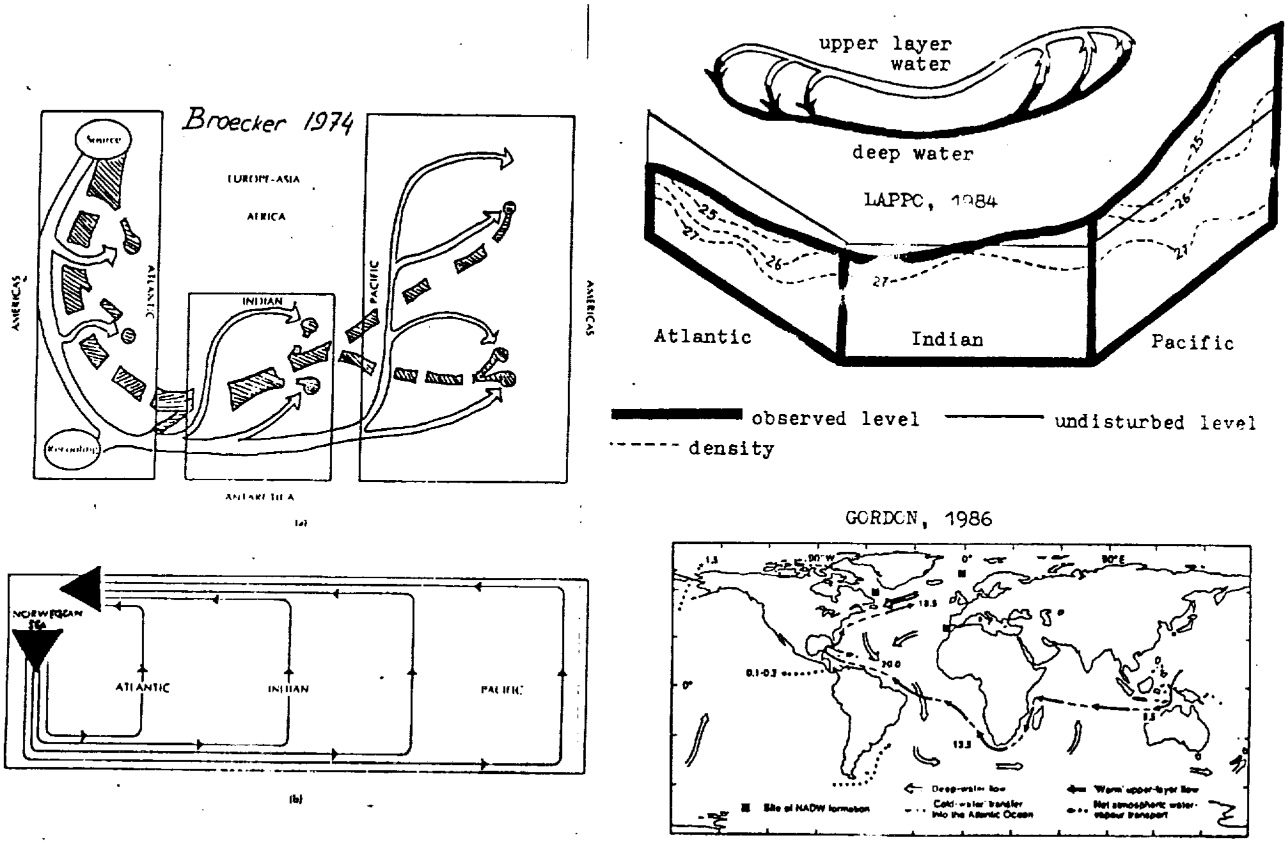

Figure 1. Scheme of "conveyor"—interoceanic circulation (after Broecker 1974, Lappo, Gulev 1984, Gordon 1986)

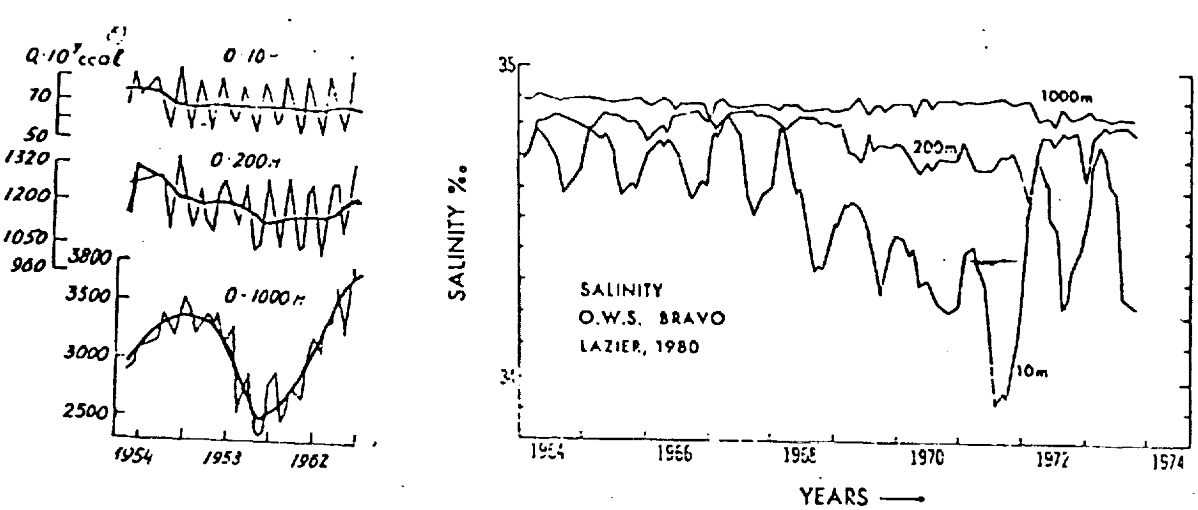

Figure 2. Time behavior of heat capacity and salinity, consequently in North Pacific (Kort, 1974) and North Atlantic (after Lazier, 1980).

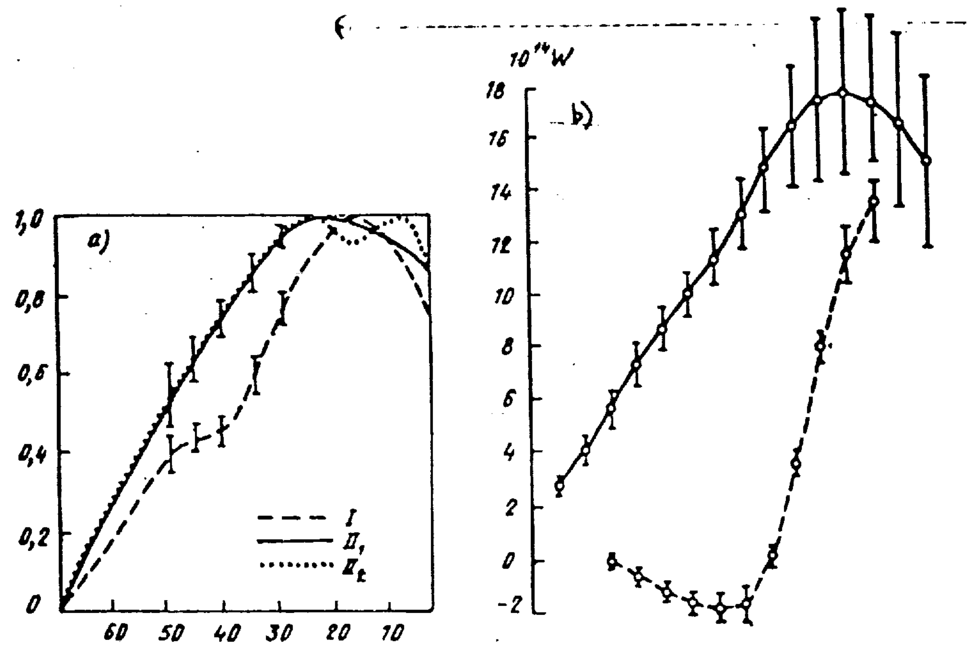

Figure 3. Different types of nondimensioned profiles of meridional heat transport in North Atlantic—profiles of mean integral (a) and Ekman heat flux (b).