

**FISHERIES RESEARCH BOARD  
OF CANADA**

**MANUSCRIPT REPORT SERIES  
(OCEANOGRAPHIC and LIMNOLOGICAL)**

**No. 51**

**Oceanographic Seminars**

by  
**Michitaka Uda**

**Pacific Oceanographic Group  
Nanaimo, B.C.**

**August 1, 1959**

**Programmed  
by**

**THE CANADIAN JOINT COMMITTEE ON OCEANOGRAPHY**

**FISHERIES RESEARCH BOARD  
OF CANADA**

**MANUSCRIPT REPORT SERIES  
(OCEANOGRAPHIC and LIMNOLOGICAL)**

**No. 51**

**Oceanographic Seminars**

by  
**Michitaka Uda**

**Pacific Oceanographic Group  
Nanaimo, B.C.**

**August 1, 1959**

Programmed  
by  
**THE CANADIAN JOINT COMMITTEE ON OCEANOGRAPHY**

## Foreword.

Dr. Michitaka Uda, Professor of Oceanography, at the Tokyo University of Fisheries, spent the period September 15, 1958 to May 15, 1959 with the Pacific Oceanographic Group of the Fisheries Research Board of Canada at Nanaimo, B. C. In addition to studying some oceanographic features of the sub-Arctic Pacific Ocean, he presented the following seminars, taken from his lecture notes at the University.

The seminars are reprinted here because they provide a broad appreciation of the oceanography and its relation to fisheries which is not available elsewhere in the literature in the English language.

The questions and discussions arising from the seminars are not recorded.

## OCEANOGRAPHIC SEMINARS

by

Michitaka Uda

### Seminar 1. History of the development of oceanography in Japan.

#### A Background.

- A.1 Oceanography in Japan is based on the experience of seafarers and fishermen, dating from the earliest time. There are remains of "shell domes" dating from the stone age more than 3000 years ago.
- A.2 The Japanese islands form a long chain. They are surrounded on the south by the warm Kuroshio and its branch, the Tusima Current. From the north they are influenced by the cold Oyashio.
- A.3 The great variety and abundance of sea life sustained the demand of the people for sea food and encouraged its exploitation. This commenced near the sea coast and gradually extended offshore.
- A.4 Sea disasters resulting from Tsunami (seismic waves) storm-tides, strong currents, and complex tidal conditions excited researches to protect lives and find sea routes.
- A.5 Sea salt is a necessity of life and has been produced since ancient times along the Japanese coast.
- A.6 The rice crop fluctuates from year to year due to climatic variations, which are closely related to the fluctuation of the great ocean currents (Oyashio, etc.).

#### B Modern Oceanography.

This started in the Meizi era (1868-1912) and developed in the Taisyo (1912-1926) and Syowa eras (1926- ).

- B.1 United States whale catchers were active in the eastern and southern waters of Japan as early as 1818. Japan was awakened from her long period (more than 350 years) as a closed state by the uninvited visit of Commander Perry's fleet (U. S. A.) in 1853. After this Japan began to follow the well-developed European methods in marine science. Fortunately, because of the long mari-

time history and experience, the advanced sciences were speedily and easily absorbed. This was done with the help of many invited European and American scholars and technicians (e.g. Professors Morse, Whitman, Ewing, Milne, etc.) Also many Japanese students were sent abroad by the Meiji Government to learn foreign methods.

B.2 The visits of European oceanographic research vessels initiated Japanese interest in oceanography (The U.S.S. Tascarora (1874) discovered the Tascarora Trough in the Japan Trench. Also there was the British Challenger expedition around the world (1873-1876), the Swedish Vega expedition (1879) which first cruised across the Arctic Ocean, the Russian Vitiaz (1886-1889), the U. S. A. Albatross on the Agassiz expedition (1888-1897)

B.3 The oldest map of Japan was made by the Dutchman, P. Shenck in 1650, based on the survey of M. G. Vries in 1643. The Japanese learned surveying methods from the Dutch.

The Japanese surveyor Tadataka Ino completed an excellent map of Japan, in 1821, based on his coastal surveys from 1800 to 1816. In 1862 the first sea chart of the central Japanese coast, near Ise Bay, was made by the Japanese.

B.4 The Japanese Hydrographic Office (J.H.O.) under the Navy, was founded in 1871 by Admiral Naroyosi Yanagi (1832-1891) who learned surveying from the British in H.M.S. Silvia (1869-70) in the Inland Sea of Japan. He started the production of marine charts, tables, and tidal observations, and published his first chart in 1872.

Since 1918 the Hydrographic Office has conducted an active program of offshore hydrographic observations, especially in the Kuroshio area and north Equatorial Current area. In 1925 the echo sounding technique was adopted (a table of sound velocities in sea water, S. Kuwahara, 1940-1943). This expedited the collection of sounding data resulting in a large number of detailed bottom depth charts. These included the detail of the Japan Trench (first chart 1925, revised 1952) as well as the discovery of the Yamato-Tai Bank, etc. by Dr. S. Ogura et al (chart No.6901). Charts were also prepared of the marine sediments by Professor S. Hanzawa et al and the coral atolls in the North Pacific Ocean by Dr. R. Tayama. Dr. Sinkiti Ogura was the founder of Tidology and published "Tides in the waters adjacent to Japan" in 1921.

After World War II the Hydrographic Office was incorporated into the Maritime Safety Agency.

B.5 In 1948 fish finders were developed, based on the principles of the echo sounder and sonic ranger. These followed the studies made in 1929 by K. Kimura using the Langevin piezoelectric system. K. Miyosi and H. Miyazaki studied the magnetostriction pattern in 1942.

Loran and radar were introduced in 1952, and 1954 the bathythermograph and G.E.K. (Kaken Co.) and the self-recording current meters of K. Ono, T. S. K., and Namiti, came into general use.

A second encouragement after World War II has been given to the progress of oceanography by the visits of research vessels, namely H.M.S. Challenger VIII (1952), U.S.S. Spencer Baird (1953), U.S.S.R. Vitiaz (1957-58).

We are now in the new Syowa era in oceanography.

B.6 Dr. Yuji Wada (1859-1916) proposed that drift bottles should be used for current surveys. In 1893 the Fisheries Agency released 400 bottles in the Oyashio area and recovered 56 bottles. The next release was in the Kuroshio area. The program was expanded and from 1913 to 1917 13,357 bottles were released and 2920 bottles (22%) were recovered. From these data Dr. Wada plotted a current chart of the waters adjacent to Japan. Physical oceanography in Japan started from this experience by Dr. Wada, 65 years ago. This corresponds to the start given to World Oceanography by the Challenger expedition, 85 years ago.

Dr. Wada (Chief Physicist of the Weather Bureau) first published the monthly normal surface water temperature charts in the North Pacific Ocean, based on data collected from 1882 to 1901.

In 1901, Dr. Kishinoue et al attended the International Conference for the Exploration of the Sea in Christiana, Sweden. There he learned the method of systematic coastal observations. These were started in 1909 by the Fisheries Bureau, and in 1918 the first systematic observations were made at sea by the Teno Maru (163 tons). Mr. Tasaku Kitahara, with the aid of Dr. Kintaro Okamura (Biology, marine plants, plankton), Professor Torahiko Terada (Physics), who first (1914) introduced the Bjerknes-Sandstrom method of the dynamical computation of ocean currents, Professor Z.Hara (Chemical Oceanography) and Professor K. Kishinous (Fishes).

From 1901 to 1913 density was determined with Akanuma's hydrometer, an improved Kiel pattern. In 1913 the chloride titration (Knudsen, 1901) was introduced by Hisatosi Marukawa in the survey of the Yellow Sea and Okhotsk Sea fishing grounds. In 1915 the reversing thermometer was introduced.

Tasaku Kitahara (1850-1922), founder of fisheries oceanography in Japan, introduced the Lucas hand winch (1906), the electric hydrographic winch (1916), Kitahara's water bottle (an improved Knudsen heat-insulated pattern), the Hensen plankton net, core sampler, Ekman Current meter, etc., and remarked the accumulation of fish shoals near the "Siome" (lines of convergence). This last study has been further developed by Uda (1938).

Since 1913 those prefectural Fisheries Experimental stations with ships have been making regular lines of oceanographic observations. The results are published in the Semi-Annual Oceanographic Investigations, Volumes 1 to 75. Most of the results are from the prefectures of Tyosen (afterward Korea) using the Misago maru (154 tons), Taiwan, using the Syonan maru (417 tons), and from Hokkaido, using the Tankai maru (85 tons). The Imperial Fisheries Experimental Station (Marukawa, Uda, Aikawa, Kimura, et al) have had the Soyo maru. During the period 1931-1942 simultaneous surveys were made by many ships using Nansen bottles with reversing thermometers in the Japan Sea and the Pacific Approaches. Since 1949 the 8 regional fisheries research laboratories with the Soyo maru and the Tenyo maru, etc. have been carrying out similar observations mainly for the conservation and exploitation of the fisheries resources. The most active people are N. Watanabe, Z. Nakai, T. Hirano, T. Tsuzita, T. Shimomura, K. Kimura, H. Nakamura, T. Hanaoka, H. Kawai, R. Fukai, K. Kitano, etc.

In the Imperial Fisheries Institute Mituyo Okada conducted the practical estimation of ocean currents during the period 1932 to 1941. Mr. H. Marukawa (and later Dr. Hiroshi Niino) used the dredge to examine the bottom fishing grounds around Japan, during 1927 to 1930.

After the war the Imperial Fisheries Institute was changed to the Tokyo University of Fisheries.

B.7 The Meteorological Agency started oceanographic observations when the Kōbe Marine Observatory was founded by Dr. Takematur Okada in 1920. They had the Shunpū maru (125 tons) and approached the subject from the geophysical point of view. This corresponded to the demand of navigators and shipping companies for a service similar to the "Seewarte" (Hamburg). The most notable studies are the North Pacific weather charts, the mechanism of typhoons (Y. Horiguchi), theoretical studies of oceanic circulation (Koji Hidaka), and practical studies (Kanji Suda). In 1937 a new research ship, the Ryōhū maru (1181 tons) was launched.

In 1942 the Hakodate Marine Observatory started work with the Yushio maru (140 tons) and in 1947 the Nagasaki Marine Observatory obtained the Umikaze maru. In the same year the Maizuru Marine Observatory was established.

In 1941 the Oceanographical Society, with the publication of Journals, was started by Dr. T. Okada, and in 1955 the society published the Manual of Oceanographic Observations.

B.8 The activities of the Universities and Colleges.

Professor Kakiti Mitukuri (Biologist) of the Tokyo University established the first Marine Biological Laboratory at Aburatubo near Misaki in 1887. Many other laboratories,

Kominato, Asamusi, etc. followed.

The Imperial Fisheries Institute, which later became the Tokyo University of Fisheries, built a training and research ship, the Kaiyo maru (140 tons) in 1900. This was followed by the Unyo maru (442 tons) in 1909, the Hakuyo maru (1327 tons) in 1929, and finally the Umitaka maru (1387 tons) and the Shin-yo maru (236 tons). The Hayabusa maru, originally the Fukuryu maru (the Fortunate Dragon of Bikini fame) was also added to the fleet.

The ships associated with the fisheries departments of several universities are:

Hokkaido U.	<u>Oshoru maru</u> , <u>Hokusei maru</u>
Kagosima U.	<u>Kagosima maru</u> , <u>Keiten maru</u>
Simonseki Inst.	<u>Shunkotu Maru</u>

All these are carrying out training and researches in fishing navigation, and oceanography.

In 1908 Dr. Kotaro Honda, Torakiko Terada, et al published the monumental work on the secondary undulation of tides (seiches) in the harbours of Japan. This included the model experiments based on the principle of dynamic similarity, and the surveys made with Honda's pressure tide gage.

Dr. Morisaburo Tauti of the Tokyo University of Fisheries, who succeeded Professor Terada, made physical studies of the fisheries using the fish-lamp and electric screening of fish. He devised the hatching thermostat. He wrote many theoretical works on population dynamics. In addition, he founded the Japanese Society of Scientific Fisheries.

B.9 The method of manufacturing sea salt has been studied since 1894 and improved by the Central Experimental Station under the Ministry of Finance (Kenzo Oku, et al)

B.10 Summary

Generally, oceanographic research in the Meizi era (1868-1912) was confined to the coastal or near shore regions. In the Taisyō era (1918-1928) systematic offshore observations were undertaken. In the present Syōwa era (1926- ) systematic observations have been made on the high seas. In 1955 Norpac, in 1956 Equapac, and in 1957 and 1958 world-wide co-operation was attained in the International Geophysical Year.

(a) TOKYO UNIVERSITY OF FISHERIES  
A. Goto, H. Iwano, M. Shimizu, A. Sakai, H. Fukui,

Japanese Oceanographic Organization.

Fisheries Agency

- (a) Tokai Regional Fisheries Laboratory  
K. Gensho, Z. Nakai, N. Watanabe, T. Hirano, R. Fukai,  
T. Kawana, M. Abe.  
Ships - Soyo maru, Tenyo maru.
- (b) Hokkaido Regional Fisheries Laboratory.  
K. Ogaki, K. Kitano, A. Iiduka.  
Ship - Tankai maru
- (c) Tohoku Regional Fisheries Laboratory.  
K. Kimura, K. Kawai.
- (d) Nihonkai Regional Fisheries Laboratory.  
K. Uchihasi, T. Shimomura.
- (e) Seikai Regional Fisheries Laboratory.  
K. Ito, T. Tsujita.
- (f) Nankai Regional Fisheries Laboratory.  
H.. Nakamura, H. Yabe, H. Yamanaka.
- (g) Naikai Regional Fisheries Laboratory.  
T. Hanaoka.

Hydrographic Office

K. Suda, D. Shoji, S. Hikosaka, S. Miyahara, H. Hori, K.  
Iwata, K. Ono.  
Ships - Takyo, Kaiyo, Tenkai, Satuma. The suffix "maru" is not  
used with these new ships.)

Meteorological Agency

- (a) Weatherships and routine (Tokyo)  
K. Terada, Y. Takenouti, M. Hanzawa, J. Masuzawa, M. Miyazaki,  
I. Ichiye, M. Yasui, R. Marumo, A. Okubo.  
Ships - Ryofu, Yushio, Shunpu, Umikaze, Kuroshio.
- (b) Tokyo Research Institute.  
N. Nakano, S. Unoki, T. Nanniti, J. Fukuoka, T. Abe, K.  
Saruhasi.
- (c) Kōbe Meteorological Institute.  
K. Hishida, Y. Moriyasu.
- (d) Nagasaki Meteorological Institute.  
M. Koizumi, S. Ishiguro

- (e) Maizuru Meteorological Institute.  
H. Kawasaki.
- (f) Hokodate Meteorological Institute.  
Z. Yasui, J. Sugiura.

Universities.

- (a) Tokyo University.  
Geophysics and physical oceanography: K. Hidaka, K. Yoshida,  
M. Tsuchiya, K. Takano.  
Geology: T. Sakamoto, N. Nasu.  
Fisheries Biology: Y. Matue, Y. Komaki, Y. Suehiro, Y. Hiyama.
- (b) Hokkaido University.  
Geophysics of sea ice: K. Hukutomi, H. Rusunoki, T. Tabata.  
Plankton and fish: S. Motoda, T. Kawamura, I. Saito.  
Physics Oceanography: N. Inoue, H. Koto, S. Mishima.
- (c) Tokyo University of Fisheries.  
Geology: H. Niino.  
Physics and Chemistry: Y. Morita, Y. Saito, M. Uda, T. Sasaki,  
M. Ishino, T. Kumagori.  
Biology: I. Kubo.  
Nihon Daigaku University (Fisheries).  
Plankton: S. Kokubo, S. Kadata.
- (d) Tokyo University of Education.  
Chemistry: Y. Miyake, H. Hamaguti.  
Whale Research Institute: H. Omura, K. Nasu, Nemoto.
- (e) Nagoya University.  
Chemistry: K. Sugawara, T. Koyama.
- (f) Mie Prefectural University.  
Biology: Y. Okada.  
Estuaries: I. Sakamoto.
- (g) Tokoku University  
Biology: C. Matsudaira
- (h) Hiroshima University.  
Chemistry: Y. Matudaira.
- (i) Kyushu University.  
Fisheries Biology: H. Aikawa, K. Uchida, O. Tanaka.
- (j) Kyoto University.  
Fisheries: T. Kawakami.  
Physics: S. Hayami, M. Outi.  
Chemistry: M. Ishibashi.  
Biology: D. Miyadi, K. Yamaji.

- (k) Simonoseiki Fisheries Institute.  
Biology: H. Matue, T. Chiba.
- (l) Kagosima University  
Physics: T. Kuroki  
Nagasaki University.  
Biology: T. Yamada, H. Trie.

C. Present Work and Problems.

- C.1 Kuroshio researches since 1951. (S. Hatai, K. Hidaka, M. Uda, Masuzawa, Nakai, Shozi).
  - C.2 Deep Scattering Layer researches 1952-55 (M. Uda, T. Hasimoto, Y. Matue, T. Kumagori).
  - C.3 Tusima Warm Current Research 1952-1958. (M. Uda, S. Motoda, T. Tsuijita, Y. Matue, H. Aikawa, K. Uchida, T. Shimomura).
  - C.4 Radioactive Pollution in the Equatorial Pacific, 1954- (K. Suda, Y. Miyake, M. Uda, M. Fujinaga).
  - C.5 Water Pollution (Y. Matue, T. Hirano).
  - C.6 Sardine research 1949 (Z. Nakai).
  - C.7 Salmon research 1953 (M. Fujinaga, K. Taguchi, North Pacific Fisheries).
  - C.8 Norpac (1955) (Hydrographic Office, Central Meteorological
  - C.9 Equapac (1956) (Office, Fisheries Agency, Fisheries University,
  - C.10 International Geophysical Year, 1957-1958 (Tokyo University).
- Antarctic expedition (Soya, Umitaka.)
- Multiple ship survey in polar front and deep currents.
- C.11 The terminology of oceanography 1952 - (Uda).
  - C.12 Hydroelectric power development in its relation to fisheries - 1956-58 (M. Uda, Y. Matue, I. Gensho, Y. Okada).
  - G.13 The prediction of oceanographic conditions (Central Met. Office, Fisheries Agency, et al).
  - C.14 Basic investigation of Physical Oceanography 1957 - (K. Yoshida).

- C.15 Improvement of Fisheries Oceanography, 1957-58 (M. Uda, S. Kurita, T. Hirano).
  - C.16 Bathysphere (Kuroshio-go), 1951 (N. Inoue, T. Sasaki).
  - C.17 Bathyscaphe survey in Japan Trench, 1958 (T. Sasaki).
  - C.18 Deep sea research project (Japan Trench, etc.) 1958 - under auspices of the Rockefeller Foundation (K. Wadachi, Y. Miyake, K. Sugawara, etc.).
  - C.19 Exploitation of mineral resources of the sea bottom, 1957 (K. Suda, H. Niino).
  - C.20 Myojin reef eruption studies 1952-1954 (K. Suda).
  - C.21 Coastal erosion problem, 1950 - (Meteorological Agency, et al).
  - C.22 Joint Tsunami Researches, 1956, (R. Takahashi).
- D. Future Problems.
- D.1 A national institute of oceanography and fisheries resources. This has been proposed by the National Academy of Sciences in Japan, and is in the planning stage.
  - D.2 Oceanographic instrumentation. (Self-recording electronic devices, etc.)
  - D.3 Numerical prediction of oceanographic conditions based on the mechanism of oceanographic structure.
  - D.4 Determination of environmental factors of importance to commercial fisheries, especially those controlling fluctuation (herring, sardine, etc.)
  - D.5 Deep sea exploitation.
  - D.6 Water pollution problems in general, particularly estuary problems.
  - D.7 The riddle of the meandering of the Kuroshio.
  - D.8 Secular variation of ocean climate.
  - D.9 Systematic joint oceanographic organization. Special Joint Committee of Oceanography in Japan, 1958 - , founded in National Academy of Science.

Seminar 2. Water mass boundaries - "Siome". Frontal theory in oceanography.

Water masses are usually defined by a particular oceanographic property, such as temperature-salinity relation, phosphate, dissolved oxygen, etc. which may be designated, in the generalized sense, by  $\phi$ . Then the boundaries of the water mass are in the region where the gradients of the property are maximum (i.e. the Polar Front, etc.). These are designated by

$$(\nabla \phi)_{\max.}$$

The terms used are:-

Front.

Siozakai, surface of discontinuity.

Grenzfläche, border line, front, or frontal zone.

These frontal boundaries limit the distribution of sea life such as fishes, molluscs, sea mammals, plankton, benthos, and marine plants. They correspond to the lines of zoogeographical features of the shores and sea bottom.

The modification of a property, such as salinity (S) in a water mass depends on the amount of mixing and the velocity of the current. Mathematically this can be expressed:

$$\frac{\partial S}{\partial t} = D \Delta S - \text{div}(S \cdot U) \dots\dots\dots(1)$$

or more simply in the two dimensional case by

$$\frac{\partial S}{\partial t} = \frac{A}{\rho} \frac{\partial^2 S}{\partial z^2} - \frac{\partial(US)}{\partial x} \dots\dots\dots(2)$$

Water mass boundaries in the ocean near Japan (Figure).

1. Oceanic boundaries

- (a) Oyashio Front (sub-Arctic convergence).  
Polar frontal zone (The Oceans, Sverdrup et al. 1942)  
Boundary between the Central and sub-Arctic waters.
- (b) Kuroshio front (off Japan).
- (c) Sub-Tropical convergence (south of Ogasawara Island).
- (d) Equatorial front. North boundary is a divergence. South boundary is a convergence.

2. Coastal fronts.
  - (a) Coastal front (near the edge of the continental shelf) between oceanic and coastal water.
  - (b) Estuary front, between coastal and river water, such as shown by aerial photographs of the Fraser River estuary.
3. (a) Temperature fronts.

Oceanic fronts between cold and warm waters, e.g. Oyashio and Kuroshio.
4. Local fronts, around islands, capes, banks, etc.

#### Siome.

At the boundary between water masses we can usually find a visible line of demarkation which is a convergence (current-rip), (tide-rip) or a divergence (slicks). Japanese fishermen call these "Siome", in French they are called "clapotis" (clapotage), in German, "stromkabelung", Tierstrom, "Zoologeuparadise, Ansammlungen, Schaumrand, Meeres-Leuchten".

They have been discussed by M. Uda in Researches on Siome or current-rips in the seas and oceans. (Geophysical Magazine Vol. II, No. 4, 1938).

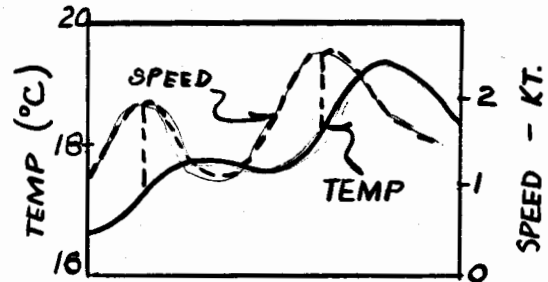
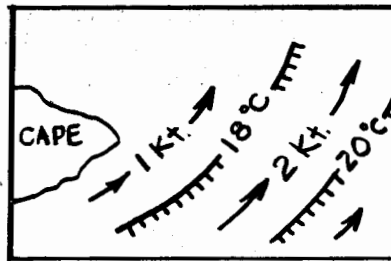
The Siome forms narrow bands or streaks, sometimes with ripples or waves, and usually with accumulations of flotsam. The Siome are very important to fishermen as indicators of fishing localities.

#### Types of Siome.

1. Young stage: oily streaks, hair-like streaks, string-like streaks (slicks).
2. Growing (mature) stage: rippling streaks, corresponding to currents greater than 1.5 knots, difference of temperature greater than 2°C per 10 miles. There may be a boiling or bubbling appearance accompanied by a low noise (butu-butuu, chabu-chabu, saa-saa). An acoustic study should be made.
3. Sio-nami is the fisherman's name for a strong Siome. It originally meant waves caused by strong tidal or oceanic currents moving against a strong wind. It is accompanied by a recognizable noise (Zaa-Zaa). It is a Siome with steep

white-capped waves, resembling a crossed or confused sea. It corresponds to a current of more than two to three knots and a temperature difference greater than 5° C per ten miles.

4. A more vigorous type of Siome occurs with a train or zone of pyramidal waves which can reach the deck level of a boat. It is accompanied by a roaring noise (Goo-Goo) which may be heard for several miles. In stormy weather a very ugly, dangerous sea occurs. Uda (1958) classified two distinct types of sea disaster due to this type of Siome; a river-mouth crossed wave type; and an open coast onshore wind type.
5. Sima-zio (streaked current) or larger Siome is a broad band containing parallel streaks of small Siome. It frequently consists of alternating bands of warm and colder water.



Several observations are recorded

- (i) Off Cape Siono Misaki, by Dr. Shoji (JHO) in 1958 with a G.E.K. and thermographs.
  - (ii) Off Ensyunada, by T. Onaga (1957, U. Sora, Kobe Marine Obs.).
  - (iii) Chatham Sound by W. M. Cameron (P.O.G.) in 1948 with thermographs. (Pac. Prog. Report).
  - (iv) Southern Strait of Georgia, J. A. Shand in 1950 with aerial photography (Trans. Amer. Geophys. Union).
6. Flotsam accumulates along the Siome line of convergence. Usually this includes the whole food chain from lower to higher orders. Plankton is concentrated by the converging currents. Fishes are attracted by the concentration of food. The predators, sea mammals, birds, and finally man follow. Thus the Siome becomes a fishing area. cf. W. Beebe (1926) The Arcturus Adventure.
  7. Siome are associated with eddies. Helmholtz wave.

Cyclonic (anti-clockwise, positive) eddies are cold because deep water upwells in the center. Anti-cyclonic (clockwise, negative) eddies are warm because surface water accumulates and sinks in the center.

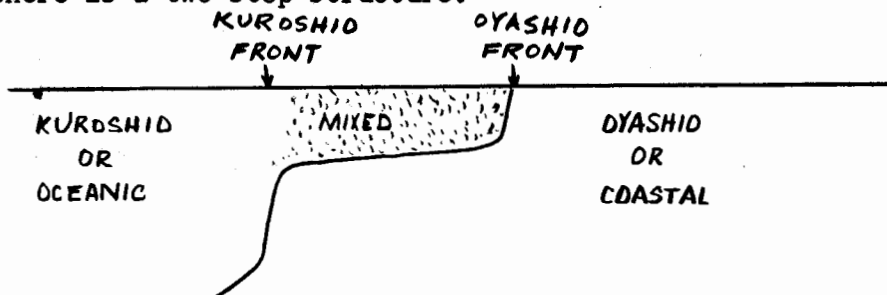
An eddy with horizontal axis presents a vortex sheet on the surface. Along the edge of this there are vortex filaments which develop into eddies with vertical axes. These grow, mature, and decay.

All eddies have a life span in which they grow, mature and decay. The time scale varies from seconds to months. Short life eddies may be observed in the wake of a bridge pier, or in a narrow passage.

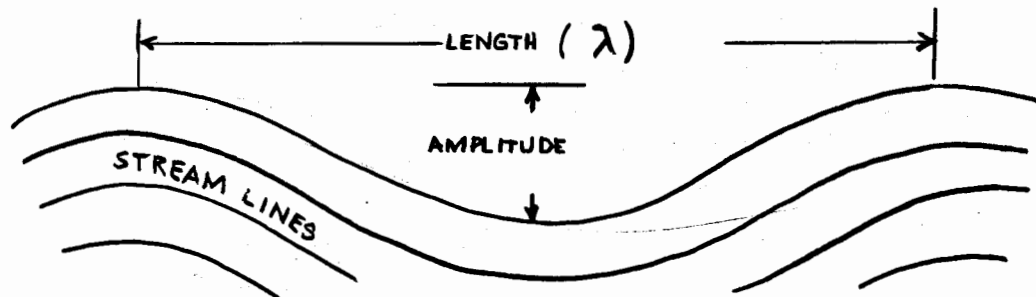
8. The current direction, or at least the speed, changes abruptly from one side to the other of a Siome. A ship crossing a Siome veers abruptly, rolls, and if the weather is stormy the rudder may not be effective. A sea disaster may result if there are crossed pyramidal waves.

Characteristics of Siome.

1. Locations of frequent occurrence, distribution.
  - (i) at the boundary between a cold and warm current, a warm and cold front.
  - (ii) at the boundary between coastal and oceanic water masses; at a coastal front.
  - (iii) around banks, reefs, shoals, an island shelf, along a shelf edge.
  - (iv) off estuaries.
  - (v) along the margin of areas of upwelling.
  
2. The gradient of iso-lines of oceanographic properties ( $\nabla\phi$ ). In an oceanic front  $\nabla\theta$  varies from 0.5 to 5° C per ten miles. (5° C/10 miles). In the front between the Kuroshio and Oyashio, or between oceanic and coastal water, there is a two step structure.



3. The boundary zone (siozaki) meanders. Perturbations (waves) develop and travel along the stream.



This phenomenon in the Gulf Stream has been discussed by Haurwitz and in Kuroshio by Uda (1938), Ichiye and Masuzawa. In the North Pacific the wave lengths of the perturbations are 100 to 200 sea miles, and the amplitude is 40 to 100 miles.

4. Vorticity =  $\zeta = (\text{rot } U)_z = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} = \frac{1}{A} \oint U ds$   
 Consider the vorticity ( $\zeta$ ) due to the Earth's rotation where the Coriolis parameter =  $f = 2\omega \sin \phi$ . Rossby's (1938) concept of the conservation of absolute vorticity

$$\eta = \zeta + f \quad \text{may be expressed}$$

$$\frac{d\eta}{dt} = \frac{d(\zeta + f)}{dt} = 0$$

Then setting

$$\beta = \frac{\partial f}{\partial y} \quad \text{and} \quad \frac{df}{dt} = 0$$

The vorticity equation becomes

$$\frac{\partial \zeta}{\partial t} + U \frac{\partial \zeta}{\partial x} + \beta v = 0$$

To solve this equation, the boundary conditions must be specified.

5. Convergency =  $K = \text{conv } U = -\left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right) = -\text{div. } U = \frac{1}{A} \oint U_n ds$

(i) Hence the vorticity for a simple model .



then

$$\zeta = \text{rot } U = \frac{u_1 - u_2}{L} = \frac{\rho_2 - \rho_1}{2 \omega \sin \phi}$$

$$\frac{\int_0^H g \frac{d\rho}{\rho_2} - \int_0^H g \frac{d\rho}{\rho_1}}{2 \omega L^2 \sin \phi} = \frac{\rho_1 - \rho_2}{\rho_1 \rho_2} \frac{1}{2 \omega L^2 \sin \phi} \int_0^H g d\rho$$

Where H = depth of no motion

In a cold/warm water front, where salinity difference is negligible

$\rho_1$  is the density of water of temperature  $\Theta_1$

$\rho_2$  is the density of water of temperature  $\Theta_2$

$$\rho_1 \rho_2 \doteq I$$

Therefore,

$$\zeta \sim \frac{\rho_1 - \rho_2}{L} \sim \frac{\Theta_1 - \Theta_2}{L}$$

That is, the vorticity near a cold or warm front is proportional to the gradient of density. In the sub-Tropic seas this is nearly proportional to the gradient of temperature. This is not always true in the sub-Arctic Pacific where the density differences are dominated by salinity, not temperature. In this case we can substitute salinity (S) for temperature in the above equation.

(ii) When

$$K > 0 \quad w = \frac{1}{\rho_0} \operatorname{div} S$$

$$(\text{accumulation}) \quad a = - \int_0^t c w_0 dt = \bar{c} \bar{w}_0 t = \int_0^t \frac{c}{\rho_0} \operatorname{div} S dt$$

$$\text{where } S = \sqrt{S_x^2 + S_y^2} = \sqrt{\int_0^h (\rho u dz)^2 + \int_0^h (\rho v dz)^2}$$

and  $\bar{c}$  is the mean concentration of flotsam in the time  $t$ .

$$\text{if } \rho = \rho_0 \quad \text{then } \frac{d\rho}{dt} = 0$$

$$\text{and } a = - \int c \left( \frac{du}{dx} + \frac{dv}{dy} \right) dt = \bar{c} K t$$

That is: accumulation ( $a$ ) increases in time in proportion to the convergency ( $K$ ).

6. In a meandering frontal zone, having wave length  $\lambda$ .

$$y = a \sin \frac{2\pi (x-b)}{\lambda} + k$$

then setting

$$K = K_0 \sin \frac{2\pi (x-b)}{\lambda} = \frac{\pi}{4}$$

$K$  exists only if  $x > b$ ,  $C_0 = \text{constant}$

Let the origin be  $x = 0$ ,  $t = 0$ ,  $\alpha = \frac{8b+3}{8}$

$$A_1 = \int_{b/8}^{\alpha} C_0 K dt = \left(1 + \frac{1}{\sqrt{2}}\right) \frac{\lambda}{2\pi v} C_0 K_0$$

That is, if the front is a line of divergence the amount of accumulation decreases with the elapse of time in proportion to the convergency ( $K$ ), which is negative in this case.

7. Two dimensional diffusion (Uda, 1936)

$$C = \frac{1}{2t} e^{-\frac{(x-vt)^2}{ax^2} + \frac{y^2}{ay^2}}$$

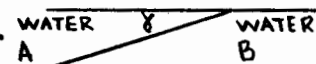
$C$  = constant concentration isoline of flotsam.

The isolines form ellipses as the concentration diffuses. This is confirmed by drift bottle experiments. Sardine eggs, and larvae, may be dispersed by this mechanism. Thus, coastal eddies enhance those nursing areas.

8. T. Cromwell and J. F. Reid, Jr. (1956, Tellus, Vol.8 No. 1) defined a front as a band along the sea surface across which the density changes abruptly. They studied the equatorial front using the bathythermograph and discussed the stability of the frontal layer (transition zone).

9. Statical equilibrium .

The inclination ( $\gamma$ ) of the boundary surface where one water mass under-runs another



$$\tan \gamma = -\frac{l}{g} \frac{\rho v - \rho' v'}{\rho - \rho'}$$

$$\gamma = \tan^{-1} \left( \frac{l}{g} \frac{\rho' v' - \rho v}{\rho - \rho'} \right)$$

where  $l = 2 \omega \sin \phi$

Uda (1938) studied an example in the Polar Front region off Japan.

Here  $v = 1$  cm/sec

$v' = 50$  cm/sec

$\rho = 1.025$

$\rho' = 1.0235$

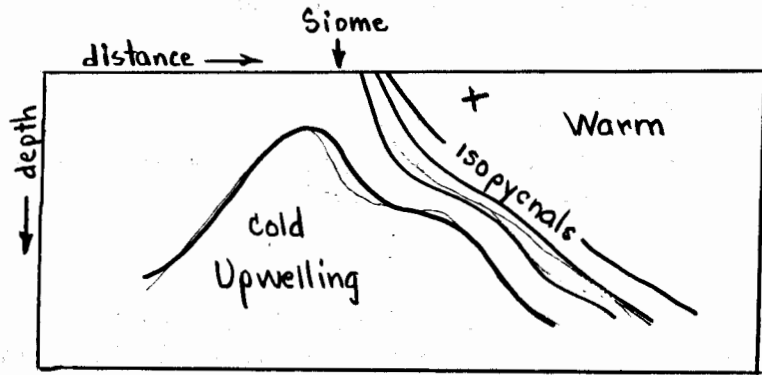
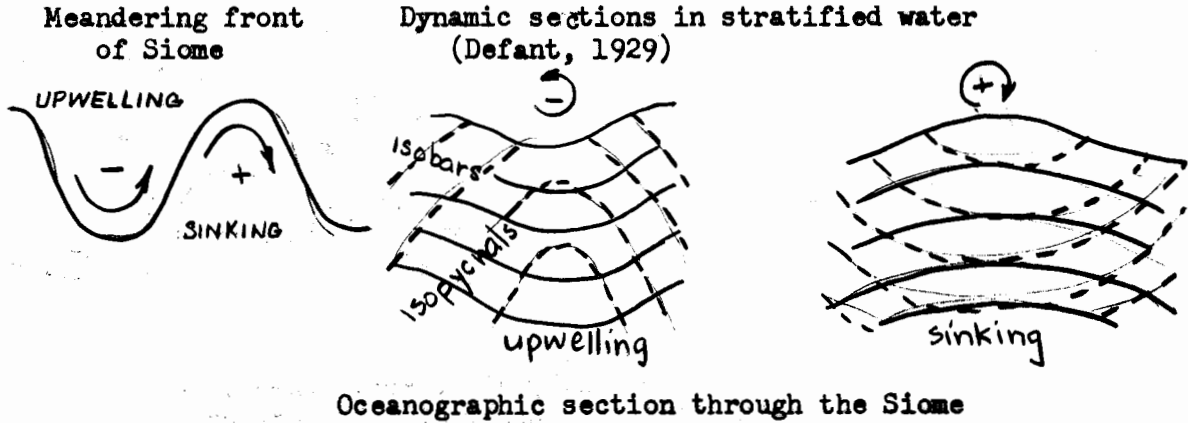
$\phi = 38^\circ$  N.

$\gamma = 8'$

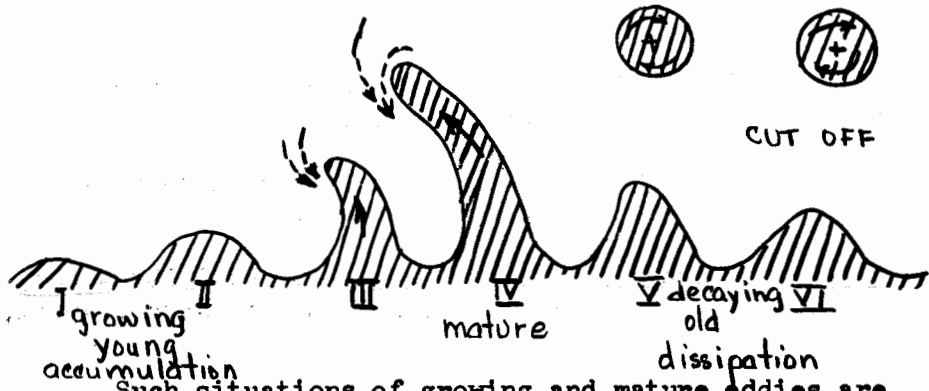
D. Shoji (1958) examined the Kuroshio near Shionomisaki. Here

$v = 100$  cm/sec,  $v' = 200$  cm/sec,  $\gamma = 17'$

10. A train of eddies or a lattice of vortices is formed by the coupling of positive and negative eddies (Uda, 1938).



11. A front usually has a loop-sack pattern of growth and decay.



Such situations of growing and mature eddies are very favourable fishing areas.

An isolated cold core, or warm core, is sometimes occluded by its surroundings which prevent a cut-off. It then forms a stationary front,



These situations are biologically different. When considering the kinematic frontal theory it is necessary to keep the biological contrast in mind.

#### Time variation of Siome

This has been studied by Uda (1938) and reported by John A. Knauss, *Tellus*, Vol. 9, No. 2, 1957.

##### 1. Seasonal variation

In the waters near Japan there is a conspicuous northward shift of the Kuroshio - Oyashio front in the spring and early summer; usually from April through July.

The front along the sub-Tropical convergence (south of Ogasawara Island) is conspicuous in the late winter. In Spring it shifts northward.

##### 2. Phytoplankton blooms occur in the coastal waters in early spring through the early summer.

A. Spring; March, April, and May; the snow melts and the rivers discharge into the coastal waters.

B. The drift ice melts forming cold, low salinity water, which forms the Oyashio front ("Yakumidu") in March, April, and May.

C. In the coastal waters of Japan

(i) The rainy season is early summer. Red water (red tides) ("Akashio") occur.

(ii) The typhoon season is August and September. Red water ("Akashio") again occur.

3. Upwelling usually occurs along the Pacific side of the Japanese Islands during the spring months. A Siome occurs along the outer margin of the areas of upwelling. These are conspicuous off Kumanonada and east of Nozimazaki.

The period of spring upwelling is the prosperous season because it brings good fishing.

#### Associated Phenomena

1. Stratified current. ("Hutaezio")

These are currents in stratified waters where one water mass under-runs another and the currents are in different directions at different depths. They are traced by isentropic spreading on constant density ( $\sigma_t$ ) surface.

Cascading occurs near the continental shelf. There are intrusions. Coastal and estuary fronts are formed with violent tidal currents, especially during the ebb.

2. Internal Waves.

Internal waves usually occur in active frontal regions (cf. southern Strait of Georgia). These make fishing difficult, but in Japan there are rich catches in such regions. The nets and lines become tangled.

3. Fog.

In the vicinity of the Siome of the Polar Front there are frequent dense advection fogs during the summer (June, July, and August). These are sometimes dangerous, but the catches are abundant at these times, if in the modern vessels navigation is aided by radar, direction finders, radio beacons, etc.

Seminar 3. Intrusion and isolated water masses. Storm currents ( $\Phi = \frac{\partial \phi}{\partial t}$ )

A. General.

A1. Transgression of a water mass, or shift of a front indicates a noticeable change of oceanographic properties (temperature, salinity, transparency, colour of water, etc.).

Let a surface of discontinuity

$$f(x, y, z, t) = 0 \quad (1)$$

then the front shifts with velocity  $V$ , and the expression becomes

$$f(x + dx, y + dy, z + dz, t + dt) = 0 \quad (2)$$

therefore the change is

$$\frac{df}{dt} = -v \cdot \nabla f$$

so that if  $\nabla f = \text{const}$ ,  $\frac{df}{dt} \sim v$

In the case of a periodic change (tidal, seasonal, etc.)

$$v = v_0 \sin(nt).$$

and the mean position is

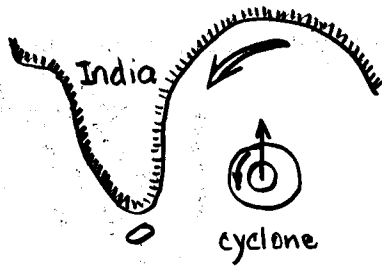
$$\overline{\Delta f} = \frac{1}{T} \int_0^T \frac{df}{dt} dt = \frac{Kv_0(1 - \cos. nt)}{T}$$

where  $T$  is the time unit of a complete cycle of change.

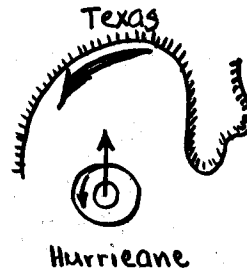
Since a frontal zone is a boundary between two water masses, it follows that the water mass in any limited region is changed when a frontal zone moves through it (i.e. transgresses). Such transgressions are usually accompanied by abnormally strong currents. Such currents are called "Kyutyō" (rapid current) or "Sikezio" (storm currents) by Japanese fishermen. These currents are caused mainly by meteorological disturbances such as the passage of a typhoon, cyclone, hurricane, meteorological front, etc. These transgressions have been discussed by Uda (1955), I. Cline (1926), I. R. Tannehill (1945), and H. Weidemann (1950).

A2. Typical regions of such occurrences are

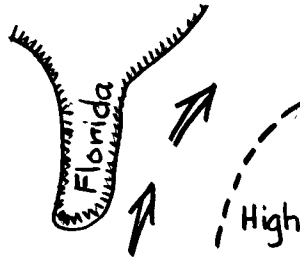
(a) Bay of Bengal



(b) Gulf of Mexico



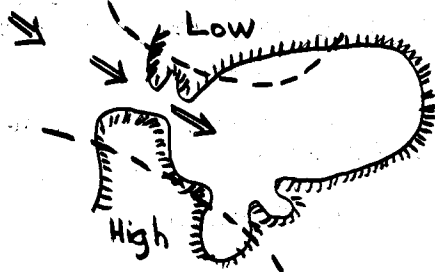
(c) Gulf Stream accelerated



(d) Gulf Stream retarded



(e) Baltic Sea inflow



(f) Baltic Sea outflow

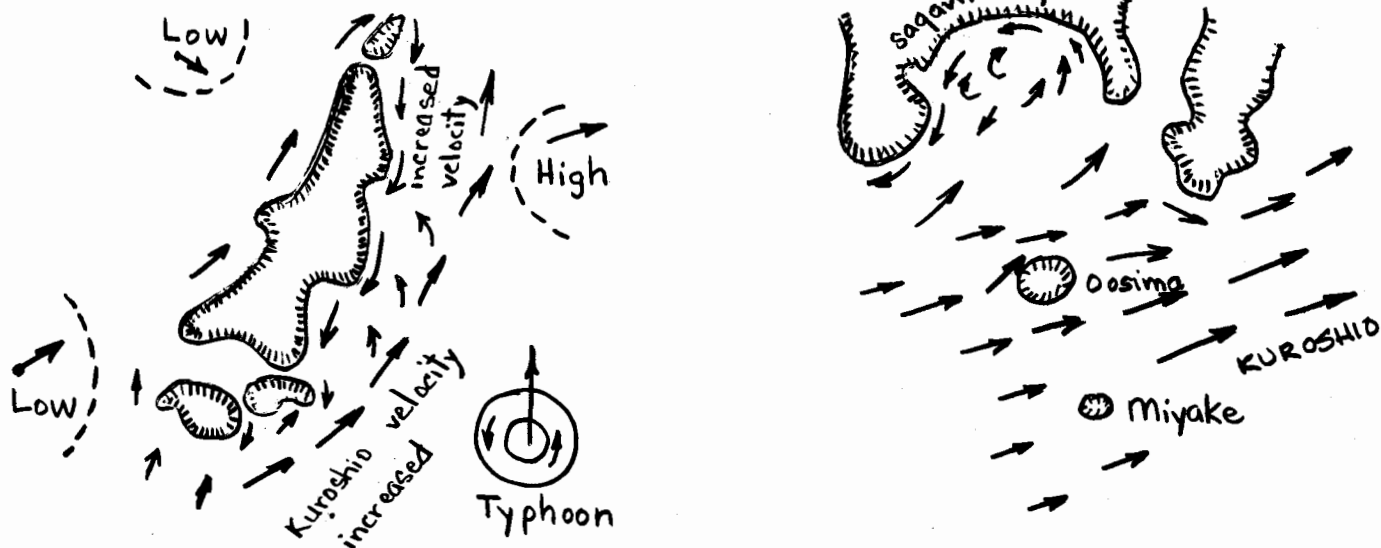


(more persistent than inflow).

B. The phenomena of intrusion, or storm current, and its mechanism.

B1. Storm currents in the cold seasons due to temperate latitude cyclones.

Occasionally these strong currents occur along the coast of Japan.



(i) Usually one or two days before and after a cyclone the strong coastal current occurs in Sagami Bay. (T. Kiura, 1927; K. Kimura, 1940; M. Uda, 1953). At such times set nets cannot be lifted, and sometimes they are washed away and lost in deep water.

K. Kimura (1940) classified the occurrences of Daikyu-tyō (violent storm currents) in Sagami Bay as -

Year end - end of November to early December.

Winter - end of January to early February.

Spring - end of March to early April.

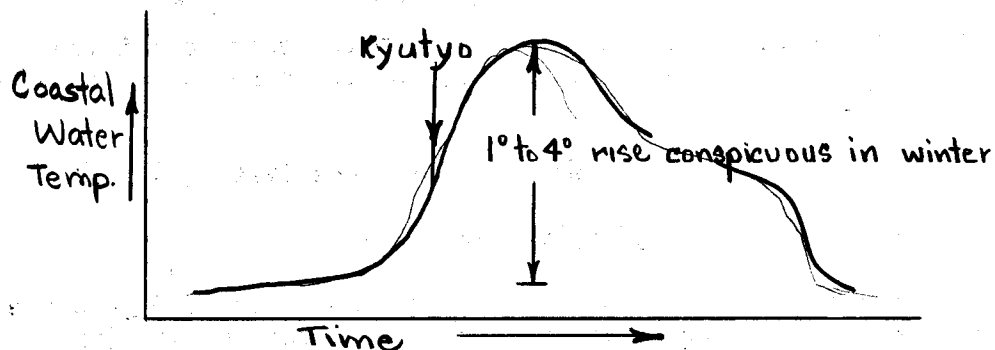
(ii) Before the storm arrives, the offshore current (such as Kuroshio) increases and changes direction towards the coast. In this way a temporary onshore current develops. At the same time the coastal current (counter to the offshore current) becomes stronger. Finally eddies develop.

(iii) This intrusion of the warm Kuroshio water causes the water temperature to rise; first at the offshore islands, Hatidyo, Miyake, and Idu Osima; and later along the Japanese Pacific coast, e.g. Sagami Bay (Uda, 1953).

(iv) As the storm approaches, warm (Kuroshio) water intrudes the normally cold coastal region ahead of the storm. The coastal water temperature rises.

When the storm arrives, the waters are mixed to homogeneity by the winds, waves, and strong currents. During this time the water temperature decreases somewhat.

After the storm passes, offshore relaxation currents and upwelling occur. The temperature falls, almost to the original level.



(v) Such temperature increases are almost always related to the approach of storms, cyclones, or fronts with storm winds. Uda (1953) emphasized that the very dangerous Kyutyō (storm current) not only accompanies cyclones, but also occurs with spring tides, during the period of the full or new moon.

(vi) The catches of fish in the coastal waters are best during the years of onshore set (1924, 1938, 1952) in spite of the damage to nets. Usually there are swarms of fish carried in the onshore storm current (yellow-tail, tuna, mackerel, sardine) which are caught by the nets surviving the storm.

(vii) Such intermittent inflow due to storm currents was observed in Tokyo Bay. It occurred after a southerly gale accompanying the winter passage of marked atmospheric front (December 1926 to January 1957). There was a marked rise of water temperature and salinity. This was noticeable first at the entrance and later at the head of the bay. This storm seriously damaged the Laver (a seaweed called Asakusa-nori) harvest (S. Kadota, unpublished).

R2. The storm current in the warm season due to typhoons (Tropical cyclones) and its associated phenomena.

(i) Accompanying the approach of a typhoon (or hurricane) a huge vortex dome of water is formed. There are submarine oscillations, noise, swell, and a gradual rise of sea level. Coastal currents change and increase. At first the transparency of the sea water increases, then as the storm arrives it becomes turbid. Seiches (Abiki) and strong currents (Mabiki) occur. The coastal bottom sediments and beach sands are loosened. Fishes and shellfish (abalone, top-shell, etc.) behave in a peculiar manner. All these phenomena indicate storm tides or surges.

D. Shoji (1954) showed that the violent storm currents were accompanied by changes of sea level.

(ii) Observing the coastal temperatures off the southern coast of Japan, Uda (1955) found that the water temperatures rose to a maximum two to three days before the approach of a typhoon, and fell to a minimum two to three days after its passage.

He showed that

$$\frac{\partial \theta}{\partial t} = \nu \frac{\partial^2 \theta}{\partial z^2} - v \frac{\partial \theta}{\partial x}$$

where  $\theta$  is the water temperature,  $\nu$  the eddy coefficient as a function of wind waves and currents, and the current velocity ( $v$ ) was cyclic.

$$v = v_0 + A \cos(\omega t + \alpha) + B \cos(2\omega t + \beta).$$

The following (iii, iv) are examples

(iii) In the summer of 1942 (August 25 to Sept. 2) a survey was made in Bungo Strait at the entrance to Seto Naikai (the Inland Sea) by four boats using Eckman-Merz current meters, thermometers, etc. Before the passage of a typhoon, on August 27, there was a strong inflow of stratified water. After its passage there was a strong out-flow of homogeneous water. The stratification had been destroyed. In the vicinity of the intrusion of a branch of the Kuroshio the temperature rise was 1° to 4° C. Also there were semi-diurnal maxima and minima of temperature corresponding to the flood and ebb of the tide.

(iv) The mechanism of a storm current caused by a typhoon is similar to that caused by a cyclonic disturbance in the temperate zone during the cold season.

The pre-storm currents are probably barometric (T. Nomitu, 1932-38) pressure differences in the area. After the storm arrives, wind currents develop ( $v = 0.02 W$  approx.) and pile up water along the coast ( $h = aw^2$ ). (Refer to M. P. Shepard, Long shore currents and rip currents caused by swell.)

Current shifts may be disastrous.

$$\Delta \Phi = \Phi_{\alpha} - \Phi_{\omega}$$

Fish die or escape from a region when  $\Phi_{\omega}$  exceeds the upper or lower limit of favourable range.

### Intrusion of a warm current

The famous El Niño occurs occasionally (1891, 1925, 1953) in the Peru Coastal Current. This corresponds to an abnormal change in the Equatorial wind system; a northerly wind replaces the Southeast Trade Wind, and oceanic water intrudes the coastal region.

At first this brings a transitional increase of neritic fish, but later the whole fish population vanishes. There is catastrophic mortality of cold water fishes (Squid, etc.). El Niño is accompanied by heavy rains which cause much damage on land.

In 1957 (January) there was an intrusion of warm water, northward along the Canadian Coast. This has continued to the present (September 1958) and has markedly affected the migration pattern of the sockeye salmon and whales. Also some subtropical species of fish (barracuda, skipjack, sea turtle, etc.) have migrated into the area.

### Intrusion of a cold current

Hachey reported the shift of a cold front along the Scotian Shelf. J. Eggin (1940) reported a sharp, cold water front along the Scandinavian coast. In 1937 (Jan. 15 to Feb. 2) southeast gales caused an outflow of cold, brackish water from the Baltic Sea (Baltic Current) along west of Sweden to southeast Norway, with a speed of 0.4 knots. At first it caused a rich catch of herring, which later declined and vanished.

In Japan, if the northwest winter monsoon is strong, it results in the appearance of a cold water mass in the shallow pearl oyster grounds of Ago Bay, Mie Prefecture, and Omura Bay, Nagasaki Prefecture. This is caused by upwelling and surface cooling. Sometimes the innermost parts of the Bays are frozen. Then there is heavy damage to the pearl oysters. Such cold spells in the Inland Sea may, in a severe winter, cause the warm water fishes, sea breams, etc., to die. These conditions are possible after the severe winter monsoons (late January to early February) and actually occurred in 1934, 1936, .....

In the spring of 1947 the Kuroshio was weak and the Oyashio influence was strong. All along the broad stretch from Ibaragi, Chiba, Kanagawa, to Siduoka Prefectures and the Idu Islands many kinds of fish died, and floated on the sea surface (I. Amemiya et al, 1957). The same thing occurred to a lesser extent in 1943, 1944, and 1945.

Sardines died, and were piled upon the shore, on the northeast Korean coast during the autumn of 1923. This was due to the intrusion of cold water after a gale, October 24-26 (Z. Nakai, 1939). In the autumn of 1933 sardines were piled in hills on the beaches along the southern coast of Hokkaido. This was caused by the intrusion of a branch of the cold Oyashio following a southwesterly gale.

The lower critical temperature for sardines is about 8° C.

Uda (1952) reported an abnormal abundance of euphausiid (Euphausia Pacifica) along the Nagasaki coast, in February, 1948, following a northerly gale. These important food organisms were followed by their predators (squid, sardine, and mackerel) which were migrating northward to Toyama Bay with the seasonal shift of their favourable temperature zone (13° to 16° C.)

In March 1882, tremendous dead tile-fishes were found floating in the margin of the Gulf Stream, of the east coast of the United States. This was caused by a southward intrusion of the Labrador Current after furious northwest gales.

Along the east coast of Japan, "Yaku Midu" (a kind of diatom) "outbursts" in the early spring at the top of the Oyashio, in brownish, turbid, cold (0° to 2° C.) water.

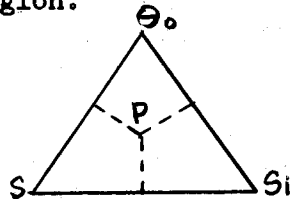
In Japanese coastal waters the major phytoplankton blooms (Harudowari, Siogusare) occur in the spring and autumn, and cause seasonal variation in the transparency of the water.

In autumn the Oyashio front moves southward, intermittently, in step with the passage of successive cyclones. This affects the location of the main saury fisheries, which are in the areas of favourable temperature, 16° to 18° C.

Seminar 4. Coastal water masses in relation to weather.

A. Characteristics.

1. Coastal water is the mixture of land drainage (fresh water) and oceanic (saline) water lying between the coast and the oceanic region.



The ratio of the source waters can be computed from the concentrations of its components, S, Si, etc.

K. Suda (1934) applied the equation of continuity to the coastal waters of Japan. Where  $\rho$  is the density and  $q$  the quantity

$$\rho_c q_c = \rho_r q_r + \rho_o q_o$$

Coastal water
river water
ocean water

Kuroshio area	$S_e = 33.5\%$	$S_o = 34.8\%$	$\rho_c q_c = 27.0 \rho_r q_r$
Oyashio area	$S_e = 32.5\%$	$S_o = 33.5\%$	$\rho_c q_c = 35.5 \rho_r q_r$
Tusima current	$S_e = 33.0\%$	$S_o = 34.0\%$	$\rho_c q_c = 34.0 \rho_r q_r$

In general

$$\rho_c q_c = (30 \pm 5) \rho_r q_r$$

or within the limits of accuracy, coastal water contains about one part of river with 30 parts of ocean water.

2. In general coastal water has a lower salinity than ocean water, is more turbid, has more colour (Forel's Scale), is usually colder in winter, and warmer in summer, has more dissolved oxygen, has more nutrient salts (phosphate, silicate, nitrate, etc.), vitamin (B<sub>12</sub>) and organic substances. Usually it has a higher concentration of plankton, benthos, bacteria, and fishes. Its productivity is greater than ocean water.

3. The occurrence of minor chemical elements (Fe, Mg, I, Co, etc) in coastal waters are different than in oceanic waters.

According to D. J. Rochford (1955-1958) the water mass composition in the eastern Australia coastal region may be identified by the composition of the ash residue of the suspended organic matter, in conjunction with determinations of total phosphorus, chlorophyll,

etc. This appears to be a useful diagnostic tool.

B. Effect of abnormal weather conditions

1. It is possible for coastal waters to be influenced by land conditions. The mixture of the soil and rocks can have some small effects, but the weather effects (precipitation, wind, and temperature) are more important. The character (salinity) of the coastal waters fluctuates in proportion to precipitation, or more accurately, with land drainage (run-off).

2. During especially dry periods the run-off is small, hence the region and degree of its influence is reduced from the average. The oceanic water occurs closer to the coast. This was observed during the dry summer of 1934 in Seto-Nakai when the surface salinity was 1 to 3 ‰ more than usual. Plankton, nutrient salts, etc., were less than usual.

Further, since dry seasons are usually associated with clear skies, insolation is a maximum and the surface temperature rises.

3. During especially rainy periods, the run-off increases, and the salinity of the coastal waters is reduced, and they become noticeably stratified. Also the temperature is lower than normal because insolation is reduced by the overcast skies. However, when there is bright weather after a rainy period, there is marked surface warming and the stratification is intensified. This limits the surface mixing, and aeration. Frequently there is a remarkable diminution of dissolved oxygen below the thermocline. However, during such rainy periods the surface waters are rich in nutrient salts, and plankton. Sometimes "Red-tides" occur.

Examples in Seto-Nakai (Inland Sea of Japan) (Uda, 1940).

(i) In June and July of 1938 there was exceptionally heavy rainfall. The surface salinity decreased to 5 ‰ less than normal. In Ise Bay the decrease was about 2 ‰.

(ii) June, July, and August of 1939 were exceptionally dry. By August the surface salinity rose to 3 ‰ more than normal.

4. During especially rainy periods the coastal waters become turbid (Secchi disc readings decrease) and the colour of the sea changes toward yellow. This is partly due to silt transported from the land, and partly to the increase of plankton. This is additional to normal mud and sand stirred up by the currents in coastal regions.

In Seto-Nakai, during the very wet July, 1938, the waters were turbid. In contrast, during the very dry July, 1939, the water was very transparent. Secchi disc readings were about 5

meters greater than the previous year.

5. In general the survival and growth of larval and juvenile fishes (sardines, anchovy, horse mackerel, etc.) are small during very dry periods. Their survival is usually very good during rainy summers.

6. In a wet summer there are both salinity and temperature stratification. In a dry summer the stratification is primarily due to temperature. During the winter cooling the convection currents (overturn) occur earlier after a dry summer than after a wet summer. Hence, the autumn enrichment (re-fertilization) of the upper layers is usually earlier and better after a dry summer.

C. The development pattern of coastal water and its mechanism.

1. The mean salinity of a sea basin at any time is

$$S_t \sim - \left\{ (N-V)_t + K' \frac{A'}{A} \sum_{t-x}^t N_t \right\}$$

where

N - - amount of precipitation

K' - - ratio of run-off to precipitation

V - - amount of evaporation

X - - phase lag after rain fall

A - - area of sea basin

A' - - area of land drainage

r - - coefficient of correlation between salinity and precipitation.

$$r = \frac{S}{N} = 0.7 \text{ to } 0.8$$

Seto-Naikai

The concept may be simplified to

$$S_t \sim (V-N)_t$$

$$S_t \sim (V-N - \frac{A'}{A} N)$$

Uda and Watanabe (1933) examined these equations and found in the Seto-Naki that

$$S_t \approx -N(t_0 - x)$$

where  $x$  is one month, except at the entrance.

In Owase Bay it was observed that the salinity minimum occurs several days after the rainfall.

Consider a sea area having uniform depth ( $H$ ) and horizontally uniform salinity ( $S_0$ ) at time ( $t = 0$ ). The total amount of water after precipitation = original amount + inflow from the land - evaporation - outflow to the sea.

If there is no outflow to the sea, and no phase lag

$$\bar{S}_t = A \int_0^H \frac{S_0 dz}{AH + A(N-V) + K'A'N} = \frac{\bar{S}_0}{1 + \frac{N}{H} \left( \frac{N-V}{N} + K' \frac{A'}{A} \right)}$$

and if complete mixing occurs  $\bar{S}_0 = S_0$  Then the change of salinity associated with the precipitation,

$$\Delta S = \bar{S}_t - S_0 = - \frac{\frac{N}{H} \left( \frac{N-V}{N} + K' \frac{A'}{A} \right)}{1 + \frac{N}{H} \left( \frac{N-V}{N} + K' \frac{A'}{A} \right)} S_0$$

for example in Seto-Nakai

$$S_0 = 30\% , H = 30m. , N = 200mm. , \Delta S = 2\%$$

$$K' = 0.3 , V = 10mm. , \frac{A'}{A} = 3$$

Therefore

$$K'NA = 0.3 \times 0.2 \times 3A = 0.18A \approx NA$$

Land drainage  $\approx$  precipitation on this particular sea.

2. If the outflow velocity ( $v$ ) is considered

$$-\frac{\partial S}{\partial t} = \underbrace{v \frac{\partial S}{\partial x}}_{\text{advection}} + u \underbrace{\frac{\partial^2 S}{\partial z^2}}_{\text{mixing}}$$

where  $u$  is the eddy coefficient of turbulent mixing.

Then defining the salinity distribution in the horizontal and vertical sense by the arbitrary expression

$$S = S_0 (1 + az^2)(1 - e^{-\lambda x})f(t)$$

where  $(1 + az^2)$  is a function fitted to the vertical distribution of salinity at a position,  $(1 - e^{-\lambda x})$  is a function fitted to the seaward increase of salinity at a fixed depth, and  $f(t)$  is an indefinite function of time. Then the change of salinity due to precipitation in time ( $t$ ) is

$$\begin{aligned} -\Delta S &= \int_0^t v \frac{\partial S}{\partial x} dt + u \int_0^t \frac{\partial^2 S}{\partial z^2} dt \\ &= S_0 \left[ \lambda v (1 + az^2) e^{-\lambda x} + 2au(1 - e^{-\lambda x}) \right] \int_0^t f(t) dt \end{aligned}$$

This expression cannot be evaluated in advance of the precipitation. However, practically

$$\gamma = \tan^{-1} \frac{K'NA'}{AL}$$

where  $\gamma$  is the slope of the sea surface from the estuary to seaward, caused by the run-off, and  $L$  is the distance through which this slope is effective.

In the outflow from Osaka Bay

$$N = 200 \text{ mm.}$$

$$\frac{A'}{A} = 3$$

$$K' = 0.5$$

$$L = 50 \text{ Km.}$$

Then

$$\gamma \doteq 00^\circ 01'$$

But in a narrow passage generally

$$v = C \sqrt{\frac{2g K'NA'}{A}}$$

where C is a particular constant of the locality.

In Naruto Strait (S. Ogura)  $C = 1$ ,  $v = 240$  cm./sec.

In some other passages  $C = 0.5$ ,  $v = 120$  cm./sec.

In Osaka Bay (Uda, 1940)  $H = 10$ m., varied from .50 to 100 cm./sec

$v$  varied from 110 to 222 (c.g.s.) due to heavy rain in Kii Channel, and there was a strong outflow.

3. The surface of Sinzi Lake is above sea level. It is connected to the sea by a river whose bottom is below high tide level. Normally sea water is prevented from entering the lake by the continuous outflow of fresh water. However, sometimes in a dry summer some sea water intrudes the lake. This intrusion was observed in 1938 and studied by Koitiro Takahasi (1940).

Let  $Q_1$  be the river discharge

$Q_2$  be the outflow from the estuary to the sea corresponding to the sea level difference  $(h_1 - h_2)$  where  $h_1$  is the mean sea level in the estuary and  $h_2$  is the tidal rise.

$$h_2 = A \sin. \omega t. + \text{etc.}$$

Then, if  $Q_1 = \text{constant}$ , and  $\alpha$  is a constant of proportionality (days/cm.<sup>2</sup>)

$$h = h_1 - h_2 = \frac{Q_2}{\alpha}$$

and where A is the surface area of the estuary

$$A \frac{dh_1}{dt} = Q_1 - \alpha(h_1 - h_2)$$

$$h_1 = \frac{Q_1}{\alpha} + \sqrt{\frac{\frac{\alpha Q_2}{A}}{\frac{\alpha^2}{A^2} + \omega^2}} \sin(\omega t + \phi)$$

where  $\phi$  is the phase lag, then

$$\tan \phi = - \frac{\omega A}{\alpha}$$

Then in Sinzi Lake (Koitiro Takahasi) (1940)

$$Q_1 = 0.9 \times 10^{13} \text{ cm}^3/\text{day}, \quad A = 83 \text{ Km}^3$$

$$\omega = 3.5 \times 10^{-5} \text{ sec}^{-1}, \quad h = \frac{Q_2}{\alpha} = 1\text{m}, \quad a = 20 \text{ cm.}$$

and we can compute

$$\alpha = 1.1 \times 10^{-12} \text{ days/cm}^2$$

$$\phi = 3 \text{ hours (phase lag)}$$

A similar occurrence was observed in the Tone River Estuary in 1958 (M. Ishino).

4. Tidal estuaries have been extensively studied on the Pacific Coast of Canada, Alberni Inlet (Tully, 1949), Bute Inlet, (Tabata and Pickard, 1957), Strait of Georgia (Waldichuk, 1957; Tully and Dodimead, 1957), Fraser River Estuary (Fjarlie, 1951; Tabata, 1957; Herlinveaux, 1957; Pickard, 1953, 1954).

D. Associated features.

1. Near the edge of the continental shelf there is a marked change of surface salinity, and a corresponding change of the current. There is a geostrophic current along the shore corresponding to the seaward salinity gradient.

2. Uda et al (1930) made a harmonic analysis of the cycles in the monthly data of temperature, salinity, and transparency. Then where  $\bar{\Phi}$  is the property

$$\bar{\Phi} = \bar{\Phi}_1 + \bar{\Phi}_2 = a_0 + a_1 \cos(\alpha t - \beta) + b_0 + b_1 \cos(\alpha t - \beta + \frac{\pi}{6})$$

where  $\bar{\Phi}_1$  is the annual component

$\bar{\Phi}_2$  is the semi-annual component

Inspecting the features of the ratios of the properties

$$\bar{\Phi}_1 / \bar{\Phi}_2 \quad (S_1/S_2, \theta_1/\theta_2, \text{etc.})$$

it is possible to define southern ( $\bar{\Phi}_1$ ) and northern ( $\bar{\Phi}_2$ ) type waters, and the transitional types along the coast of Japan.

3. Cascading occurs in winter on the edge of the continental shelf in the east China Sea. This feature was described in the Celtic Sea by L. H. N. Cooper (1949).

4. Estuary mechanism involves the features of entrainment, halocline, and fresh water budget. These have been investigated by Tully (1949, 1952, 1954).

5. Mixing of the waters and the heat budget have been studied in the Strait of Georgia by Waldichuk (1957).

6. A correlation between the variation of "Offshore" temperature (salinity) and coastal temperature (salinity) is important to the prediction (Hollister, 1958).

#### E. Coastal Circulation.

The circulation of coastal waters is determined by the run-off, tidal currents, intrusions of ocean water, and the weather. The eddies and wake streams caused by the topographical features are important in relation to nursery and fishing areas. Near shore circulation is a particular problem which must be studied locally.

Seminar 5. Upwelling and eddies in relation to the biological enrichment pattern in the sea.

- A. There are many physical oceanographic factors which affect basic productivity in the sea. These include optimum temperature and salinity structure, favourable submarine illumination, turbidity, critical depth, and favourable currents, gyral with upwelling and divergence, or convergence and sinking.

Convergent currents are general in the western part of the three great oceans, namely; Kuroshio, East Australian Current, Gulf Stream, Brazil Current, Mozambique Current. Divergent currents occur on the eastern side of the oceans, namely; California Current, Alaska Gyral, Peru Current, Canary Current, Benguela Current, West Australian Current. Moreover there are northern and southern Polar Fronts in the Pacific and Atlantic Oceans. These are due to the meeting of sub-Tropic and sub-Arctic gyral between latitudes 40° and 50°.

- B. The difference of velocity from one side to the other of a front results in a shear. This develops undulations and eventually eddies.

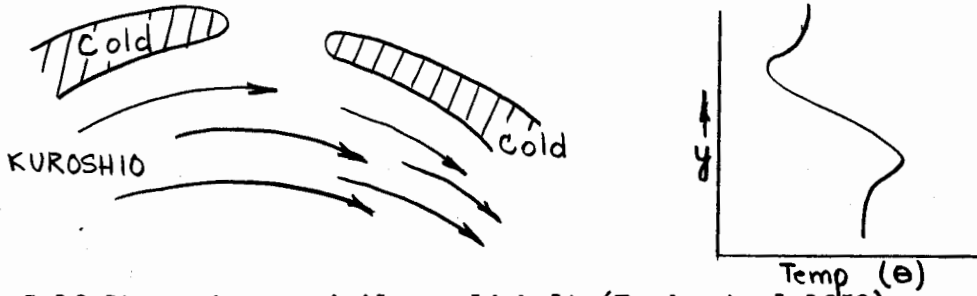
Upwelling occurs in regions of divergence. These occur mainly along continental coasts or in the lee of islands or banks where there are prevailing offshore winds, or currents. There is always a corresponding onshore movement in the underlying deep water. Upwelling may also result from the meeting of deep currents in the open ocean (east Tropic region). Regions of upwelling are always rich in nutrient salts and consequently have plenty of marine life. This was noted by the Meteor survey (A. Defant, 1930, 1931) and recently in the California Current by the California Co-operative Oceanic Fisheries Investigation (1950-1958).

- C. Uda (1958) classified the nutrient enrichment pattern resulting from eddy systems into three types.

1. Dynamical eddy system.

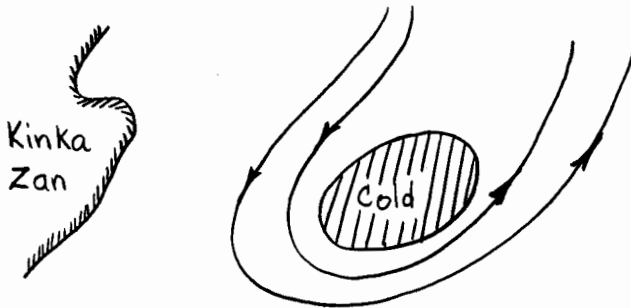
The meeting of two current systems forms a front which meanders according to the prevalence of the current on either side. It forms a dynamically conditioned eddy system subject to the fluctuation of the current intensity in each water mass. For example:

- (i) Kuroshio front surrounding a cold belt (Uda, 1943; H. Kawai, 1955; J. Masuzawa, 1956)

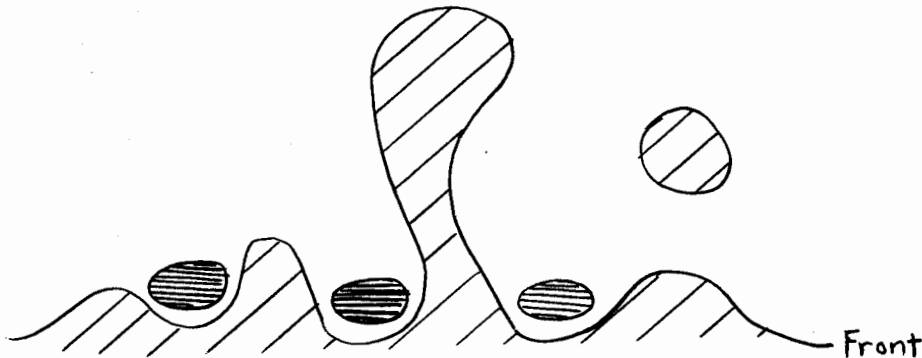


The Gulf Stream has a similar cold belt (Ford, et al 1952).

(ii) Recurved portion of Oyashio front.



(iii) In general, in the north-western Pacific the most productive zone lies very close to the eddies associated with the frontal zones; particularly the cold patches at the center of cyclonic eddies, and the loop-sac (pocket) type warm cores in the anti-cyclonic eddies.



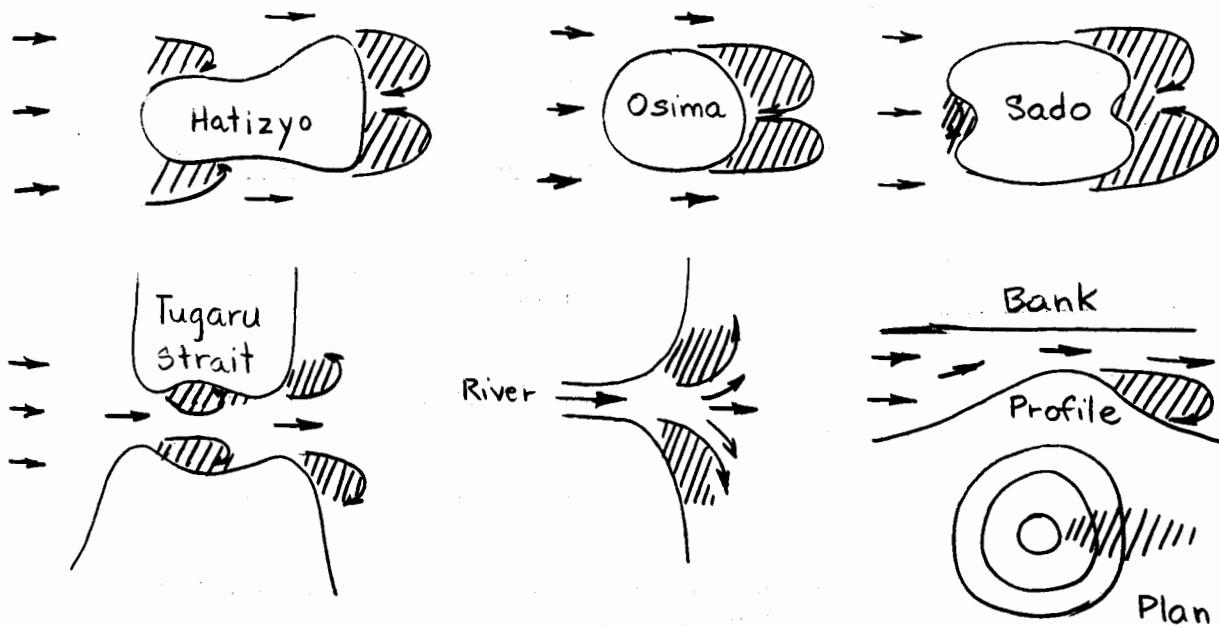
These occur in the Oyashio front in summer and autumn, and in the Kuroshio front in spring and early summer.

## 2. The topographical (Orogrophic) eddy system.

Uda and Ishino (1958) studied the eddy systems caused by topographic irregularities. These included elevations and depressions of the sea bottom, banks, islands, and the size and depth of bays, straits, etc. In these, the eddy systems are caused or restricted by fixed boundaries. The effects were studied in hydraulic models and in oceanographic surveys.

Model studies were made of eddies caused by islands, peninsulae, straits, bays, etc. such as occur in familiar fishing areas. These models were based on the principles of dynamical similitude, derived from the fundamental equations of motion (M. Okada et al, 1933; S. Ogiwara, 1949).

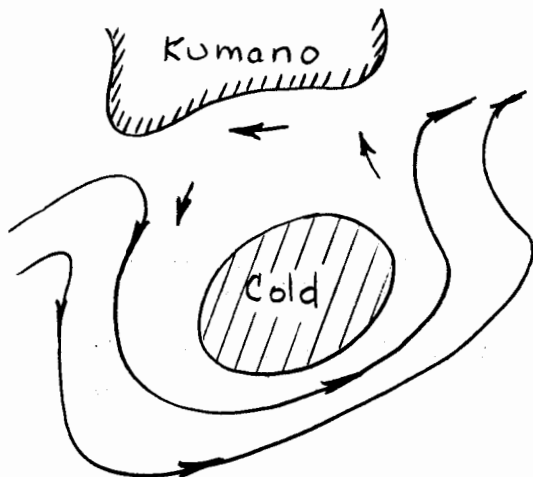
The results were shown in photographs (Uda and Ishino, 1958; Okada and Miyoshi, 1933). They explain the eddy mechanism constituting the location of some important commercial fisheries, and the migration route from one eddy system to another.



T. Ichiye (1953) proposed a theory on the hydrographical conditions around an island.

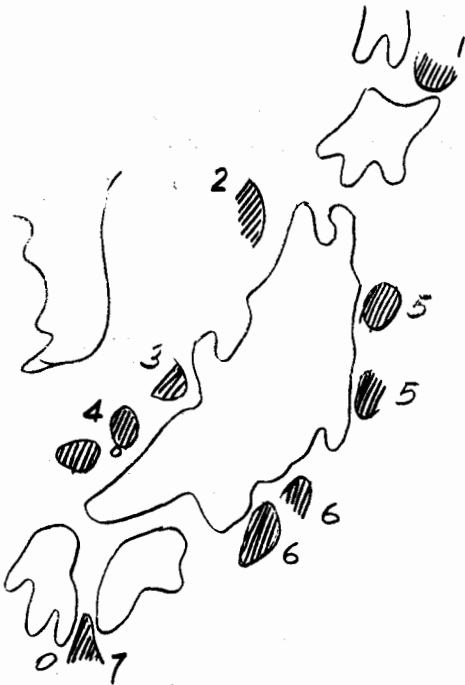
D. Combined type of eddy system. Partly dynamical, partly topographical.

(i) The cold eddy in the meander of Kuroshio off Kumano Nada



This eddy is quasi-stationary. Through a period of several years it grows and decays, and finally vanishes (Uda, 1940, 1949).

(ii) The cold eddies.



(a) Cold water intrusion associated with eddies.

1. Hokkaido, north coast Okhotsk Sea side, belt of coastal upwelling.

2. In the Japan Sea west of Tugaru Strait.

3. North of Wakasa Bay.

4. Around Oki Island.

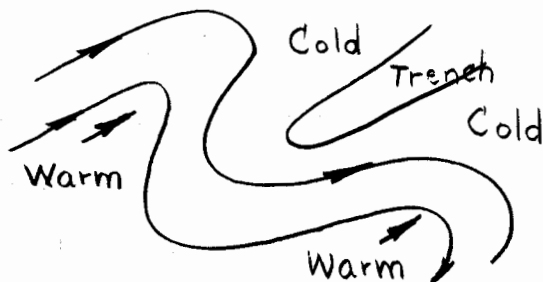
5. Kasima Nada, and off Kinkazan

6. Ensyu and Kumano Nada.

7. Hyuga Nada.

On the Pacific side between the coast and Kuroshio, cold water upwells from 300 or 400 meters depth.

(iii) At the north end of Ogasawara Trench (Japan Trench) near the sub-Tropical convergence. (M. Uda, 1955).



E. The eddies fluctuate from year to year, seasonally, and in short periods associated with meteorological disturbances.

The greatest productivity seems to occur in the active periods of the eddies following the winter convection (turn-over) period, and the wind stirred period.

F. Upwelling is the upward penetration of a mass of water into the surface wind-mixed layer. It is associated with divergence. It may be classified roughly into three types.

1. Upwelling due to offshore wind. It varies with the wind, as may be observed during and following the monsoons.
2. Topographical upwelling associated with irregularities of the bottom and coasts.
3. Upwelling due to cyclonic eddies.

G. The upwelling of nutrient-rich deep water produces plentiful marine organisms in the euphotic layer. (Nathansohn's theory, Liebig-Brandts' theory).

It is well known that the regions of upwelling correspond to the great fishing areas, eg. Oyashio, California Current, Peru Current, Benguela Current, Guinea Current, Somali Current, Malabar coast of India, Equatorial Counter Current, etc.

H. Although the intensity of upwelling can be denoted relatively by the area of a cold water mass in an oceanographic section, it is better indicated by the abundance of nutrients or plankton.

The photosynthetic assimilation of carbon dioxide by marine plants (phytoplankton) releases an excess of dissolved oxygen. This occasionally results in super-saturation in the layers above the compensation depth (about 100 meters, where the biological production of oxygen is balanced by the demand).

Where the solubility of dissolved oxygen at the salinity and temperature in situ is expressed by  $O_2'$ , and the observed concentration is  $O_2$ , the degree of saturation (%) is

$$100 \frac{O_2}{O_2'}$$

Then the degree of excess (or deficiency (%)) is expressed by

$$\Delta O_2^! = 100 \frac{O_2}{O_2'} - 100$$

Accordingly the integrated excess of dissolved oxygen (Q) in a column of water (z) in an area (A)

$$Q = \iint \Delta O_2^! dz dA$$

may be taken as a measure of the productivity which varies in proportion to the quantity (P) of the marine organism (Uda, 1953; Bull. Japanese Soc. Sc. Fish, Vol. 19, No. 4. pp 435-438.

In a resting water area the excess of oxygen ( $Q_0$ ) due to a plankton population (P) is considered to be a function of the light intensity (I) and the concentration (N) of nutrients. The light intensity may be defined as

$$I = I_0 (\sin wt) e^{-mz}$$

where  $I_0$  is the surface illumination, which varies through an annual cycle ( $\sin wt$ ) and is attenuated with depth ( $e^{-mz}$ ).

The concentration of nutrients (N) may be expressed

$$N = N_0 \cos (wt + \alpha) z^n$$

where  $N_0$  is the concentration at the surface, which varies through an annual cycle ( $\cos (wt + \alpha)$ ) and varies with depth as some power of the depth. This is proportional to vertical mixing, and inversely proportional to the vertical stability.

Hence

$$Q_0 = kIN = k \frac{I_0 N_0}{2} \sin 2(wt + \alpha)$$

in the euphotic zone. It shows semi-annual maxima; one in the spring (April - May) and another in autumn (October - November).

Observations in the Japan Sea (1932, 1938) and in the Pacific Ocean (1933 to 1935) indicate high concentrations of oxygen near the frontal zones. Presumably this is due to aeration by turbulent mixing of the water mass ( $Q'$ ) and to photosynthesis ( $Q_0$ ). Accordingly we may put

$$Q = Q_0 + Q' \quad \text{standing crop (P)}$$

The active photosynthetic zone is found in the depth (H) range 0 to 50 meters, and most frequently at 25 meters. Then plotting the distribution of the maximum oxygen concentration and its depth

$$\sum_0^H \Delta O_2' \Delta z$$

with the plankton content (cc. or numbers of individuals) and considering the vertical temperature gradient, simply denoted by

$$\nabla_z \theta = \frac{\partial \theta}{\partial z} = \theta_0 - \theta_{50} \quad , \quad \text{etc.}$$

and transparency the following features are remarked:

1. The greatest excess of oxygen (Q), i.e. the region of Q max. in the northwest Pacific occurs near the maximum horizontal temperature gradient between the surface and 50 meters depth, i.e. along the frontal zones.
2. The greatest excess of oxygen (Q) max. coincides pretty well with the greatest vertical temperature gradient.
3. Combining P (statical productivity) and vertical gradient of temperature ( $\nabla_z \Theta$ ) we can obtain Q (Kinematical productivity). In the Japan Sea the areas of greatest abundance (P, Q,  $\nabla_z \Theta$ ) lie near the frontal zones, and in the regions of upwelling (Uda, 1953).
4. We can recognize the cold northern waters (upwelling areas) as the source of marine production in combination with the influence of convergence areas. Consequently the vertical gradient of water temperature ( $\nabla_z \Theta$ ) in the photosynthetic zone is a useful indicator of marine production.

#### 1. Characteristics of an area of upwelling

In an area of upwelling, the water is colder than the surrounding water at the same depths. It has relatively high salinity, less dissolved oxygen, more nutrient salts (phosphate, etc.) and plenty of plankton. Also the stream lines diverge, and there is frequent fog.

The characteristics of an area of sinking are the converse of the above.

#### 3. Phenomena associated with upwelling

1. Theoretical studies of upwelling were conducted by A. Defant (1936), K. Hidaka (1953), Y. Saito (1951), K. Yoshida (1955, 1958) and other people at Scripps Institute of Oceanography.

Hidaka considered the California Current, and computed the rate of upwelling to be 80 meters per month. He showed, with some assumptions, that the upwelling was most intense when the offshore wind crossed the coast from the northeast at an angle of  $21.5^\circ$ . Yoshida pointed out the importance of the curl of the local wind stress. Moreover that the upwelling was seasonal, of limited duration, and occurred in limited localities along the California Coast. Active upwelling occurs in a strip 100 km. wide when the wind blows steadily from the north, along the coast. He emphasized that the upwelling was related to the horizontal vortical current.

The upwelling causes indirect effects, resulting in variations of coastal conditions, such as changes in density distribution due to vertical advection of mass, and horizontal divergence of motion.

Considering the two layer problem he suggested that the meridional current parallel to the coast is strongly accelerated by upwelling.

2. Upwelling penetrating the thermocline, or sub-surface upwelling is especially important. Considering the data from the Eastropic Operation, T. Cromwell (1957) showed the important meaning of a thermo-anticline or ridging which penetrated into the euphotic zone in the Equatorial Pacific, off Central America, as the tuna long-line fishing area.

Seminar 6. Some problems related to Oyashio (northern water masses).

A. Circulation in the Sub-Arctic Pacific

A review of the works of B. Schulz (1911), H. U. Sverdrup et al (1942), G. Wüst (1936), R. H. Fleming (1955), M. Uda (1929-1958), S. Mishima (1957), T. Sugiura (1957-1958), N. Watanabe (1951, 1955), A. M. Muromtsev (1958), T. Hirano (1957-1958), K. Kitano (1958), J. P. Tully et al (1955-1958), H. Koto and T. Fujii (1958)

The general circulation is shown in Figure 1.

The cold Oyashio moves south along the east side of the Kamchatka Peninsula, where it is called the East Kamchatka Current, and the Kurile Current, to Hokkaido. Off the islands of Japan it meets the warm, north flowing Kuroshio, and the two turn eastward to cross the ocean as the West Wind Drift (North Pacific Current), between latitudes 35° and 50° N. Off the coast of America they divide. Part, including all the Kuroshio extension, and some of the sub-Arctic water turns south to form the California Current flowing toward the Tropics. The remainder of the sub-Arctic water turns north and circulates around the Gulf of Alaska, as the Alaska Gyral. Along the Alaska Peninsula it is called the Alaska Stream (Bennett, 1959). This return current flows westward close along the southern side of the Aleutian Islands veering into the Bering Sea through the passes and around the end of the island chain. This, with the outflow from Bristol Bay forms a northward movement in the eastern part of the Bering Sea. Part escapes through the Bering Strait, and part turns southward along the Siberian coast to re-form the Oyashio. There the sub-Arctic circulation is largely a closed system. In the sea of Okhotsk there is an inflow on the eastern side, and an outflow on the western side along Saghalin (East Saghalin Current; Uda 1934). This is essentially a cyclonic gyral.

Associated with this sub-Arctic circulation system there are a number of cyclonic gyral, shown in Figure 2, which may be correlated to the distribution of salmon.

2. Oyashio is the cold (less than 18° C) low salinity (less than 33.5‰) current flowing along the Pacific side of Kurile Islands. Its velocity is 0.3 to 1 knot, and it is 200 to 400 meters in depth. Its transparency to the Secchi disc is less than 15 meters.

The word "Oya" means parent, and "shio" means current. The term Oyashio, parent current, may originate from the fact that it is rich in nutrients and is a feeding source for marine life.

The Oyasio Gyral in the western Pacific, (longitude 141° to 151° E) is formed by the southern flow along Hokkaido and the return northward flow, further offshore. In this there are a number of sub-gyral.

3. Vertical circulation in the Sub-Arctic Waters.

This has been studied by G. Wust (1928, 1957), M. Uda (1929, 1935, 1938, 1950), H. U. Sverdrup et al (1942), S. Kishindo (1942), H. Stommel, (1957), A. R. Redfield (1927).

On the basis of Temperature-Salinity diagrams, and the method of core analysis, the distribution of an intermediate water (salinity minimum) and intermediate current, a deep current, and a bottom water were discussed. The sub-surface extension of Oyashio water, called the Oyashio under-current, to the south and east, was discussed by Uda (1953) on the basis of salinity minimum contours with its depth contours. A. M. Muromtsev (1958) has made a similar analysis. A. Iizuka and M. Tamura (1958), C. W. Beklemishev and V. A. Burkov (1958) have shown the planktological line of demarkation between sub-Arctic and sub-tropical species in the North Pacific.

4. The amount of sea ice coverage, and the abundance of cold ice-melt water are proportional to the degree of winter cooling. However, the amount of outflow of this cold water, the intensity of the Oyashio, is modified by the prevailing winds and storms during spring and summer.

5. The main pattern of salinity structure in the sub-Arctic waters is formed by land drainage and the excess of precipitation over evaporation and is modified by circulation.

The main sources of land drainage are along the American continental slopes, north of the Columbia River, and on the Asiatic coast north of Hokkaido. These create a peculiar fresh water dominated domain, and attract salmon in their homing migration.

6. Dodimead and Hollister (1958) reported the circulation of the Gulf of Alaska from drift bottle observations.

Recently V. A. Burkov et al (1958) with data from the Vitiaz expedition (May, June 1955) described the meandering coastal front of the east Kamchatka Current. This showed conspicuous eddies, and a warm water intrusion from the south-east along the Aleutian Islands. This had already been shown by K. Taguchi (1942, 1957) from drift bottle data.

B. Water masses and Fronts

Bering Sea.

- |                                 |                               |
|---------------------------------|-------------------------------|
| (a) North Alaskan Coastal water | } North Alaskan coastal front |
| (b) Bering Basin water          |                               |

- (c) East Kamchatka Coastal water ) Kamchatka front.  
(East Kamchatka Cold current )

Gulf of Alaska

- (d) South Alaskan coastal water (South Alaska coastal front)
- (e) British Columbia coastal water (British Columbia coastal front)
- (f) Gulf of Alaska central water Polar Front
- (g) North Pacific Transitional Water, II (North Pacific current)
- (o) Californian water

Okhotsk Sea

- (h) West Kamchatka coastal water West Kamchatka coastal front
- (i) Okhotsk interior coastal water Okhotsk coastal front
- (j) Saghalin coastal water Saghalin coastal front  
(East Saghalin cold current)

Kurile Islands Kurile front (local)

Seas east of Japan

- (k) Oyashio water Oyashio front (Polar front, sub-Arctic conv.)
- (l) North Pacific Transitional water, I Kuroshio extension, West Wind Drift.  
(modified or mixed water).
- (m) Kuroshio water Kuroshio front
- (n) Eastern Pacific sub-Tropical water Polar Front

Cold cores in the sub-Arctic waters (Fig. 2). In each cyclonic eddy there is a cold core shown in Figure 2.

- (1) East Saghalin
- (2) Oyashio
- (3) Kurile
- (4) South east Kamchatka
- (5) Anadir
- (6) Aleutian
- (7) Alaskan
- (8) California

These cold cores are nursing, feeding, and wintering regions for salmon.

#### C. The origin of Oyashio

The main source of Oyashio water is in the Okhotsk Sea, particularly in the western part, where there is most sea ice in winter. It is maintained by the persistent outflow through the Kurile Islands. This outflow can be recognized by the continuity of the ice-melt waters from the Okhotsk under the warmer Pacific waters. There is another independent source of such water in the Bay of Anadir. These waters are somewhat modified by land drainage and upwelling as they move south past Kamchatka. Oyashio is the compound cold current from these two sources.

#### D. Effects of Weather Conditions on Oyashio

1. During particularly cool summers in Japan the rice crop is poor or fails altogether. These occurrences are coincident with oceanographic and meteorological phenomena. These have been reported by T. Seki (1906), Y. Tuizi (1906), K. Ando (1931), T. Okada (1915), K. Suda (1931), M. Uda (1938, 1953), S. Fujiwhara (1949), M. Hanzawa (1952, 1957), N. Watanabe (1953).

- (i) Abnormal prevalence of Oyashio.
- (ii) Prevalent north-easterly winds from the Okhotsk high atmospheric pressure area, in early summer.
- (iii) Abnormal development of the Aleutian low pressure area, and winter monsoons. (e.g. in the years, 1833, 1866, 1869, 1884, 1902, 1905, 1913, 1931, 1934, etc.)
- (iv) Occurrence of relatively warm water in the Bering Sea near the Aleutian Islands, and colder than normal waters in the seas south of the Kurile Islands (e.g. 1931, 1934, 1941, 1953, 1958).
- (v) The atmospheric pressure of the north Pacific high is less than normal in the early summer of such years.

2. The development of the Aleutian Low due to the prevalence of the Kuroshio extension (North Pacific Current) and its consequence.

This is similar to the Icelandic low pressure area caused by the prevalence of the Gulf Stream system.

The anti-cyclonic atmospheric circulation around the Aleutian Low ( $P_A$ ) and the following winter monsoons ( $W$ ) are proportional to the square root of the pressure difference between the Siberian High ( $P_S$ ) and  $P_A$ .

$$W = k_1 \sqrt{P_S - P_A}$$

This causes a southward extension of the Oyashio current ( $V$ ) such that

$$V = kW = k k_1 \sqrt{P_S - P_A} = k' \sqrt{P_S - P_A}$$

where  $k$  is the wind factor (0.02 to 0.03).

The direction of the wind induced current in the sea runs nearly parallel to the isobars. The direction of the wind is usually about  $30^\circ$  to the left of the isobars, and the wind driven current is about  $30^\circ$  to the right of the wind.

3. The development of Siberian High and/or the Aleutian Low increases the pressure difference and the consequent winter monsoons strengthens the Oyashio cold current from winter to early summer.

The phenomena appears to alternate in successive years (e.g. 1933 warm, 1934 cold, 1941 cold, 1942 warm). The abnormal sea conditions in 1958, cold in the western sub-Arctic Pacific and warm in the east may be related to similar atmospheric condition (see section D. 1. iv).

4. Usually the Aleutian Low pressure area disappears in early summer. Then the prevailing westerly winds are replaced by the southerly monsoons as the north Pacific High develops. These winds bring frequent advection fogs over the cold waters south of Kamchatka and the middle Aleutian area. They cause weak north flowing surface currents. These are presumably accelerated by the change of sea level associated with the change of barometric pressure (barometric currents), and have been estimated on this basis. These north flowing currents are called the North Kurile warm current and the south Aleutian warm current. They occur only in summer (June, July, August) but are very important in relation to the fishing localities and to the migration of salmon.

5. Some part of the south Aleutian warm current mixes with the Alaska current extension and enters the Bering Sea through the Aleutian Passes. Similarly the water entering the Sea of Okhotsk contains a mixture of waters from the East Kamchatka cold current, the north Kurile warm current, and the south Aleutian warm current.

6. The extension of the Alaskan current (warm and of remarkably low salinity) developed along the south side of the Alaska Peninsula (Bennett, 1959) forms a narrow stream close along the south side of the Aleutian Islands. In summer it intrudes through the passes into the Bering Sea where it meets the cold Bering Basin water, and the south Aleutian warm current. Hence, in the mid-Aleutian region there are some peculiar oceanographic structures which are intimately related to the salmon resources.

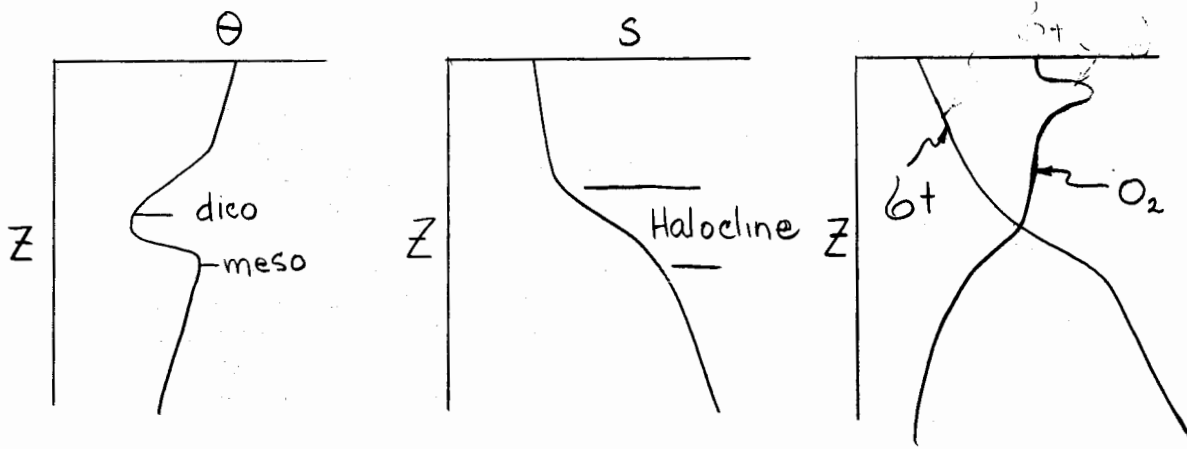
7. The modification of currents near the Aleutian and Kurile Islands by the submarine topography results in eddies and modification of the water types, which are important to salmon.

8. In the northern hemisphere currents tend to follow close along the right hand shore. The direction of the currents, and the structure of the waters vary abruptly across the Aleutian ridge, as shown by Dodimead (1958). There are similar changes over the Kurile ridge.

9. In summer the sub-Arctic waters are warmed because the insolation exceeds the heat losses due to evaporation, conduction, and radiation. This is modified by cloud cover, advection and winds.

Cooling occurs in winter because insolation is reduced and evaporation increases. This causes convection currents which mix the sub-Arctic waters, forming a homogeneous surface layer. This process is aided by strong winter winds and limited by salinity structure.

Dichothermal Structure



### E. Dichothermal Structure

In dichothermal structure there is a temperature inversion associated with a halocline at mid-depth. The structure is stable because the density increase inherent in the halocline is greater than the density decrease implied in the temperature inversion.

This structure is a peculiarity of sub-Arctic waters, particularly in the north Pacific.

1. Dichothermal structure ( $\ominus$ -min) was observed by S. Makarov (1894) "Le Vitiaz et l'océan Pacifique" p. 102 "cauche intermédiaire d'eau froid". H. Marukawa (1915) reported it in the Okhotsk Sea in observation from Unyo maru.

The area of dichothermal water, colder than  $0^{\circ}$  C coincides with the regions of thickest winter sea ice in the Okhotsk and Bering Seas.

Its nature, origin, movements, and fluctuations were discussed by Uda (1934, 1935, 1953). The dichothermal water is produced mainly by convection due to winter cooling, by mixing due to the severe persistent winter monsoons, and by advection. These were proved by the distribution of temperature, salinity, dissolved oxygen, etc.

2. Convection occurs in the sub-Arctic region during the winter (December through March). In the western Pacific the convection occurs to almost 200 meters depth, where it is limited by the halocline. This upper layer is isothermal, isohaline (33.0 to 33.5 ‰) and has a high oxygen content (6 cc/l). Convection ceases in April when surface warming begins. Thereafter a warm surface layer develops through the summer. With the occurrence of southern monsoons in summer and autumn some relatively warm, saline southern water intrudes below the winter-cooled water.

Stratification increases during the summer because of heating, and the decrease of salinity in the surface layer.

During the winter the water is cooled and the salinity increases, and the stratification vanishes. When the sea freezes, the salinity, and hence the density, of the water below the packice increases. It sinks to the level of the halocline. This feature, as well as the precipitation and land drainage on the sea contribute to the formation of the halocline.

3. The temperature of dichothermal water ( $\ominus$  min) increases from  $-1.8^{\circ}$  to  $7^{\circ}$  C from west to east, and from north to south in the sub-Arctic region. Using this tracer we can observe a northward intrusion of southern water (temperature minimum warmer than  $3.5^{\circ}$  C into the mid-Aleutian region between Longitudes  $170^{\circ}$  E and  $170^{\circ}$  W.

4. The lateral and vertical movement of the dichothermal water can be recognized. In each sea region the minimum temperature and its depth are characteristic.

Region	Temperature Minima (°C)	Depth of Minima (meters)
Sea of Okhotsk	-1.8 to -1.0	50 to 150
East of Murile Is.	1 to 2	50 to 150
Near Aleutian Is.	2 to 4	75 to 150

5. The area of dichothermal water shrinks northward with the approach of summer, and the temperature minimum warms. However, the persistent outflow of cold water through the Kurile Islands continues throughout the year.

F. Mesothermal Water ( $\Theta$  -max)

Mesothermal water is included in the dichothermal structure, (M. Uda, 1958):

1. It is believed that mesothermal water originates from warm saline surface water intruding the sub-Arctic region from the south. In the sub-Arctic it cools, subsides, and intrudes as a sub-surface layer.
2. The mesothermal water, lying beneath the dichothermal water is limited by the halocline (or pycnocline). It has low dissolved oxygen content because it is screened from surface aeration.
3. In the north-western part of the sub-Arctic Pacific the oblique subsidence of warm water from the eastern or south eastern areas seems to occur along the isopycnal,  $\sigma_t$ , (isentropic) surface whose density anomaly

( $\sigma_t = 27.20$ ). This corresponds to  $\Theta = 3.6^\circ \text{C}$   $S = 34.1\%$

4. The distribution of  $\Theta$  -max, its depth, and its corresponding salinity show its boundaries occur between  $170^\circ \text{W}$  to  $180^\circ$  longitude.
5. The mesothermal water corresponds to the upper limit of the deep layer in the sub-Arctic Pacific.
6. To the north of the Aleutian ridge the change of salinity and temperature shows sinking of the water along the isentropic surface. Similar situations have been observed in some places south of the Aleutians, and in the vicinity of the Kurile Islands and Kamchátka.

G. Consideration

1. By inspecting the temperature inversion

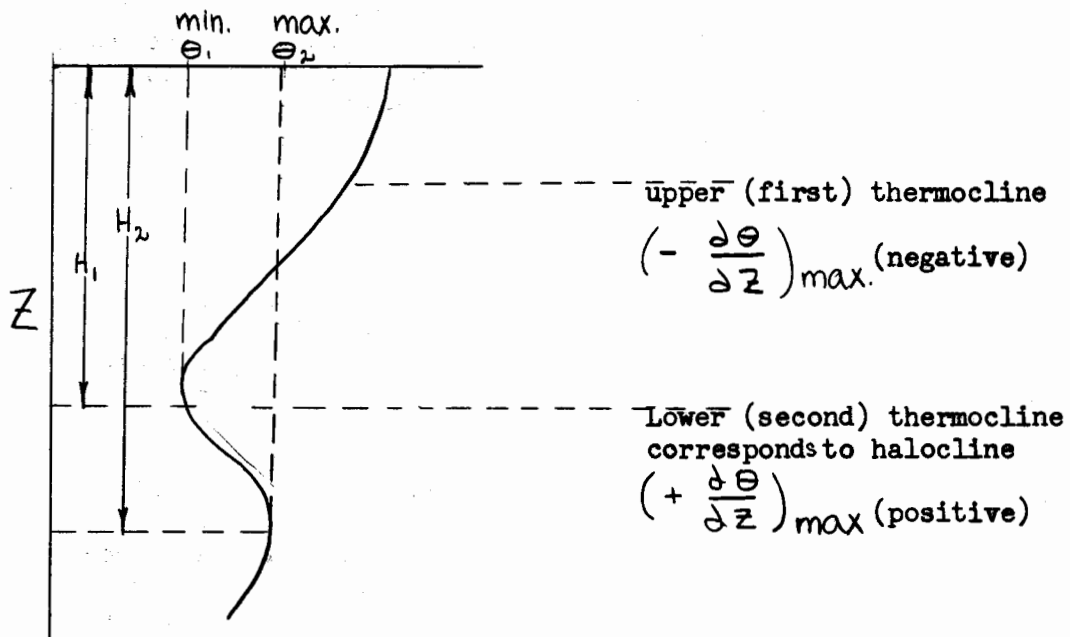
$$\Delta \Theta = \Theta_{\max} - \Theta_{\min} = \Theta_2 - \Theta_1$$

And the convectional depth where

$$H_1 = \text{depth of } \Theta_{\min} (\Theta_1)$$

$$H = \text{depth of } \Theta_{\max} (\Theta_2)$$

it is possible to estimate the winter convection and the intrusion and sinking of waters.



The intensity (degree) of temperature inversion

$$\frac{\Delta \Theta}{\Delta H} = \frac{\Theta_2 - \Theta_1}{H_2 - H_1}$$

Specifying that  $H_1$  is the depth of winter convection and that  $\Theta = \phi(z)$

$$\Theta_1 = \int_0^{H_1} (\Theta - \Theta_1) dz = \int_0^{H_1} \Theta dz - \Theta_1 H_1$$

The heat gain ( $Q_1$ ) from winter to summer by insolation and advection is

$$Q_1 = \bar{\rho} \bar{c} \Theta_1 \sim \Theta_1$$

where  $\bar{\rho}$  is the mean density and  $\bar{c}$  is the specific heat, and are nearly constant ( $\bar{\rho} \bar{c} \doteq 0.98$ ).

$H_1$  can be determined as a function of wind force and air temperatures from empirical graphs.

If there is no advection,  $\Theta_1$  depends mainly on insolation.

The heat budget in northern waters was discussed by N. Watanabe (1955), and S. Tabata, (1957, 58)

#### H. Halocline

The halocline depends on land drainage, precipitation, sea-ice formation, advection, etc. The isohaline layer above the halocline is about 100 meters in depth. The bottom of the halocline coincides closely with the isohaline 33.8‰ (Tully and Dodimean, 1957). Below the halocline the salinity increases slightly into the abyss. Salinity is least along the coast. In the core area of the Gulf of Alaska the salinity is higher than in the surrounding areas and exhibits some features of a dome.

#### I. Secular Variation

1. Historically the years of poor rice harvest in northern Japan are cold years, corresponding to strong influence of Oyashio. Conversely, years of rich harvest are warm, corresponding to weak influence of Oyashio.
2. The southern boundary of sub-Arctic water is defined by the limit of dichothermal water structure, and coincides with the southern limit of salmon water in the western Pacific. This boundary fluctuates from year to year. The area advanced southward in the years 1934, 1935, 1941, 1952, and 1953, and retreated northward in 1937, 1938, and 1939. A recent strong southward extension of dichothermal water has been observed since 1940.

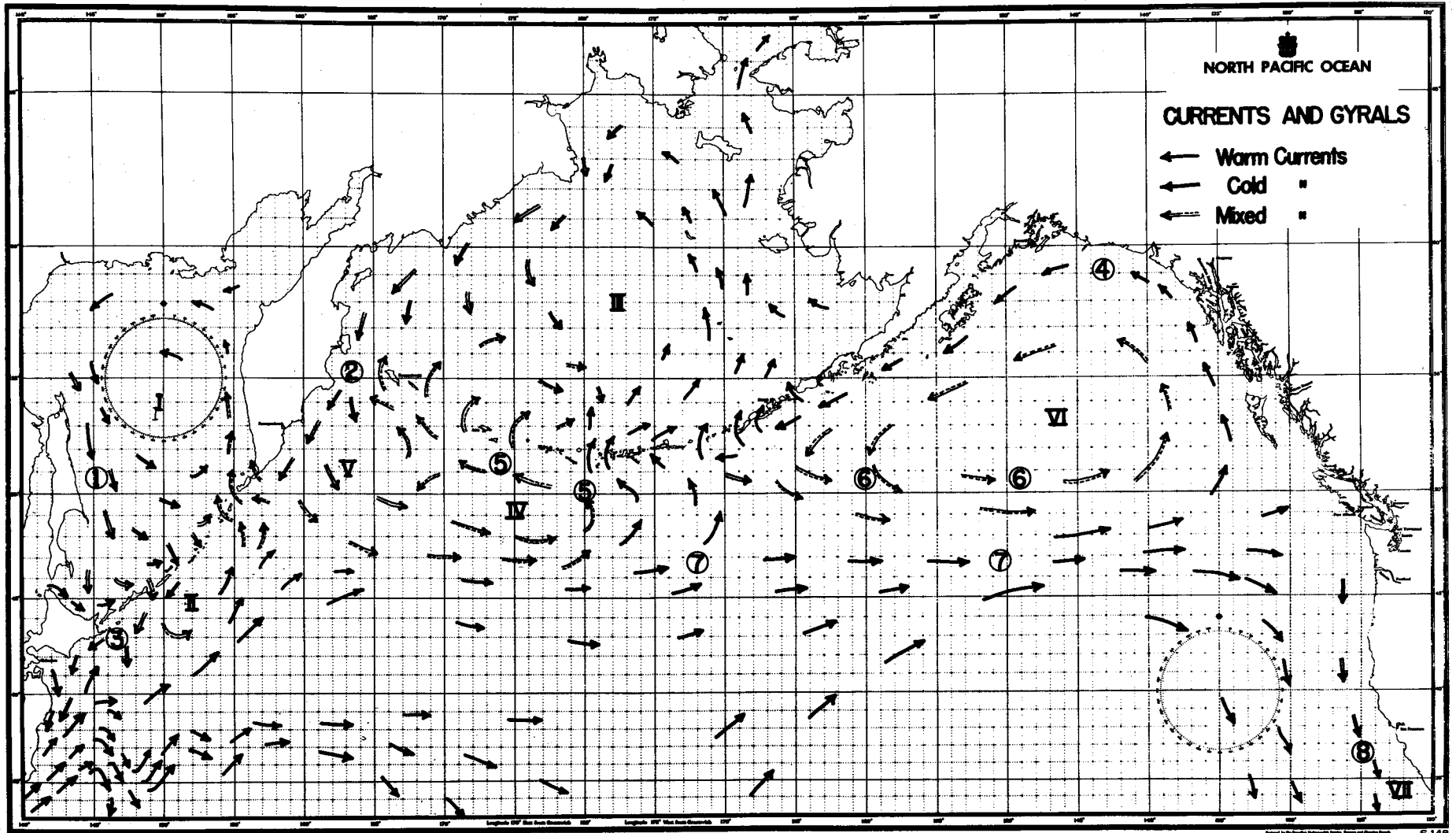


Figure 1



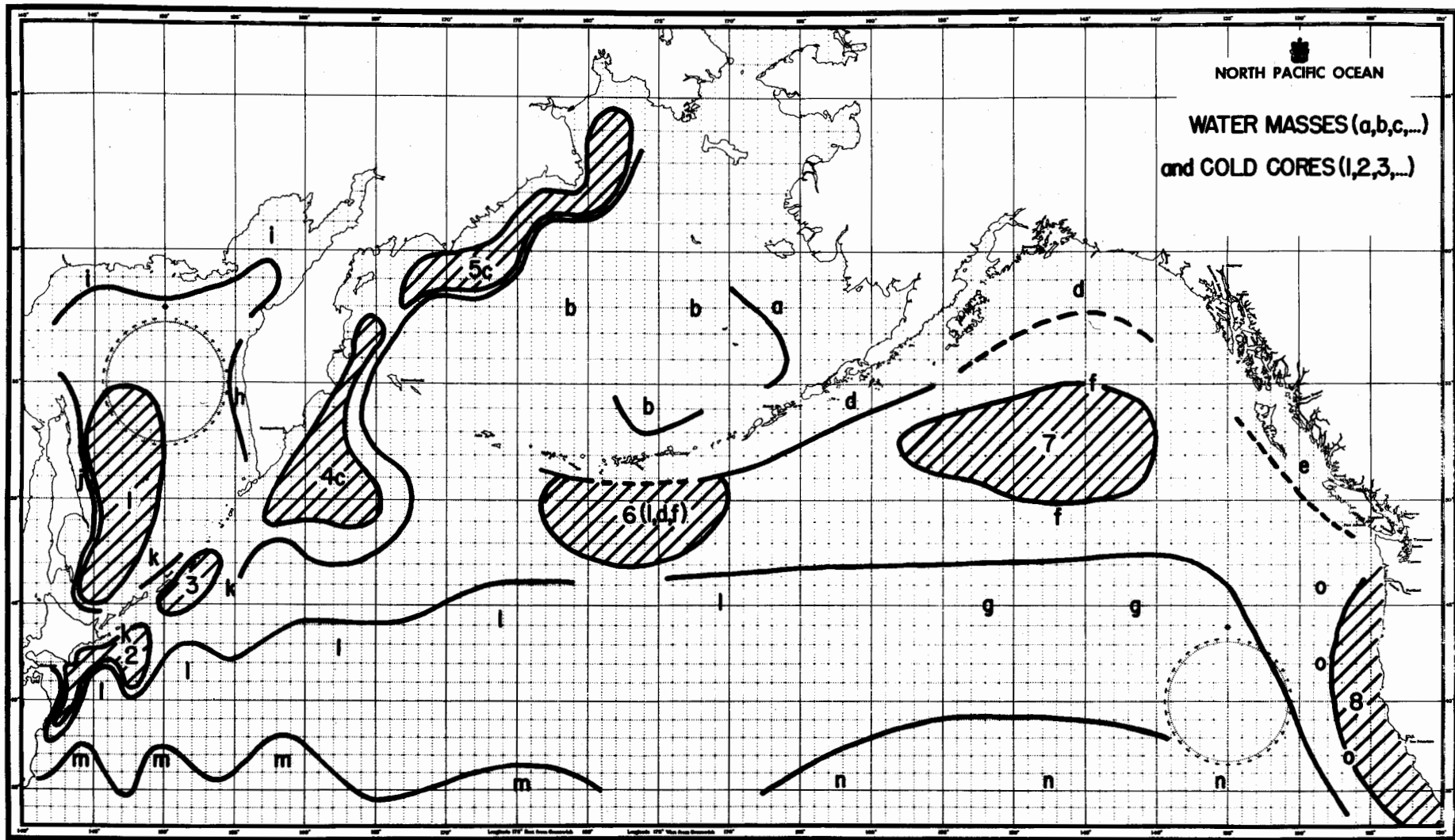


Figure 2



Seminar 7. Some problems related to Kuroshio (southern water mass).

1. Kuroshio, its nature and origin.

Kuroshio in the North Pacific, corresponds to the Gulf Stream in the North Atlantic. It is one of the greatest oceanic currents in the world.

The Japanese terms "Kuro" means black, "shio" means current. It originated from the colour of the water which is blackish, ultra-marine, or cobalt blue.

Kuroshio has been known to the Japanese fishermen and navigators from ancient times. In European works it was first noted by Varenus (1650) on his geographical map. Its velocity (1 to 3 knots) was observed by Captain King, formerly of Cook's expedition (1776-1780) and reported (1784). Also Captain Krusenstern (1804) described it under the name Kuroshio. Bergaus (1837) adopted the name Japan Current instead of Kuroshio.

Kuroshio is the belt of strong northeasterly flowing current off the south coast of Japan. It has its source in sea southeast of Taiwan (Formosa) where the current increases to 2 knots and the depth increases from 200 to about 400 meters. This distinguishes it from a mere extension of the North Equatorial Current.

N. Munk, K. Hidaka, H. Stommel, and others have discussed the phenomenon theoretically and concluded that it results from the westward intensification of the geostrophic current maintained by the energy supplied by the winds. In this it is similar to the Gulf Stream.

Kuroshio runs along the western frontal zone of the North Pacific Central Water Mass (sub-Tropic water mass) which rotates clockwise. Its velocity varies from 1 to 5 knots and its central width is about 30 sea miles (confirmed by G.E.K. measurements). It meanders in the eastern seas of Japan. The amplitude of the undulations are 50 to 250 sea miles. The wave lengths are 150 to 250 sea miles.

The waters are always warmer than 15° C in the surface layer, and are commonly 20° C or more to depths of 100 meters or more. The salinity is always more than 34.5‰, and the core salinity is usually between 34.9‰ and 35.1‰. The transparency to the Secchi disc is 25 to 40 meters. This decreases to about 15 meters in the coastal regions and Idu Island district when the plankton blooms in spring. The colour is blackish to cobalt blue. The Forel colour scale number is usually 1 to 2, but is sometimes 3. The water has a relatively low content of dissolved oxygen (about 5.5 cc/l dissolved nutrients, and plankton.

Kuroshio water analysed by temperature-salinity (T-S) curves (K. Koenuma, 1937) shows successive modification during its flow

from the seas off Taiwan, Okinawa, and past southern and eastern Japan. This is due to the addition of coastal waters from the east China Sea, and from the Japanese Islands. Also it mixes with sub-Arctic waters, sub-Tropic waters, and upwelled deep water. Schematically the Kuroshio resembles a mosaic of water masses.

The temperature, salinity, dissolved oxygen, and current structure in Kuroshio (Uda, 1930) shows that it is about 400 meters thick in the region of the main current. Its salinity is greatest in its core between 50 and 200 meters depth. The stream becomes thinner and weaker in its branches and extensions.

Beneath the Kuroshio water there is "Intermediate" water at about 600 to 800 meters depth. It rises to about 400 meters near the coasts such as Kumano Nada, and Hyuga Nada. This intermediate water is less saline (34.0 to 34.3 ‰) and colder (6° to 8° C) than Kuroshio water. Deep water occurs in the depth range 1000 to 2000 meters. It is again more saline (34.5 ‰) and colder (3° to 5° C). The bottom water in the abyssal circulation is more saline (about 34.7 ‰) and still colder (1° to 2° C). These have been discussed by Wušt, 1929; Sverdrup et al, 1942; Uda, 1930; Kishindo, 1940, etc.

Recently the abyssal circulation was discussed by H. Stommel (1958). The dynamics of Kuroshio were studied first by K. Suda (1936, 1938, etc.); K. Hidaka (1955-58); T. Ichiye (1955) and others.

## 2. Time variation of Kuroshio.

A. Generally the velocity of Kuroshio varies seasonally. It is strongest from spring through summer (May to August). It declines in autumn. It strengthens again in winter (January, February) and declines again in early spring.

Kuroshio is ever changing. Occasionally, like a gusty wind, it accelerates with the passage of storms. Also it accelerates during the periods of spring tides.

D. Shoji (1954) studied the fluctuations of Kuroshio, based on the variations of daily mean sea level. C. Cox, (1958) studied it by means of the potential difference in an electric cable between Idu Niisima and the mainland of Japan.

B. Kuroshio fluctuates year by year, and in some years shows very abnormal patterns (Uda, 1939 to 1958). The meanders of Kuroshio can be considered as the serial continuation of vertical currents. This was first suggested by S. Kishindo (1929). Recently there has been some evidence of multiple current structure (shingles) similar to that described by Fuglister (1955) in the Gulf Stream. These were emphasized by J. Masuzawa (1957) based on the multiple ship surveys of Kuroshio during the international Geophysical Year (1957).

Transport of Kuroshio off Cape Sionomisaki

Volume transport ( $T_p$ ) (cu m/sec)

$$= L \int_0^P V_p dp = \frac{10}{2\omega \sin \rho} \int_0^P (\Delta D_{1000} - \Delta D_p) dp$$

The values were first computed from a few observations by G. Wüst (1936). Later, and with more data J. Masuzawa (1954) computed a volume transport 37.9 to 48.3 x 10<sup>6</sup> cu m/sec. D. Shoji (1959) observed similar values off Omaezaki. Evidently the volume transport varies between 30 and 50 cubic meters per second.

C. Recently there has been a conspicuous secular variation of Kuroshio (Uda, 1940, 1949, 1951, 1953, 1958; Masuzawa 1951, 1958).

It has been recognized that the anomalous condition of Kuroshio began in the autumn of 1934. First there was abnormal development of a cold water mass beneath the Kuroshio. A west-going coastal current developed along with a general retardation of Kuroshio to the south.

Secondly, upwelling developed and brought the cold water to the surface, about 100 miles south of Sionomisaki. The diameter of this cold area was more than 100 sea miles, during the period 1936 to 1940.

The nature of the sub-surface water in the cold area is not an isolated mass of coastal water. It has been identified by T-S diagrams as a mixture of Oyashio under current (intermediate water) and Kuroshio water.

This cold area is a divergent eddy. The current moves counter-clockwise around the cold upwelled water. This causes the strange (anomalous) re-curvature of Kuroshio, and its retardation in the remote region off the coast.

The anomalous pattern attained its maximum in the spring (February to June) of 1938. At that time the diameter of the eddy was greatest, and the surface temperature was lowest (15° to 16° C). After 1939, the cold water area gradually shrank and the central core became warmer. After 1941 the cold area declined rapidly, the center moved eastward, and vanished in 1947. The normal state was fully re-established in 1948.

Through 1949 and 1950 Kuroshio was prevalent and became stronger than normal in 1952. In 1955 it was abnormally strong, with extremely warm water. This situation was of short duration, and has ended.

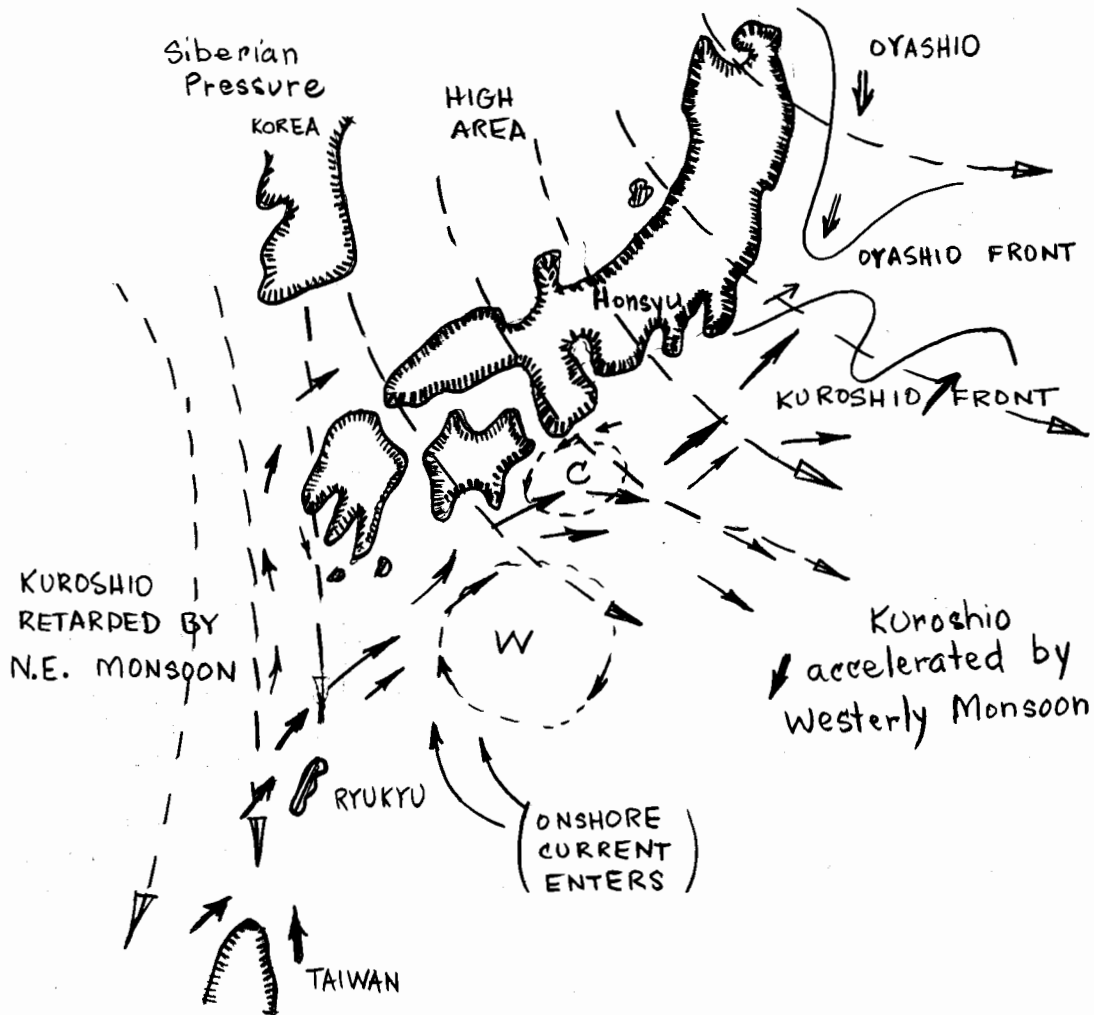
The anomalous state of Kuroshio lasted more than 10 years from

1937 to 1941, and was related to the extreme prevalence of the Oyashio cold current in the south of the Kurile Islands and Hokkaido in 1934 and 1935. Similarly the anomalous behaviour of Kuroshio in 1917 through 1919 was related to the prevalence of Oyashio in 1902 through 1905.

It may be concluded that the anomalous upwelling of cold water off Cape Sionomisaki (off Kumano Nada) appears 2 to 5 years after an extreme prevalence of Oyashio cold current in the surface waters off northern Japan. The similarity of the water masses have been identified. Following the prevalence of the Oyashio extension (i.e. Oyashio under current) the cold water mass upwelled on the coastal side of Kuroshio water. It persisted some years (two to ten) and changed the surface current pattern of Kuroshio to the peculiar meandering state.

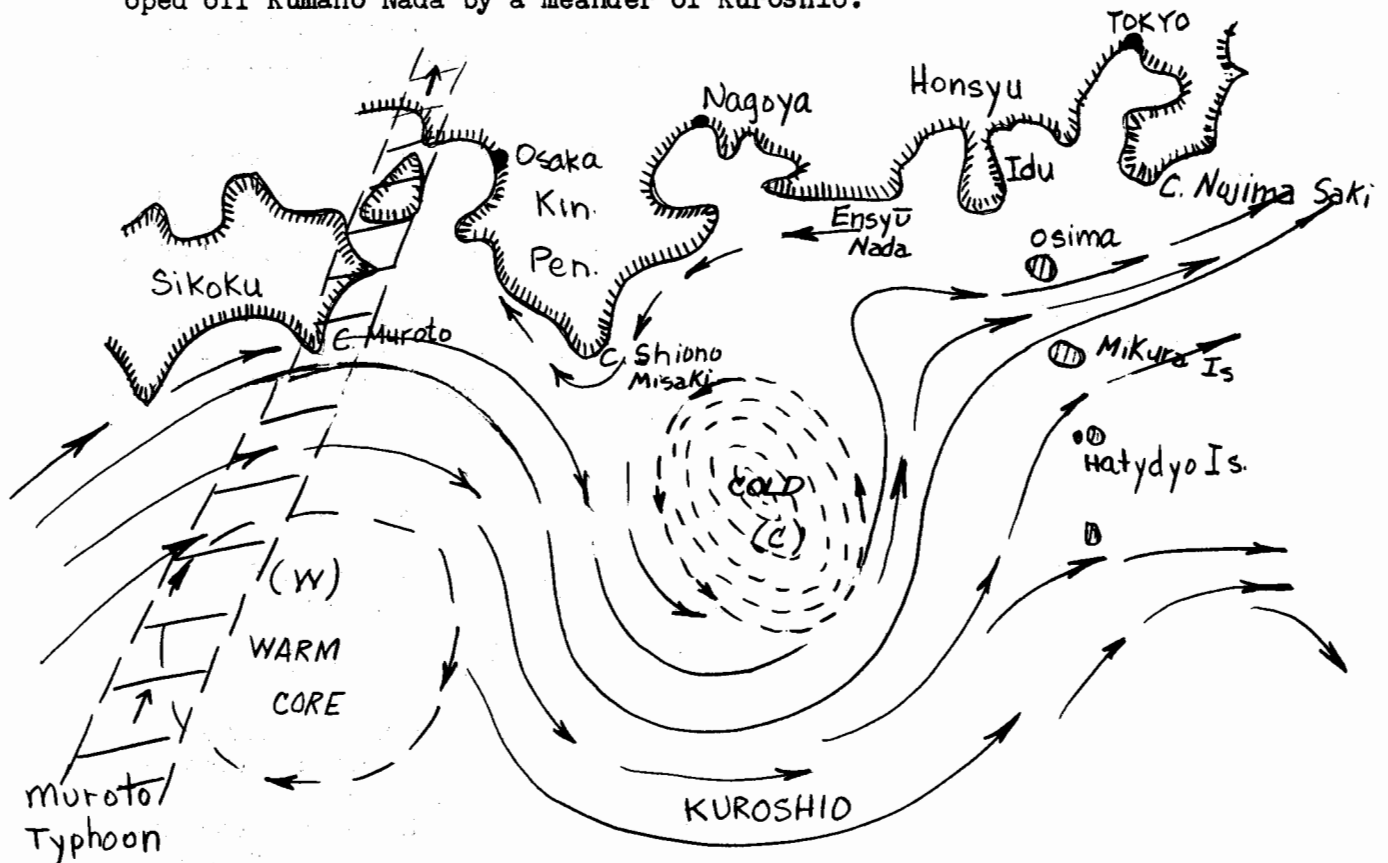
What is the motive force of such upwelling?

Uda discussed the major anomaly 1936 through 1941, of course, the primary cause was the increase of the Oyashio under-current, carrying cold intermediate water. The secondary cause was the development of the winter monsoon.



The winter monsoon in the East China Sea blows persistently from the northeast and retards the Kuroshio in the area south of Japan. Northward of Kyushu they blow from the north and northwest and accelerate the Kuroshio as it passes Honshu Island. In the region of divergence of the wind there is an on-shore set of sub-Tropic water towards Kyushu and Sikoku. This joins Kuroshio and strengthens it.

In 1934 and 1935 the winter monsoons were unusually intense. The onshore current was a maximum and expelled the warm anti-cyclonic gyral off Sikoku. In its place a cold cyclonic gyral was developed off Kumano Nada by a meander of Kuroshio.



By tracing the salinity minimum core of intermediate water, it is possible to follow the Oyashio under current along the Japan Trench around Torisima Island and off Kumano Nada. It is believed that the passage of the Kuroto Typhoon to the west of Kumano Nada (September 21, 1934) acted as a trigger for the strong upwelling of cold water off Cape Sionomisaki.

References can be made to coastal upwelling along south Kyusyu, the development of a clockwise gyral, and abnormal changes

of Kuroshio off Ryukyu and Sikoku, just before and during the period of the great anomaly.

It is probable that upwelling may be more easily generated in the periods of convectional instability corresponding to the state of the upper layer in winter and early spring.

The abnormal cold water mass first appeared, south of Sionomisaki, nearly on the path of the Murto typhoon. Later, the core of upwelling moved eastward.

The topographical features off Kumano Nada and Ensyū Nada aid the development of a cold water mass. (Uda, 1940; J. Fukuoka, 1958; S Hayami, 1955). T. Narniti (1958) proposed a theoretical consideration on the development of cold water mass.

The perturbation theory of Kuroshio meanders was proposed by T. Ichiye (1955). The cold eddies related to the Kuroshio meander in the eastern seas of Japan, along the Muroshio front off NOZIMAZAKI, and the Oyashio front off Kinkazan may be discussed similarly.

In 1937 through 1939 Kuroshio flowed strongly around the cold water mass and intruded to the north, off Hokkaido and the Kurile Islands. Warm water fishes (sardine, blue-fin, tuna, skipjack, etc.) came with this abnormally warm water.

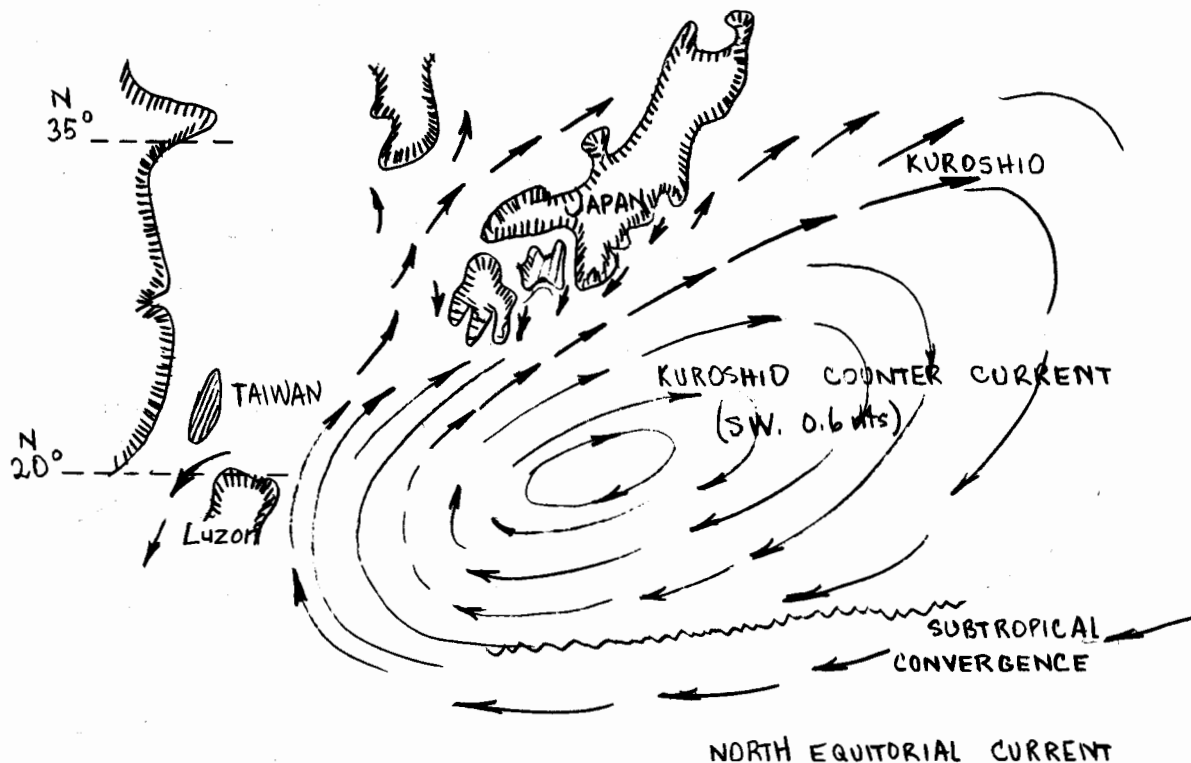
D. Fluctuations of Kuroshio in the seas east of Japan.

M. Uda (1935, 1938, 1943, 1951 to 1958); T. Ichiye (1955-1956); H. Kawai (1955); J. Masuzawa (1951-58); Y. Takenouti (1955); K. Kimura (1951-58; N. Watanabe (1955); H. Koizumi (1955-1956); J. Fukuoka (1955) etc. discussed this problem.

Between the Kuroshio front and the Oyashio front, the mixed water zone of Kuroshio and Oyashio forms very complicated structures within 600 miles of the coast. In this region there are usually two conspicuous warm current branches. One extends north-northeast from the point of latitude  $38^{\circ}$  N, longitude  $145^{\circ}$  E. Both of these are variable branches of Kuroshio. Sometime there is a cut-off (occlusion) of the warm core in the same direction.

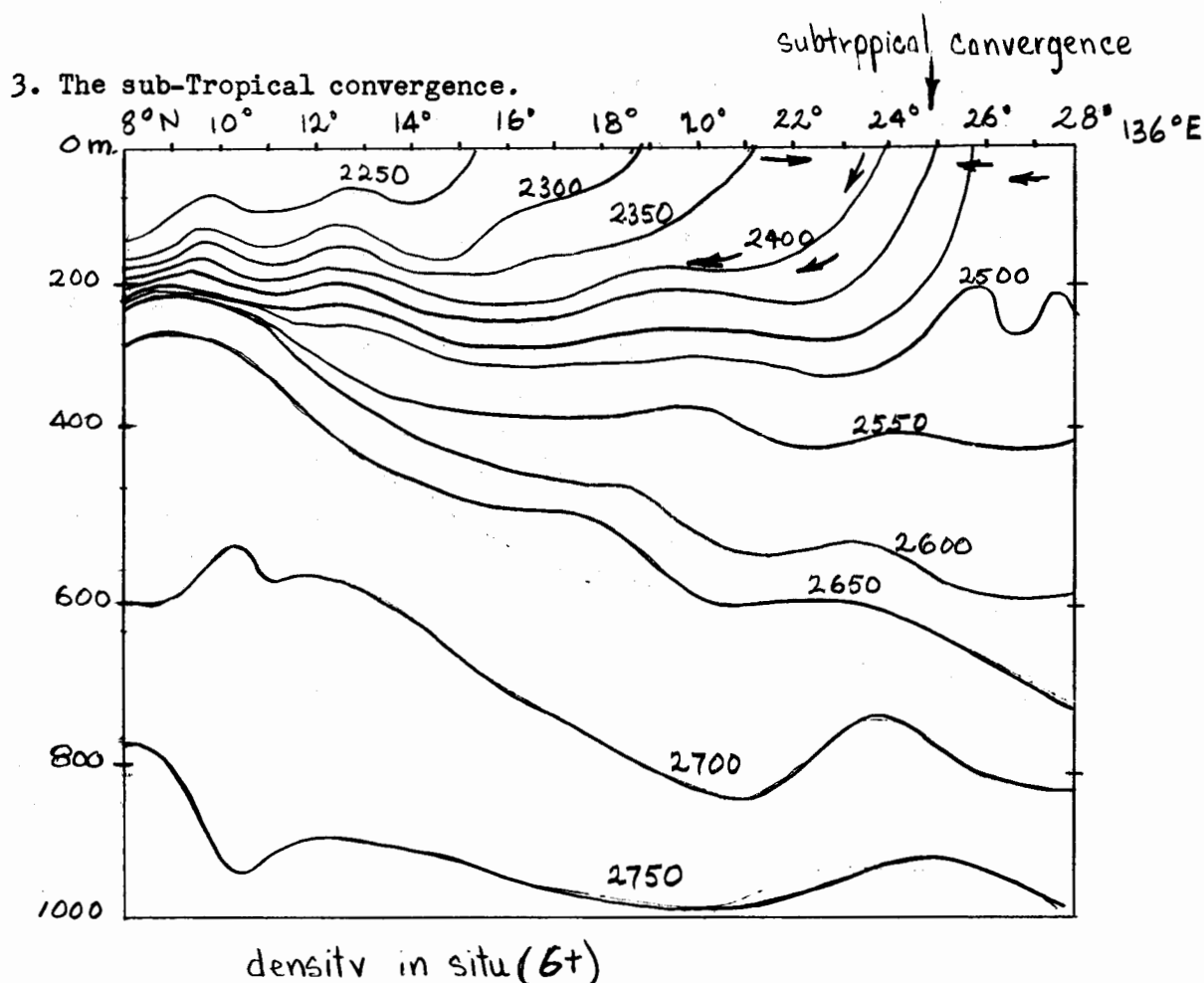
In this area the maximum velocity of Kuroshio is more than 4 knots, and is traceable for 1000 sea miles from the coast. It shows a symmetrical velocity profile with the shear zone on the northern (left) side of the current. Its volume transport was calculated by Masuzawa (1956) to be 40 to 50 x  $10^6$  cubic meters/second.

The Kuroshio main current runs to the east in the latitude 36° to 37° N. The axis has an undulating form.



The Kuroshio flowing to the north east past Honshu develops Branches to the east and south. This finally veers to the south-west forming the Kuroshio counter current or return current. This follows confocal elliptical paths towards the Ryūkyū Islands.

Drift bottles released in southern Kuroshio waters of Idu Islands from November to May were recovered in the sea around Miyako and Y ayeyama Islands south of Ryūkyū. They evidently travelled with an average velocity of 0.6 knots (about 15 miles per day) in a south-westerly direction. Punic from the Myotjin Reef eruption of 1953, and flotsam from No. 5 Kaiyo-maru (J.H.O) wrecked there has shown the same results. (M. Hanzawa, 1953; M. Nakano et al, 1957).



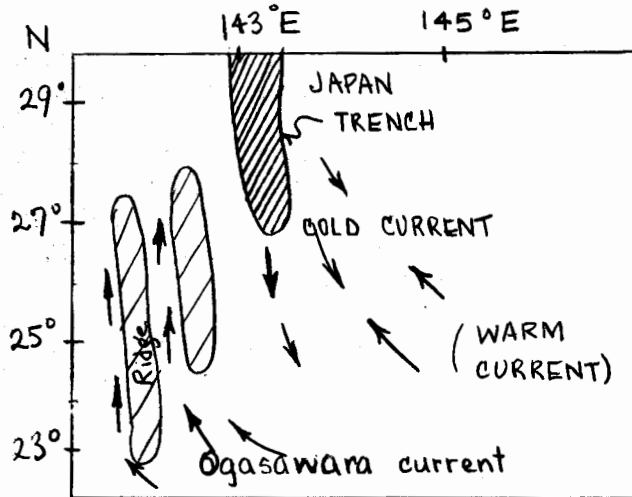
The north equatorial current, and the Kuroshio counter current meet in the sub-Tropical convergence, between latitudes  $23^\circ$  N and  $25^\circ$  N. Here evaporation exceeds precipitation, and salinity attains its maximum (35.0 to 35.1‰). The heavier saline waters sink along the convergence. This is the source of the North Pacific central water mass (sub-Tropical water mass). The sunken central water mass spreads southward along its isentropic surface to the core of the north Equatorial Current, at depths of 50 to 100 meters. Eventually its extension reaches to the core of Kuroshio (M. Uda, 1955). The isopycnal sections indicate the discontinuity of density (24.00) is nearly at the sub-Tropical convergence.

The sub-Tropic convergence is marked by the horizontal distribution of temperature and salinity. The close concentration of isotherms ( $20^\circ$  to  $26^\circ$  C) occurs in the latitudes  $20^\circ$  N to  $27^\circ$  N. The temperature gradient south of Ogasawara is  $1^\circ$  C to  $4^\circ$  C per degree of latitude, about 0.1 to 0.7° C per 10 sea<sup>c</sup>miles.

The transparency and colour of the sea changes markedly at about latitude  $25^\circ$  N, particularly in the season from January to April. Consequently, the sub-Tropical convergence marks the boundary of the marine biological environment. It is the southern-most limit of the fishing grounds for whale, albacore, etc. in the North Pacific.

The relatively cool water (more turbid and of lower salinity) of the Kuroshio counter current meets the warm central Pacific water (more transparent and saline) in the north Pacific Ocean. This locates the northern border of the North Equatorial Current near the sub-Tropical convergence. Several eddies are formed on the undulating line of the sub-Tropical convergence.

A conspicuous cyclonic eddy, in the waters southeast of Ogasawara Islands, is observed in winter and spring (from February to May) corresponding to the well-known whaling grounds.



Contrary to the south-going cold currents developed over the Japan Trench, the north-going warm current develops along the west, off Ogasawara (on the left of Kuroshio) and along the ridge east of Iwozima. It was called "Ogasawara Current" and seems to develop temporarily in spring. This coincides with the decay of the winter monsoon, and the Kuroshio counter current.

In general, in the northern hemisphere, currents tend to pass around an island or a ridge in a clockwise direction, and around a basin in an anti-clockwise sense, because of Coriolis force. This does not apply to topographical counter currents.

In late autumn the sub-Tropical convergence shifts southward, and returns northward in the late spring. The northern extreme is about 28° north latitude. The pattern is most pronounced in winter, and comparatively obscure in summer. The axis of the salinity maximum (greater than 35‰) which is the core of the North Pacific Central Water Mass, is centered between latitudes 24° and 26° N, and longitudes 165° E and 180°. It lies close along the southern side of the sub-Tropical convergence.

#### 4. Equatorial Pacific Oceanography

A. The general circulation of the equatorial waters and the mechanism of the Equatorial Counter Current have been discussed by A. Defant (1936); H. U. Sverdrup (1952, 1944, 1946); R. H. Montgomery (1939, 1940, 1954); Fofonoff and Montgomery (1955); N. G. Jerlov (1953); E. Palmer (1940); R. O. Reid (1948); W. H. Munk (1949); G. Neumann (1947); K. Hidaka (1952); K. Yoshida and Han-Lee Mao (1953, 1955); T. S. Austin et al (1954, 1956); J. M. McGary (1954); T. Cromwell (1953, 1957); Y. Miyake et al (1956); W. Wooster and T. Cromwell (1958); and M. Uda et al (1957).

Uda examined the data obtained by the Japanese Hydrographic Office, and reported to the 8th Pacific Science Congress held in 1953 (1957). In the North Pacific, the northern intermediate water extends to the south. It descends below 800 meters depth between latitudes 34° and 24° N, where its core salinity is 34.0 to 34.2 ‰. Southward it rises gradually to about 200 meters at about latitude 5° N. Here its salinity increases to 34.5 ‰ due to mixing with the upper more saline water.

The northern and southern intermediate waters meet in the zone between latitudes 2° and 12° N. The northern water lies at about 200 meters depth, and the southern water lies below it at about 800 meters (600 to 1000 m). In this region there are two salinity minima in the vertical section.

The salinity maximum is shown to occur in the sub-surface tropical water mass at 50 to 200 meters depth. In the area of the Equatorial Counter Current the layer of salinity maximum (34.8 ‰ or less) rises again above the 100 meter level. Further southward, between latitudes 3° N and 3° S the salinity maximum is greater than 35 ‰ and is encountered between 100 and 200 meters depth. This corresponds to the south equatorial current.

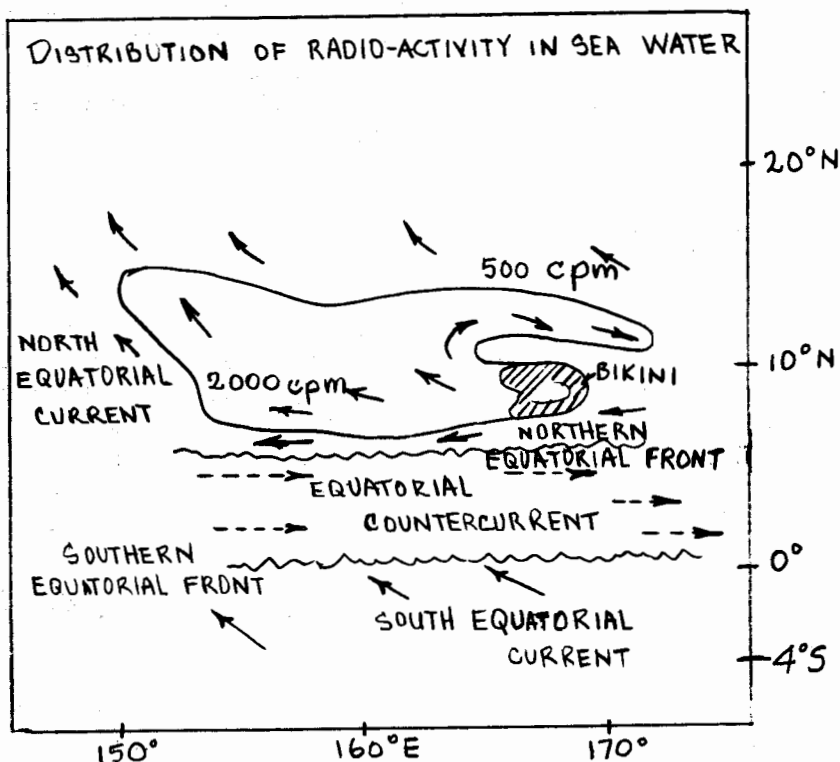
The results of Equapac (1956) have shown salinity maxima greater than 36.5 ‰ in the South Pacific, in the area between latitudes 5° and 15° S, and longitudes 140° to 150° W. This is one part of South Pacific Central Water. From this area, water of salinity greater than 35.5 ‰ intrudes across the Equator in summer (Uda, 1957). The water mass of low salinity (34.0 to 34.3 ‰) lying in the zone of Equatorial calm, or Equatorial Rainy Zone, and the underlying belt of cold water at 100 to 200 meters depth is most pronounced in winter.

The northern (divergence) boundary of the Equatorial Counter Current usually occurs between latitudes 8° and 10° N, although it is sometimes found as far as 12° N. The southern (convergence) boundary sometimes occurs at 1° N latitude, although it is usually between 2° and 3° N.

Abundant data and many findings resulted from the Shunkotsu-maru

expedition (1954-55), the Tanney expedition (1954), Equapac (1956), the International Geophysical Year program (1957-58) and Eastropic expedition (1953.58).

B. The radio-activity resulting from atomic bomb tests at Bikini has been detected in Equatorial and Kuroshio waters. This radio-activity is a good water mass tracer.



The zone of radio-active pollution originating at Bikini is almost confined to the region of the north Equatorial Current system. These waters have high temperatures, high salinity, are transparent, and relatively poor in nutrient salts. The greatest pollution lies in a narrow belt along the southern boundary of the North Equatorial Current, between latitudes 9° and 15° N. This zone is nearly 360 miles wide and the flow is westerly at 0.5 to 2 knots. The intensity of pollution is more than 1000 counts per minute in waters between latitudes 9.5° and 12.5° N, and longitudes 158° and 166° E.

Entering the waters of the Equatorial Counter Current the radio-active pollution drops abruptly to very low levels. This water has lower temperature, lower salinity, is rich in plankton and nutrients and poor in dissolved oxygen. It flows in an easterly direction at 0.5 to 1.3 knots in the zone between latitudes 3° to 8° N. The stream is about 300 miles wide.

A weaker easterly stream, of somewhat irregular form was discovered between latitudes 14° to 19° N, to the north of Bikini in the north Equatorial Current. Mao and Yoshida (1953) have

reported the existence of a narrow but strong easterly current (0.8 to 1.2 knots) between latitudes 16° and 18° N. Also T. Cromwell (1950) ascertained the belt of easterly current between latitudes 15.5° and 19.5° N from longitude 172° W to 158° W. However, our analyses showed that the water was not different from the North Equatorial Current water. This easterly current may be the counter current in the clockwise eddies along the northern boundary of the North Equatorial Current. At present the continuity of this easterly stream from the Marshall Islands area to Hawaii is doubtful. Uda (1957) attributed the appearance of the easterly stream after 1946 to an anomalous change of the North Equatorial Current. About that time its transport decreased, as it became narrower and less intense.

### C. Equatorial under-current.

During the survey of the Hugh M. Smith (POFI) in 1953, a strong, east-going sub-surface current at the Equator in mid-Pacific was discovered. (T. Cromwell, 1953; R. B. Montgomery and Straupe, 1954). This current is centered at 100 to 200 meters depth. It was called the Equatorial Under-Current. Recently it has been named the Cromwell current to commemorate its discoverer.

It was found that very favourable fishing areas for yellow-fin tuna were closely related to this current (T. Cromwell, 1953, O. E. Sette, 1955).

The current was discussed theoretically by N. P. Fofonoff and R. B. Montgomery, (1955); W. Wooster and T. Cromwell (1958) showed the detailed oceanographic structure, using data from the Eastropic expeditions of Scripps Institute of Oceanography. It is now evident that this Cromwell Current has a large volume transport comparable to the Gulf Stream.

From a study of the Equapac (1956) data Uda reported (9th Pacific Science Congress, 1957) a belt of cold water at 100 to 200 meters depth, at the Equator, in the west longitudes. This seems to be related to the Cromwell Current in the same way that the cold belt is related to the Equatorial Counter Current.

Seminar 8. Japan Sea and China Sea.

1. The Japan Sea and its adjacent waters were first studied by Admiral Makarov in the Vitiaz (1886-89). Y. Wada made a chart of normal isotherms in 1904, and a current chart in 1922. Further studies were made by H. Marukawa and S. Kamiya (1927), K. Suda used data from the Shunpu-maru (1928-1932). K. Nisida and Z. Nakai studied data from the Misago-maru (1929-1943) Hokkaido, and Tankai-maru (1930-1946). M. Uda made many studies based on multiple ship surveys (1930-58). There are recent reports by I. Yamanaka (1951), T. Shimomura, K. Miyata, Y. Matue, Y. Komaki (1957), working on the Soyo-maru. The Japanese Fisheries Agency has compiled a report on the Tusima Warm Current (Uda, 1958).

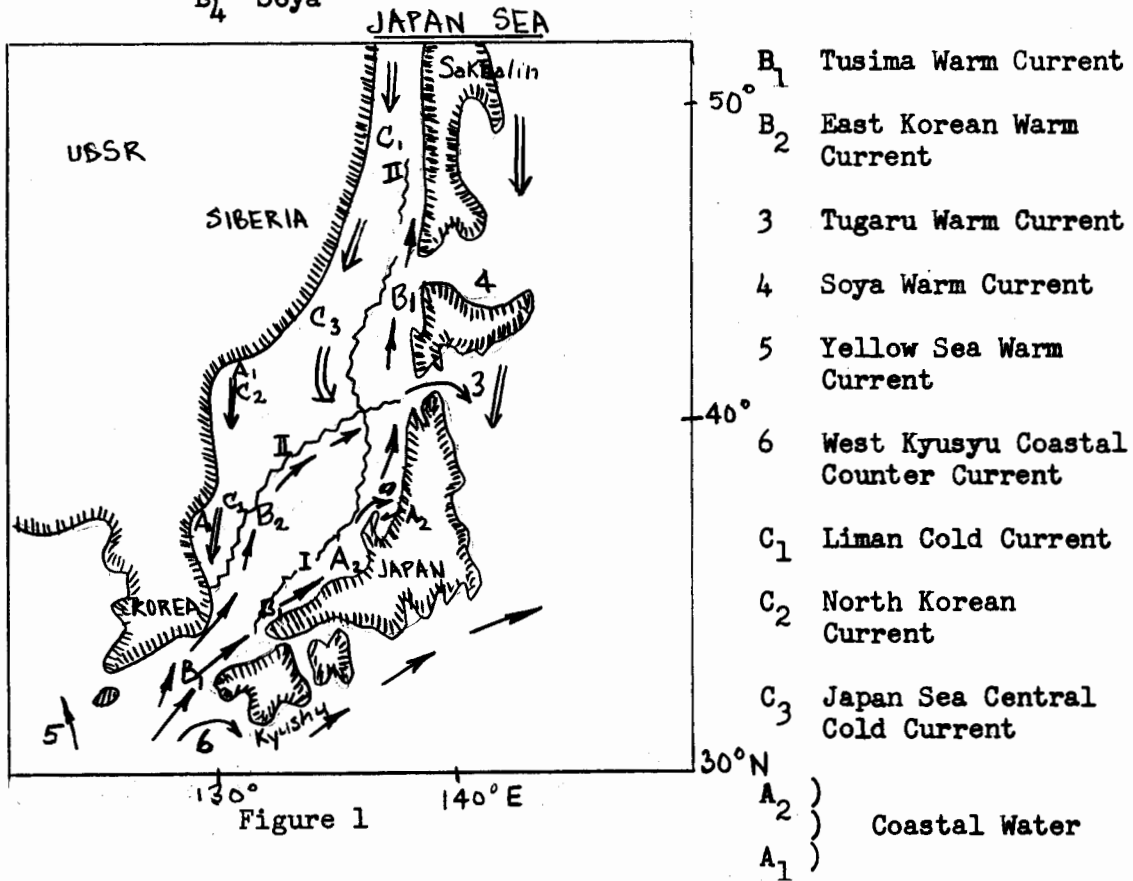
2. Currents in the Japan Sea.

Warm Currents

- B<sub>1</sub> Tusima
- B<sub>2</sub> East Korean
- B<sub>3</sub> Tugaru
- B<sub>4</sub> Soya

Cold Currents

- C<sub>1</sub> Liman
- C<sub>2</sub> North Korean
- C<sub>3</sub> Japan Sea Central



(i) Drift bottle experiments were conducted successfully for many years. The average recovery was 20 to 40%.

The Tusima Warm Current enters from Tusima Strait and divides. The main stream (0.5 to 1 knot) flows north along the coast of Japan. The East Korean Warm Current runs from south Korea (Cape Urusan) toward Utsuryo Island, Yamato Bank, then easterly to rejoin the main stream near Tugaru Strait. About 70% of this water flows through the strait into the Pacific Ocean where it is called the Tugaru Warm Current. The remainder flows past Hokkaido and through Soya Strait where it is called the Soya Warm Current

Along the continental coast there is a slow south-moving cold current, which is named in three parts. The Liman Current along Saghalin; the Japan Sea Central Cold Current, and the North Korean Cold Current.

(ii) The Tusima Warm Current originates along the edge of the continental shelf in the East China Sea. Here the Kuroshio flows northward mixing with coastal water and intermediate water upwelled from 50 to 200 meters depth to form the characteristic Tusima water mass. It branches from the main Kuroshio in the sea region west of Amami-Osima and flows north to the Japan Sea. K. Koizumi (1957) estimated that it carries about 10% of Kuroshio. Before it enters the Japan Sea, it branches to form the west Kyusu Coastal Counter Current and the Yellow Sea Warm Current. During its flow the surface salinities of the Tusima waters are lowered by run-off from the adjacent land.

### 3. Water Masses in the Japan Sea.

The fundamental water masses may be distinguished in T-S curves.

- A. Surface water (less than 25 meters depth).  
Low salinity, dominant in spring and summer.
  - A<sub>1</sub> Coastal water on the continental side (cold)
  - A<sub>2</sub> Coastal water on the Japanese side (warm).
  
- B. Core water Masses, Tusima current system  
Warm, saline, transparent relatively poor in nutrient salts and dissolved oxygen, high pH, occurs from 20 to 200 meters depth.
  - B<sub>1</sub> Tusima warm Current on Japanese side.
  - B<sub>2</sub> East Korean Warm Current.
  
- C. Lower Cold water masses  
Homogeneous water, usually below 200 meters depth, cold (0° to 1° C) low salinity (33.95 to 34.15 ‰) rich in dissolved oxygen (70 to 80% saturation) compared to the Pacific Ocean and Okhotsk Sea.

- C<sub>1</sub> Liman cold current.
- C<sub>2</sub> North Korean cold current.
- C<sub>3</sub> Japan Sea central cold current.

D. Surface water having low salinity originates in the East China and Yellow Seas. It develops in the rainy season (June to October) and varies markedly with the growth and decay of the south-west monsoon.

The positions of the water masses (S<sub>min.</sub>, S<sub>max</sub>) have been observed to shift from south to north through 7 or 8 months.

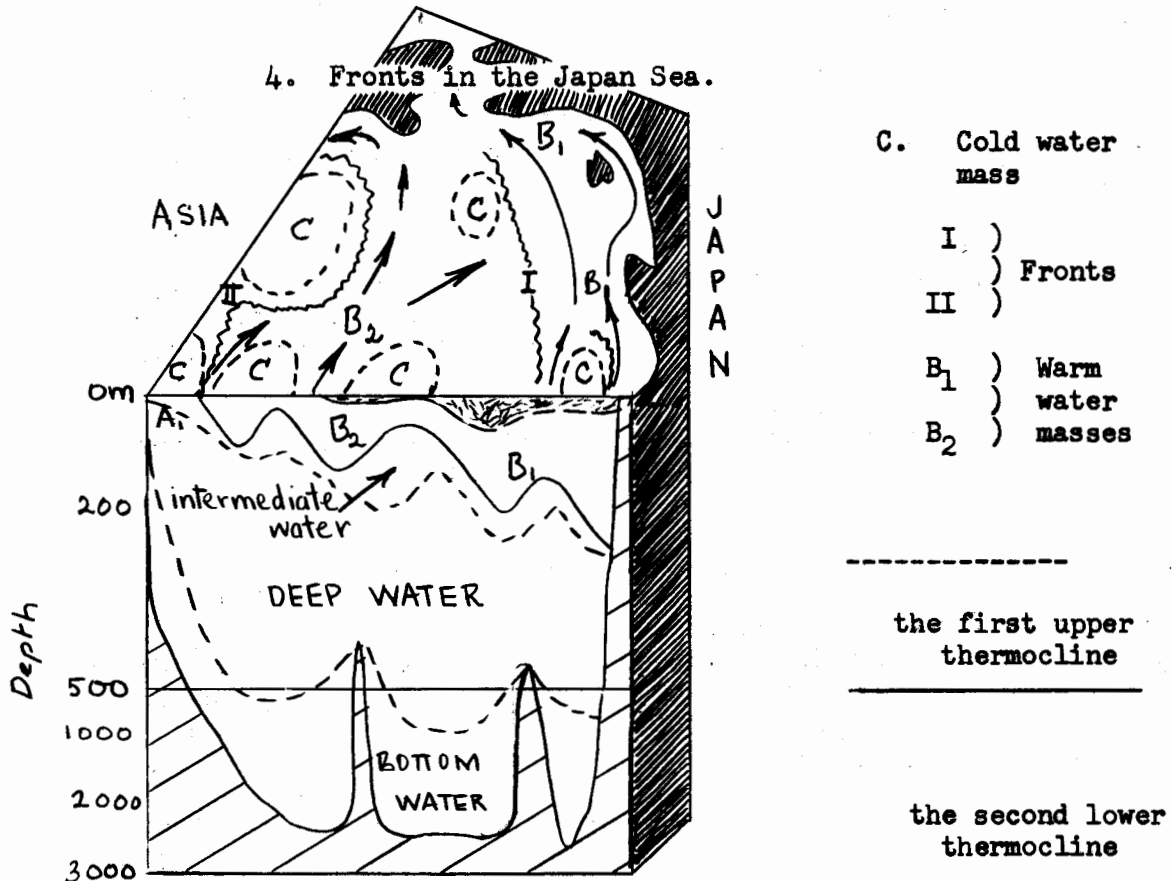


Figure 2

Fronts (water mass boundaries) are formed between the cold water masses (33.7 to 34.2‰ salinity) in the northern part of the region, and the Tusima water masses (34.3 to 34.8‰ salinity) in the southern and eastern parts. These fronts run across the middle of the Japan Sea from Cape Urusan to Tugaru Strait. This occurs in two steps similar to the Oyashio-Kuroshio front.

- Warm Front - Tusima warm front, I
- Cold Front - Japan Sea cold front, II, or Liman Front (T. Shimomura)
- Coastal Fronts - Continental coastal fronts (summer and autumn)  
Japan coastal fronts (spring, summer, autumn)

#### Secular variation

From 1941 to 1948 the cold front (II) weakened and the warm front (I) developed because of the southerly extension of cold waters. The meandering pattern of the warm front has been conspicuous in recent years.

5. The lower waters are almost homogeneous and have neutral stability. Winter convection occurs and they are aerated, hence they are rich in dissolved oxygen (K. Suda 1932, Uda 1934, 1936).

This lower water, below 200 meters depth can be divided into Deep and Bottom water. They are separated by an oxygen and temperature minimum at about 1000 meters depth.

6. There are usually two thermoclines. The upper thermocline occurs between 0 and 10 meters in May, deepens to 50 to 100 meters in November, and vanishes in the winter convectional period from December to April. The lower thermocline usually occurs between 150 and 200 meters depth between the Intermediate and Deep water. It is present throughout the year. It is shallowest on the continental side and deepest on the Japan side.
7. There are sills at 100 to 200 meters depth in all the straits leading into the Japan Sea. These separate the lower water masses from the Pacific Ocean and the Okhotsk Sea.

### 8. Cold Cores.

Meander of front and cold water intrusion

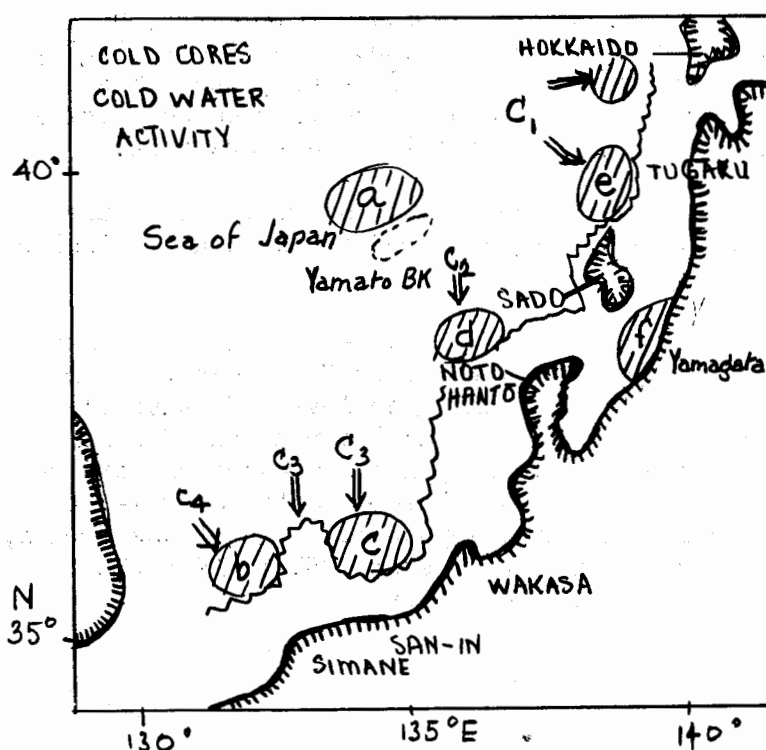


Figure 3

(i) There are a number of cold water masses associated with specific localities. These correspond to favourable fishing areas. However they fluctuate seasonally and secularly.

- (a) Yamato Bank
- (b) Simane
- (c) San-in, Wakasa
- (d) Noto
- (e) Sado
- (f) Yamagata

In addition there are cold cores (C<sub>1</sub>, C<sub>2</sub>, C<sub>3</sub>) associated with the cold currents.

Eddies associated with the meanders of the Tusima Current from lattices of cyclonic cold cores and anticyclonic warm cores. These are defined by the topographically fixed vertical pattern superimposed on the Marman vortices.

(ii) The activity of the cold lower water varies seasonally, as shown by the shifts of the 2° and 5° C isotherms, at depths between 50 and 200 meters. The centers C<sub>1</sub>, C<sub>2</sub>, C<sub>3</sub> and C<sub>4</sub> shift

northward from spring to summer, as the warm current develops.

The main intrusions of cold water are shown in the figure. Their positions are related to the bottom topography, and they shift along the isobaths. The extreme recurvature of the isobaths corresponds to the top of the intruded cold water, upwelling occurs and fronts are formed. These constitute fishing areas for sardines, mackerel, squid, yellow-tail, etc. The upwelling is intensified by the cyclonic eddies when the Tusima current is strong, and the lateral gradients are greatest.

(iii) Eddies are occasionally developed by storms. These are rich in nutrients and marine life and produce favourable fishing areas.

(iv) The convection and wind mixes the water in the Japan Sea to homogeneity. Hence there are variations from year to year which persist in the lower water below the level of seasonal heating. From 1941 to 1946 there was active renewal of Lower Water, revealed by increase of oxygen, and decreases of temperature and salinity. The increased volume of cold water led to the increase of the cold currents, southward shift of the fronts, and decrease of the Tusima currents. From 1950 to 1955 the warm currents regained their normal state.

## 9. Drift

The total current ( $V$ ) may be considered as the vector sum of the wind current ( $V_1$ ) and the geostrophic current ( $V_2$ )

$$W = V_1 + V_2$$

Uda (1950) observed that flotsam drifts from Korea and Siberia to Japan during the winter, and the speed varies with the winter monsoon. In summer the drift is usually from Japan to the continent and is much slower. The percentage of drift bottles recovered along the Japanese coast was lowest during 1930 and 1933 when the warm currents were dominant and greatest during 1931 and 1934 when the cold currents were dominant.

## 10. Heat Budget

M. Miyazaki (1952) showed that the net heat loss to the atmosphere was greatest in autumn and winter. The estimated heat loss attains about 500 gram cal/cm<sup>2</sup>/day. This is sufficient to freeze the northern waters. This reduction of temperature and the resulting increase of salinity is sufficient to produce the Lower Water mass.

The spring and summer heating is greatest in the cold current area, consequently the annual range of temperature is greatest along the northern continental side of the Japan Sea

(J. Tsukuda et al 1935, M. Uda 1930).

The Tusima warm currents are cooled by lateral mixing with surrounding waters during their northward progress. The coefficient of transfer is about  $8.5 \times 10^7$  C.G.S. units.

### 11. Volume Transport

T. Thimomura and K. Miyata (1957) estimated the volume of the Tusima Warm Current off Noto Peninsula.

1941	$1.67 \times 10^6 \text{ m}^3/\text{sec.}$
1946	7.26
1948	4.84
1949	3.59
1955	1.81

In summer the volume transport of the Tusima Current depends on the intensity of the southwest monsoon. In winter the surface drift current depends on the monsoon.

### 12. Fluctuation of Tusima Current.

This current fluctuates from year to year. Its course appears to oscillate. The current axis recently shifted off-shore and the coastal waters became cooler.

(i) Uda (1942) considered the heat content in the cross-section (0-50 m depth) of the current through Tusima Strait in May of each year from 1919 to 1942. He concluded that there was a 7 to 10 year cycle. K. Hidaka and T. Suzuki (1949) using Margules' equation calculated the speed of the current from observations of the slope of surface of density discontinuity, and found a 7 to 8 year cycle.

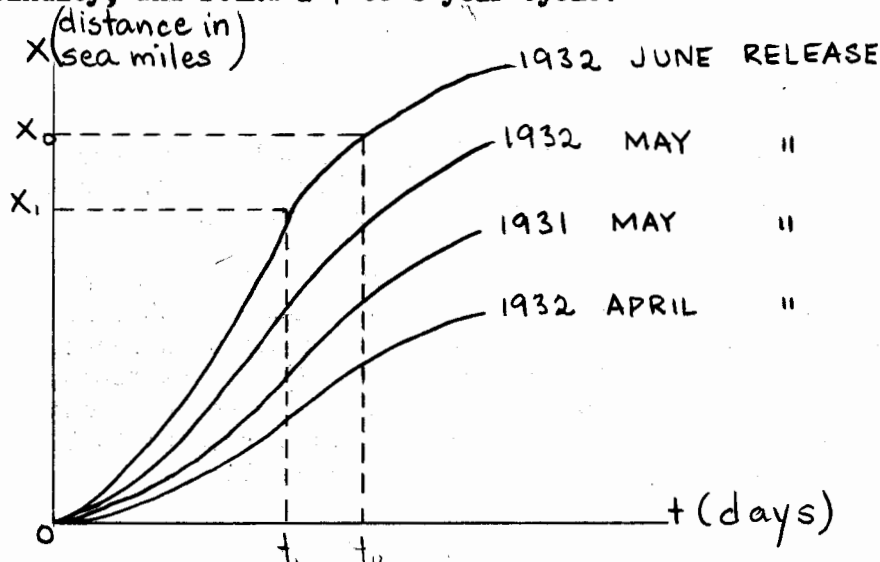


Figure 4

(ii) Uda (1942) drew the transport-time curve of drift bottles. He assumed that the volume transport was proportional to the number of bottles transported. This is roughly proportional to the farthest transport.

$$X_0 = vt_0$$

or the percentage recovery

$$G = \int_{X_1}^{X_0} 100 \frac{x}{X_0} dx$$

In this way he proved that drift bottles can be used as a measure of the fluctuating intensity of oceanic currents.

(iii) Uda (1958) investigated the water temperatures and deduced attenuations of strength of the cold and warm currents.

Warm	Cold
1917-1921	1877-1905
1932-1940	1923-1931
1952-1955	1941-1947
	1956-1957

This shows that the predominant cycle is longer than ten years.

A remarkable change of hydrographic conditions occurred after 1941, cold currents prevailed, and a series of cyclonic eddies, having cold cores, were formed in the meanders of the currents.

(iv) When the temperature data are smoothed in 5 or 7 year intervals, the general trend is upward, particularly in the warm years. This is similar to the Arctic warming in this century. The data in winter and spring are the most useful as such an indicator.

(v) Off Wakasa Bay the temperature at 100, 150, and 200 meters depth declined from a maximum in 1933 to a minimum in 1943. This was due to an intrusion of cold water from north to south.

(vi) The extent of the lower cold water was studied in the data from 1932 to 1957, in each season. The plots included isotherms at 50 meters depth, location of 5°, 10°, 15°, and 20° C surfaces, temperature differences between the surface and 100 meters depth, depth of thermoclines, etc. These showed that offshore and along the coast of Japan the warm water was dominant from 1932 to 1940. The transition to cold water dominance was quite rapid.

13. Meandering of Tusima Current.

The meander of the frontal zone was noticed in 1941 and increased to 1948. Since 1949 it gradually recovered the previous state. In 1956 and 1957 it was again increasing. When the cold current is strong it intrudes the Tusima Current, and the meandering increases. The meandering declines with the cold current.

The meanders can be shown by the isotherms at any level from 50 to 200 meters depth. The contours of heat content (integrated temperature) from the surface to 200 meters depth correspond closely to the geopotential topography in the Japan Sea. Monthly charts from 1954 to 1957 have been made. These show the meandering pattern of the Tusima Current through the area.

After 1941 the East Korean warm current declined and the Japanese branch of the Tusima Current increased. The speed of the current around the eddies in the intensified front increased to 0.5 to 1.5 knots.

The Tusima warm current forms anti-cyclonic eddies around peninsulae, banks, and ridges along the Japanese coast. These form isolated, convergent warm cores such as those near the Goto Islands off Yamaguti Prefecture, around the Oki Islands, off Noto, near Tugaru, Isikari Bay, etc. These are notable as spawning and nursing grounds where there are dense populations of eggs and larvae.

14. The Yellow Sea

In summer (July through November) the water is stratified.

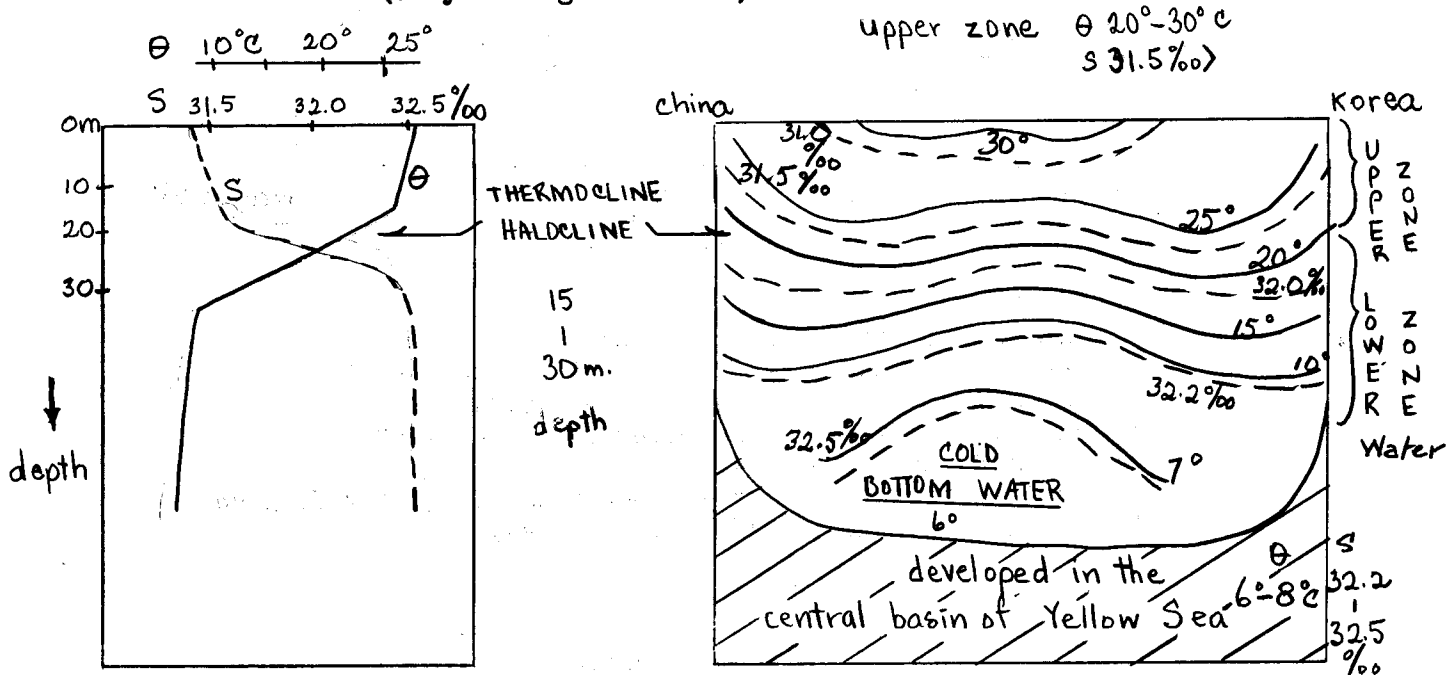


Figure 5

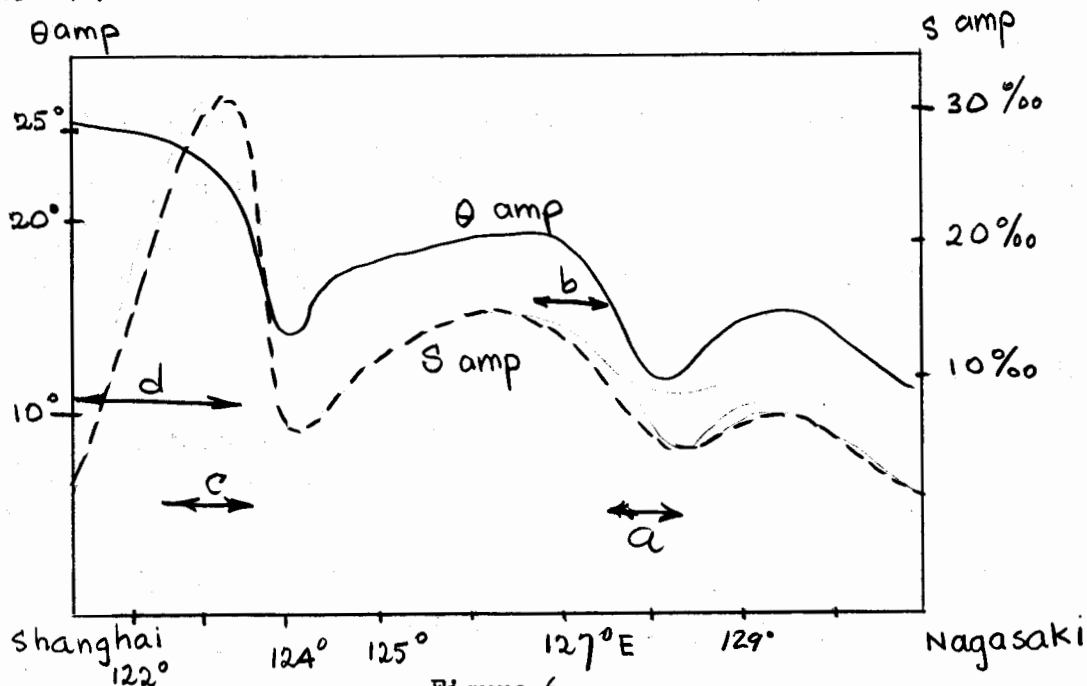
In winter (December through March) the water becomes homogeneous, corresponding to vigorous convection (Uda, 1934). This produces cold bottom water which conserves its temperature into summer. During the southwest monsoon period, commencing in June the cold bottom water moves slowly southward towards Sokotra Rock.

Normally the stratification degenerates during the autumn from October to December and there is an increase of dissolved oxygen. This is similar to the phenomena in Ise Bay and Seto Nakai.

The amount of winter cooling and convection determines the character of the bottom water that will be prevalent during the following summer. Hence it can be forecast.

### 15. East China Sea

(i) Uda (1949) classified the water masses from the surface data observed from ocean liners running between Nagasaki and Shanghai (1931-40).



- Figure 6
- (a) Tusima warm water (127° - 128° E).
  - (b) Central cold water (125° - 126° E) (source of Yellow Sea high pressure area and sea fog).
  - (c) Intermediate warm saline water (123° - 124° E) (developed in autumn and winter).
  - (d) China continental coastal water (122° E) (muddy Yangtze River water, extends for 100 miles to sea).

(ii) Water fronts (Uda 1958) distinguished by marked gradients of temperature and salinity.

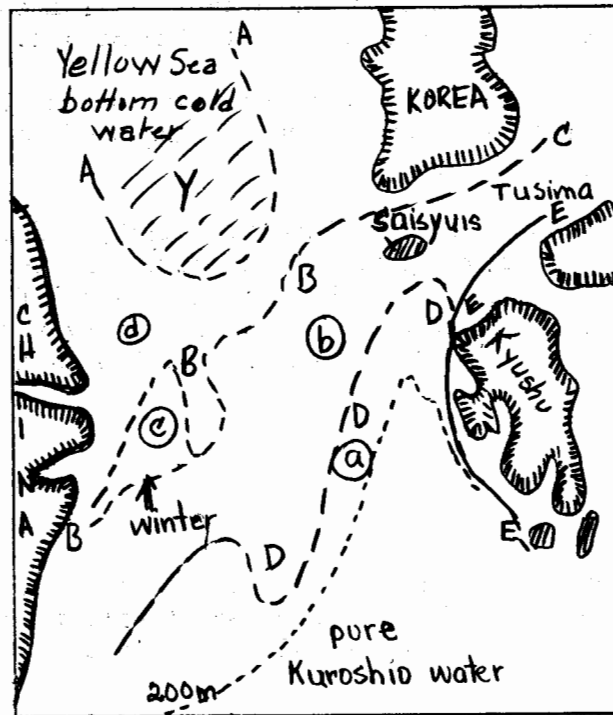


Figure 7

- A - A Yellow Sea front.
- B - B China continental coastal front (lying off the Yangtze River).
- C - C South Korean coastal front.
- D - D East China Shelf Edge front.
- E - E Kyushu front.

The relatively fresh and turbid China continental coastal water, and the saline, transparent Kuroshio waters meet to form the B - B and D - D fronts. The mixed water (a) is the source of the Tusima Current. (T. Tsujita, 1957, M. Koizumi, 1957).

(iii) We can remark the upwelling of intermediate continental slope water, particularly around sea valleys. These form eddies in the upper layer. For example in the area between latitudes 27° - 29° N, longitudes 124° - 125° E (80 - 100 meters depth) near the shelf edge, there are topographical eddies. These are

mackerel and marlin fishing areas. Near the south end of Saisyu Island there are whaling grounds in summer.

(iv) In summer, water of remarkably low salinity (d) flows in the surface layer of the Tusima Current and enters the Japan Sea. This extension depends on drainage from China, hence on the amount of precipitation. The abnormal discharge from the Yangtze in 1955 spread muddy water as far as Tusima Strait.

In the Yellow Sea and East China Sea there are strong tidal currents which cause diurnal and semi-diurnal changes of water temperature and salinity (Uda, 1941).

(v) The heat budget was studied by M. Nagayama (1957). The heat loss in winter is 400 to 600 gram cal/cm<sup>2</sup>/day. The heat gain in summer is remarkably great on the continental shelf (more or less 400 gram cal/cm<sup>2</sup>/day). The heat change by advection is large in the China coastal area because of the land drainage.

#### 16. South China Sea

Drift bottle observations (Uda 1934, 1936) showed that the winter monsoon current flows south from Formosa Strait, through the Hainan Islands, past Vietnam to the Malay Peninsula.

Serene (1955) has reported upwelling along the Vietnam coast in the northeast monsoon period (winter).

The survey made by the Soyo maru (June, July, 1939) has shown the fronts and upwelling near islands (Hainan) the continental shelf edge, and off great rivers (Uda, 1941).

There is a remarkable inflow of saline Pacific water from Bashi channel to the South China Sea.

Recently M. Ishino (1956) reported the hydrography of the South China Sea. K. Wyrzki (1956, 1957) using maps made by the Indonesia Oceanographic Institute, investigated the seasonal effect of the monsoons on circulation, and of precipitation on the salinity of the waters.

Seminar 9. Some problems in Japanese Estuaries and Inland Waters.

1. Introduction

A. We are, nowadays, witnessing a rapid expansion of "small scale" or "micro" oceanography applied to estuaries, coastal fishing grounds and controlled fish culture experiments. This has been brought about by an increasing need to develop marine resources and safeguard water from industrial pollution.

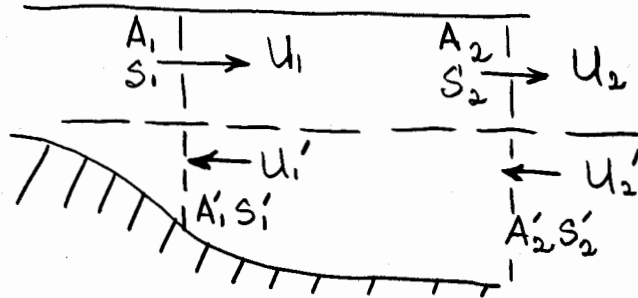
B. The problems encountered in the culturing of oysters, clams, abalone and jelly plants centered around such things as storm waves (especially those arising from typhoons), tidal currents, cold and warm water intrusions and river discharge. In addition one must consider factors such as optimum temperature, salinity and aeration and the nutrient composition of the water (including growth accelerators and sources of organic carbon, e.g. urea). The nature of the bottom is important as is the turbidity and mud content of the water and the submarine illumination. Complications can arise from natural enemies, competing zooplankton and dangers such as red tides.

C. Pollution problems are many. There is radioactive pollution to be considered, arising from atomic power development and atomic weapons testing, and, of course, many chemical industries can contribute unwanted material such as viscose, starch, pulp-mill effluent, organic solvents, etc. Mining industries may introduce toxic metal ions (e.g. copper). Insecticides used, for example, on rice fields and orchards may get into the water. There is the problem of oil pollution from tankers, or other ships in Tokyo Bay, etc. Large cities, such as Tokyo and Osaka have sewage pollution problems. Many problems are associated with the effect on coastal fisheries of changes in land drainage brought about by recent hydroelectric power developments in Japan.

D. Many new and interesting problems of marine engineering and coastal engineering are being tackled. Some of these may be listed as follows: digging new channels to prevent stagnation, coastal dam construction, formation of artificial islands, harbour engineering and submarine mining of oil and coal (Nagasaki and Akita prefectures and at Ariakekai). In addition there are plans to attempt the artificial change of ocean climate by atomic power. The recreational use of sea areas (bathing and yachting, etc) produce oceanographic problems inasmuch as pollution and the presence of rip-tides and surf are important. Finally there are the numerous different aspects to be considered, for example, underwater acoustics, surface and underwater optics, aerial scouting and the prediction of swell, surf and shore currents. These studies were given impetus because of World War II.

2. Fundamental study of mixing

A. Knudsen's hydrographic theorem (M. Knudsen, 1900) is obtained from equations of continuity applied to the system shown below



and leads to the expression:

$$\left(1 - \frac{S_2}{S_2'}\right) A_2 \cdot U_2 = \left(1 - \frac{S_1}{S_1'}\right) A_1 \cdot U_1 + r \Sigma$$

where U = current velocity

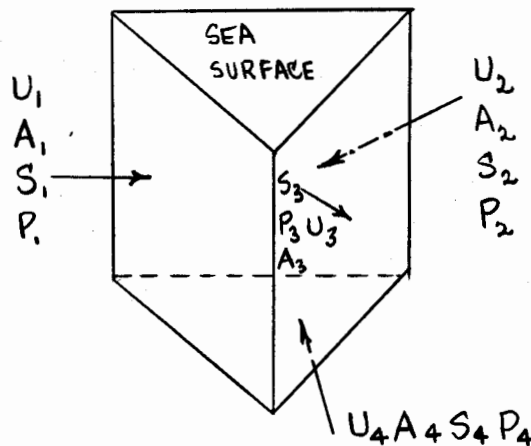
S = salinity (see diagram)

A = cross-section area

$\Sigma$  = area of sea surface

r = net inflow of fresh water (correcting for evaporation and precipitation at the sea surface).

Using this theorem G. Schott (1915) computed the inflow of Atlantic water ( $S = 36.25\%$ ) into the Mediterranean ( $S = 37.75\%$ ) as  $1.75 \times 10^6 \text{ m}^3/\text{sec}$ . Mituyo Okada (1934) extended the Knudsen equation to a three dimensional system (shown below) using salinity (S) and silicate concentration (P) as independent variables.



The equations of continuity are:

$$U_1 A_1 S_1 + U_2 A_2 S_2 + U_3 A_3 S_3 + U_4 A_4 S_4 = 0.$$

$$U_1 A_1 P_1 + U_2 A_2 P_2 + U_3 A_3 P_3 + U_4 A_4 P_4 = 0.$$

$$U_1 A_1 + U_2 A_2 + U_3 A_3 + U_4 A_4 = 0.$$

Solving these three equations simultaneously gives all velocity terms if one is known. In this manner Okada estimated the upwelling in Sagami Bay and A. Defant and H. Ertel (1939) estimated the effects of precipitation on salinity changes.

B. J. P. Tully (1949) studied oceanographic aspects of the problem of pulp mill pollution in a Canadian inlet and computed the "displacement"  $\gamma$  of fresh water ( $\gamma$ ) having the same significance as the "flushing" term used by B. H. Ketchum (1951) from the equation:

$$\gamma = \frac{Q T}{A C D}$$

where Q is the rate of fresh water discharge into the inlet.

T is the time of a tidal cycle

A is the surface area of the inlet

C is the proportion of fresh water contained in an upper zone of depth D.

Later Waldichuk (1957) studied the oceanography of the Strait of Georgia and worked out the fresh water budget.

In the period 1952-1958 there was marked activity in this field on what D. W. Prichard (1955) has classified as four main types of estuary.

H. Stommel (1953) found the characteristic mixing length of the Severn Estuary was one-thousandth of a tidal excursion giving an eddy diffusivity constant in the range between 80 and 1040 ft<sup>2</sup>/sec.

J. P. Tully et al (1952, 1956) has explained estuary structure on the basis of "entrainment". He then extended this concept to sub-Arctic oceanography in the North Pacific (1958). Entrainment of deep water was assumed to occur because of an upward flow brought about by the movement of surface layer of the ocean. The degree of entrainment depended on the lateral velocity of this surface movement and was proportional to the concentration gradient of surface and sub-surface properties.

Okada (1938) studied the intrusion of sea water in Suigetu Lake and Hyuga Lake. Using this approach T. Hirano (1955) worked on the water exchange (C) and the currents in Hamana Lake (about 10 meters deep), mainly with regard to the occurrence of clams in 1953. The exchange between the upper 5 meters and lower 5 meters was given by:

$$C = \frac{m}{\sigma_{+b} - \sigma_{+a}}$$

where  $\sigma_{+b}$  and  $\sigma_{+a}$  are the lower and upper mean in-situ densities and  $m$  is a constant depending on the turbulence of the lake water which was a linear function of the rate of inflow from the open sea.

C. M. Waldichuk (1958) made a study of the weather in the Strait of Georgia during October and November, 1957 as a possible factor in the outbreak of shellfish poisoning. Warm surface waters were not mixed by autumn winds and were augmented by a heavy August rain to form a stable brackish layer. This could have promoted the red tide bloom responsible for shellfish toxicity. Tokimi Tsujita (1956, 1957) reached similar conclusions when studying red tide blooms and decided that the chances of a red tide bloom were high after a period of high solar radiation combined with rain, as in the stagnant interior of a bay.

D. The water exchange in an estuary depends on entrainment, wind effects, river discharge, tidal currents and intrusion from the open sea.

R. H. Herlinveaux (1954) studied tidal currents in Juan de Fuca Strait. M. Waldichuk (1957) claimed that wind was the most important factor governing the circulation of the upper brackish layer in the Strait of Georgia. In Owase Bay (Uda in preparation) there are very pronounced changes of temperature, salinity, and transparency associated with different phases of a tidal period as well as the current patterns related to prevalent winds.

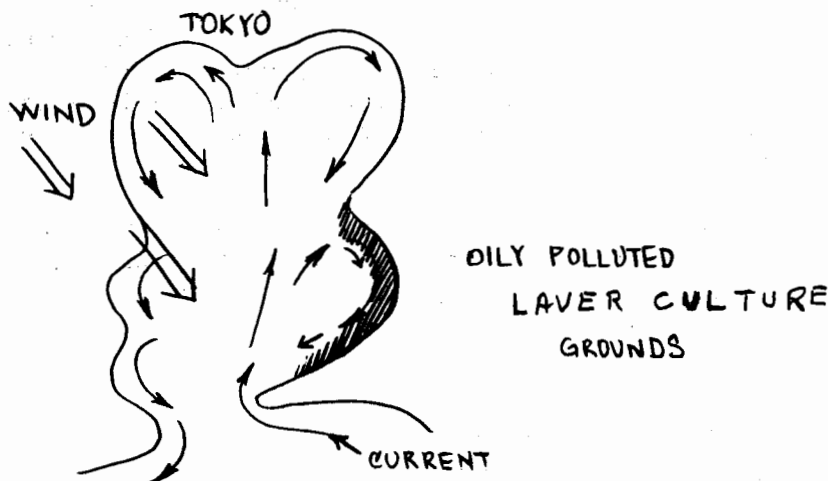
E. Seawater intrusion in the deep layers of rivers and estuaries may have interesting biological implications. S. Tabata and R. J. Le Brasseur (1958) related the infestation of *Bankia setacea* (shipworm) to seawater intrusion into the Steveston Basin from the Fraser River. E. U. Bansfield (1952) found the early stages of *Balanus improvius* larvae were in the surface at the mouth of the Miramichi estuary whereas the cyprid stage occurred in the deeper water at the upper end of the estuary. Similar studies by Prichard (1952) illustrate the mechanism of the upstream transport of oyster larvae in the James River.

The installation of a hydroelectric plant on the Cooper River resulted in an increased upstream flow rate in the deeper waters. This caused a deposition of silt which necessitated

dredging operations, at the cost of a million dollars, to keep the channel clear.

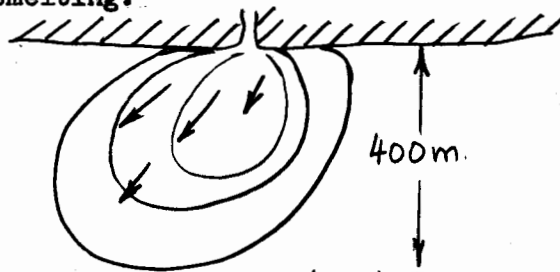
F. T. Ichiye *et al* (1952) made hydrographical surveys of the estuaries of the Yosino, Naka, Kinokawa and Kanzaki Rivers and concluded that the dispersal of river water into the sea occurred in two ways. There was a jet-like diffusion from the river mouth when the river discharge was strong and the tidal currents comparatively weak. In the reverse circumstances the river water entered the sea in isolated 'clouds'. Such 'clouds' if vertical stability is high, may survive several tidal cycles, being transported to and fro. (There are many similar examples, for example, the Columbia River).

In Tokyo Bay oil patches were stable for several days and caused serious damage to cultured seaweed. Such patches of oil move mainly in the direction of any wind-driven current. In the case of the sewage effluents we sometimes see similar wind effect.



3. Fresh water discharge related to hydroelectric power development

A. The Nikon Light Metal Company has a hydroelectric plant on the shore of Suruga Bay which discharges large quantities of fresh water taken from nearby mountains. A pipeline transports the water to the turbines and thence to the Bay. The power is used for aluminum smelting.

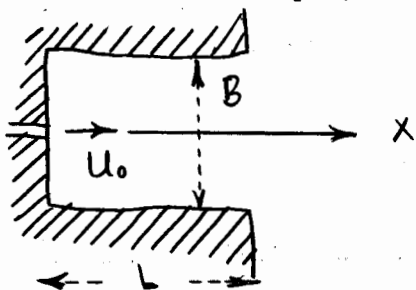


This discharge causes violent currents in the top 5 meters of the Bay water for a radius of 200-400 meters and prevents shrimp fishing. The discharge can be traced by salinity and temperature effects and shows the right hand deflection due to Coriolis forces that is observed with river discharge.

B. In Nagasima Bay (Mie Prefecture) a dam was constructed in 1957 and when this first discharged the muddy fresh water contained in the reservoir many fishes were killed near the coast. The surface currents near the coast upset fishing (ref. above) and the thin film of fresh water covering the sea gave rise to a "schlieren" effect as the water layers of different density mixed. This hazing prevented the use of the glass viewing boxes employed by some Japanese fishermen.

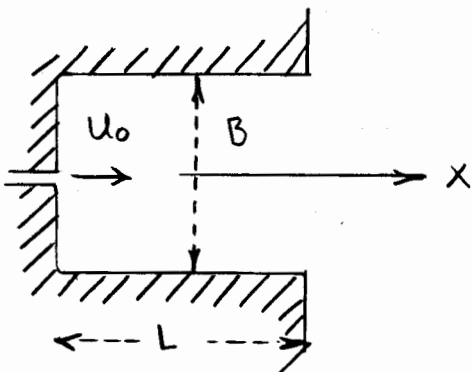
C. A study (unpublished) has been made of the effects of hydroelectric power development on a set-net fisheries (Kuki, etc.) and pearl oyster grounds. The effects of variable river discharge brought about by the presence of the hydroelectric dam may be estimated from studies of the normal discharge patterns. Immediately after discharge strong mixing appears to occur. The salinity of the upper few meters decreases markedly with a concurrent increase of turbidity. The temperature falls and current velocity increases.

We would like to know how the Japanese coastal front (a few miles offshore) varies from time to time, as along this front (at 50-100 meters depth) the yellow tail migrates.



4. Theoretical studies to forecast the salinity distribution during fresh water discharge

T. Hirano studied this problem. Consider the following idealized case of a Bay with a river discharge:



Here:

$$U_0 \frac{\partial S}{\partial x} = \frac{\partial}{\partial x} (A_h \frac{\partial S}{\partial x}) + \frac{\partial}{\partial z} (A_z \frac{\partial S}{\partial z}) \quad \dots (1)$$

In the upper layers

$$V_0 \frac{\partial S}{\partial x} = h B \frac{\partial}{\partial x} (A_h \frac{\partial S}{\partial x}) + C \cdot B \cdot (S' - S) \quad \dots (2)$$

where  $U_0$  = velocity of river discharge

$V_0$  = volume transport

$S$  = salinity

$S'$  = offshore salinity

$A_h$  and  $A_z$  are the horizontal and vertical mixing coefficients (see diagram for B and L). C corresponds to an entrainment coefficient. We may evaluate  $A_h$  by the expression given by A.

Arona and H. Stommel (1951) viz:

$$A_h = 2K S_0^2 \cdot \omega \frac{X^2}{h^2} \quad \dots (3)$$

where  $X$  = a mixing length due to tidal current

$S_0^2$  = tidal range

$\omega = \frac{2\pi}{T}$  (where  $T$  is the tidal period)

$h$  = thickness of upper zone

and  $K$  is a constant.

If we write this as

$$A_h = \beta \cdot X^2$$

we have in the case of where vertical mixing can be neglected:

$$\frac{S - S_0}{S_1 - S_0} = \exp\left(-\frac{e}{X}\right) \quad \dots (5)$$

where  $\lambda = \frac{2}{L}$

and

$$p = \frac{V_0}{h.B.\beta L} = \frac{V_0}{M_0\beta}$$

$S_0$  is the salinity of the upper zone at the end of  $x = 0$ ,  
 $M_0$  is the volume of the upper zone.)

In the case where horizontal mixing can be neglected:

$$\frac{S - S_0}{S_1 - S_0} = 1 - \exp(-g \cdot \lambda) \quad \dots\dots(6)$$

where:

$$g = \frac{C.B.L}{V_0}$$

At the end of the Bay where  $V_r$  is the volume transport of  
land drainage.

$$V_0 = V_r \cdot \frac{S_1}{S_1 - S_0}$$

(ref. the Knudsen theorem)

The case of Owase Bay may give some idea of numerical values:

$$p = 0.05 \sim 0.1$$

$$V_0 = 10 - 20 \text{ m}^3/\text{sec.}$$

$$\frac{S_1}{S_1 - S_0} \beta \approx \frac{1}{1.8 \times 10^5}$$

$$A_e = 4.5 \times 10^6 \text{ cm}^2/\text{sec at entrance to Bay}$$

$$A_e = 4.5 \times 10^4 \text{ cm}^2/\text{sec at end of Bay}$$

$$C = \frac{q \cdot V_0}{B L} \approx 2.5 \times 10^{-6} \text{ (m/sec)}$$

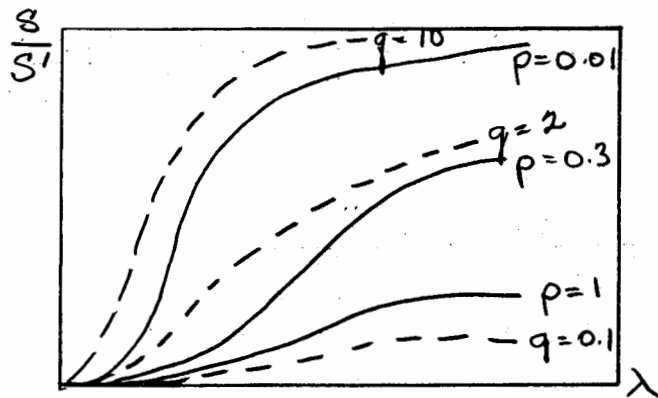
$$C(S' - S) \approx A_2 \frac{S' - S}{5 \text{ (meters)}}$$

$$A_2 \approx 10^{-1} \text{ (cm}^2/\text{sec)}$$

As an example:

When  $V_r = 30 \text{ m}^3/\text{sec}$  discharge a salinity  $S'$  equal to 32.6 ‰ changes to 21 - 24 ‰ after discharge.

The above treatment and forecasting based on these concepts have been tested experimentally by model experiments (K. Ishii et al) and by daily observations from two boats, following dye patches and making current measurements (I. Sakamoto et al). Y. Okada made biological investigations and experiments. A special diagram for predicting salinity is given by I. Sakamoto (1959).



5. The dispersion of eggs, larvae and polluted water, etc.

A. S. Hikosaka et al (1957) presented the following theory (ref. also Uda 1936) for predicting the dispersal of flotsam or floating mines (S). Assuming an equal dispersion in the

x and y directions:

$$\frac{\partial S}{\partial t} + u \frac{\partial S}{\partial x} = K^2 \left( \frac{\partial^2 S}{\partial x^2} + \frac{\partial^2 S}{\partial y^2} \right)$$

whence  $S = \exp \left( - \frac{(x-ut)^2 + y^2}{4 \cdot K^2 \cdot t} \right) \dots(7)$

Isolines for the concentration of S form concentric circles and the probability that a concentration S lies in a circle of radius (r) is:

$$P = \iint S \cdot d(x-ut) dy = 1 - \exp \left( \frac{-r^2}{4 K^2 t} \right) \dots(8)$$

The area of dispersion is proportional to time and a coefficient of diffusion K.

If we have a different dispersal rate in the x and y directions governed by two "diffusion" constants  $K_1$  and  $K_2$

$$\frac{\partial S}{\partial t} + u \frac{\partial S}{\partial x} = K_1^2 \cdot \frac{\partial^2 S}{\partial x^2} + K_2^2 \frac{\partial^2 S}{\partial y^2}$$

whence:

$$S = \exp \left( - \frac{\frac{(x-ut)^2}{4 \cdot K_1^2 \cdot t} + \frac{y^2}{4 \cdot K_2^2 \cdot t}}{4 \pi \cdot K_1 \cdot K_2 \cdot t} \right) \dots(9)$$

Isolines are now in the form of confocal ellipses.

$$\frac{(x-ur)^2}{4 K_1^2 t} + \frac{y^2}{4 K_2^2 t} = \text{a constant} \dots(10)$$

The probability that a concentration S lies in a given ellipse is:

$$P = \Phi\left(\frac{x-ut}{2K_1\sqrt{t}}\right) \Phi\left(\frac{y}{2K_2\sqrt{t}}\right) \dots(11)$$

where

$$\Phi(x) = \frac{2}{\sqrt{\pi}} \int_0^x e^{-v^2} dv \quad (\text{error function})$$

Earlier M. Hanzawa (1953) had studied the dispersal (Y) of flotsam from the Myojin Reef Eruption (17th September, 1952) and found:

$$\overline{Y^2} = 2 \overline{v^2 t} \int_0^\infty R_\xi d\xi \dots(12)$$

where

$$R_\xi = \frac{\overline{v \cdot v_\xi}}{\overline{v^2}} \quad (\text{the Lagrangian coefficient of correlation})$$

v = the instantaneous velocity of a particle

v<sub>ξ</sub> = the velocity of a particle after a time t = ξ

The coefficient of eddy diffusivity

$$K = \overline{v^2} \int_0^\infty R_\xi d\xi \dots(13)$$

$$t = \frac{x}{\eta} = \frac{600 \text{ Km}}{0.7 \text{ Knots}} = \frac{1}{6} \times 10^7 \text{ sec} \dots(14)$$

Y = 120 Km for the breadth of the observed band of flotsam, and

$$K = 4.3 \times 10^7 \text{ (cm}^2/\text{sec}^{-1}\text{)}$$

Then Ikosaka (1957) showed that

$$K^2 = \frac{r^2}{4 + \ln(1-p)} \approx \frac{5.4 \times 10^6}{\ln(1-p)} \quad \dots(15)$$

From the recent turbulence theory of Stommel (1955) it can be shown

that when  $U = 0$  then, after sufficient time:

$$h^2 = at^2$$

$$\text{and } S = \frac{1}{\pi^2} \cdot \frac{3}{4Et^3} \exp\left(-\frac{3(x^2+y^2)}{4Et^3}\right) \quad \dots(16)$$

$$\text{and } P = 1 - \exp\left(-\frac{3}{4} \frac{r^2}{Et^3}\right) \quad \dots(17)$$

Here the dispersal area is proportional to  $t^3$ .

B. Radioactive pollution has been the subject of special oceanographic work carried out by the Tokai Regional Fisheries Research Laboratory because of the Japanese atomic power plant being built at Tokai Village, Ibaragi Prefecture. The scientists concerned are N. Watanabe, T. Hirano, and Z. Nakai et al (1957, 1958).

W. S. Von Arx (1948) and W. H. Munk, G. C. Ewing, R. Revelle (1949) studied the theory of the diffusion of radioactive water from Bikini Lagoon.

H. Miyoshi (1953) used data obtained on the Shunkotsu-maru expedition.

Let S be the concentration of polluting substance in a layer of thickness 30 m.

The equation of diffusion:

$$A_z' \frac{\partial^2 S'}{\partial z^2} = \frac{\partial S}{\partial t} \quad \dots(18)$$

with boundary conditions:

$$\left[ \frac{\partial S}{\partial z} \right]_{z=0} = 0, \quad [S]_{t=0} = f(z) \quad \dots\dots(19)$$

(where  $f_2 = \frac{S_0}{3000}$ )

gave the following solution

$$S = \frac{1}{2\sqrt{A_2 \cdot \pi t}} \int_0^\infty f(\lambda) \left[ \exp\left(\frac{-(z+\lambda)^2}{4A_2 t}\right) + \exp\left(\frac{-(z-\lambda)^2}{4A_2 t}\right) \right] d\lambda \quad \dots\dots(20)$$

and putting  $x = 150$  km, current velocity 1.2 knots and  $t = 3$  days. Miyoshi concluded that  $A_2 = 5$  cm<sup>2</sup>/sec and that diffusion occurred actively along isentropic surfaces. The time required for radioactive calcite particles to reach a given depth is:

$$T(H) = \int_0^H \frac{dz}{V}, \quad \text{where } V = \frac{g D^2}{18} \left( \frac{\sigma_{\text{particle}} - \sigma_{\text{water}}}{\eta} \right) \quad \dots\dots(21)$$

This follows from Stokes law.  $\sigma$  are density terms,  $D$  the mean diameter of the particles,  $g$  the acceleration due to gravity and  $\eta$  is the coefficient of viscosity, obtained from the coefficient at a temperature  $0^\circ$  C from an expression

$$\eta = \frac{\eta_0}{1 + \alpha \theta + \beta \theta^2} \quad \dots\dots(22)$$

where  $\theta$  is the temperature and  $\alpha$  and  $\beta$  are constants

A typical result comes out at about 1000 hours for particles to reach 200 m.

W. Wooster and B. H. Ketchum (1957) reviewed the problems of the transport and dispersal of radioactive elements in various locations such as in the open sea, in coastal areas, in surface waters, etc.

A. Defant (1955) has again studied the dispersal of intermediate saline waters from the Mediterranean Sea through the Gibraltar Strait. Polar coordinates can be used.

$$\frac{A}{\rho} \frac{\partial^2 S}{r^2 \partial r^2} - \frac{\partial (v \cdot r \cdot S)}{r \partial r} = 0 \quad \dots\dots(23)$$

$$\frac{\partial (v \cdot r)}{\partial r} = 0 \quad v \cdot r = r_0 \cdot v_0 = \text{constant}$$

whence:

$$\frac{S r - S_0}{S r_0 - S_0} = \left( \frac{r_0}{r} \right)^\beta \quad \dots\dots(24)$$

Seminar 10. On the prediction of oceanographic conditions.

A. Forecasting of oceanographic conditions for fisheries purposes has been seriously requested by the fishermen. Two kinds of forecast are required.

(i) Short period - daily, tidal, 10 day, monthly, seasonal.

(ii) Long period - yearly, secular.

Yearly prediction of sea surface temperatures are of particular interest in the seas around north-eastern Japan, because they are related to years of poor or good rice crops. Tentative forecasts were made from 1934 through to 1941 (Uda, 1938) and later forecasts were made by N. Watanabe and T. Hirano (1955) and Y. Takenouti (1957).

In the United States remarkable progress has been made in the forecasting of waves, sea ice, and thermocline structure by H. U. Sverdrup, W. H. Munk et al, Scripps Institution and the Hydrographic Office.

In local micro-problems it is necessary to use self-recording devices, Broad mass problems require aerial surveys, multiple ship surveys, acoustic methods, and marine meteorological resources (for heat budget studies).

B. Methods

In Japan we have studied first the characteristic features in the adjacent sea area. The normal year has been defined as the mean condition over a period longer than the expected dominant period of variation. In this treatment the normal values fluctuate from year to year within the limits of standard deviation.

Secondly our studies were directed to the occurrence of anomalous situations, and trends. The anomalous situations were defined by their difference from the preceding years or months

$$\Delta \bar{\Phi} = \bar{\Phi} - \bar{\bar{\Phi}}$$

From these trends we can extrapolate the future values, but there remains, of course, some ambiguities.

C. 1. Statistical methods were used.

(i) Periodicity, dominant periods were found by periodogram (J. Fukuoka, 1957).

(ii) Persistency or durability (M. Uda, 1938, 1952, T. Hirano, 1957).

- (iii) Cyclic changes from positive to negative deviations (M. Uda, 1952).
- (iv) Correlation in time sequence,  $R(\theta_{t_1}, \theta_{t_2})$  (M. Uda, 1938).
- (v) Correlation with location,  $R(\theta_A, \theta_B, \theta_C)$  in a current system or in different systems (G. Okamoto, 1938).
- (vi) Degree of similarity (M. Uda, 1938, N. Watanabe, 1955)

$$X' = \sqrt{\frac{\sum (\theta_m - \theta_k)^2}{n}}$$

where  $\theta_m$  is the temperature in year m  
 $\theta_k$  is the temperature in the standard year  
 $n$  is the number of months adopted in computation.

- (vii) Comparison of similar oceanographic patterns.
- (viii) Integration of the quantity of heat in a section or area and observation of its variation. The shift of isotherms is also observed.
- (ix) Observation of the amount of drift ice, and areas of freezing.
- (x) Correlation with sun spots (11 year, and 22 year periods).
- (xi) Correlation with volcanic activity (T. Okada, 1934).
- (xii) Correlation with weather conditions.
- (xiii) Observations of fisheries, biological symptoms.

C. 2. However, the physical method is more advanced. In this the mechanism is studied in theoretical and physical models and the behaviour forecast. In general -

$$\Delta\theta_p = \underbrace{\left(\frac{\partial\theta}{\partial t}\right)\Delta t}_{\text{time variation}} + u \underbrace{\left(\frac{\partial\theta}{\partial s}\right)\Delta t}_{\text{advection}}$$

### C. 3. Numerical prediction.

The method of numerical prediction of weather has been developed since 1953. It follows from proposals made by V. Bjerknes (1904) and C. F. Richardson (1920). T. Terada (1926) proposed the adoption of the group theory in weather forecasting. F. M. Kibel (1940) and C. G. Rossby (1940, 1942) developed the planetary wave theory at Chicago after the War. J. C. Charney (1955) finally promoted the numerical method of prediction.

Its principle is, to adopt the existing conditions as initial values, and keeping some boundary conditions, to compute the probable future values by the vorticity equation controlling oceanic circulation.

T. Nan'niti (1957) tried the study. He showed that potential vorticity is conserved in the Kuroshio system. H. Stommel (1953, 1955) showed that it is conserved in the Gulf Stream. In the steady state the geostrophic contours run parallel to the isolines of vorticity.

However, in order to carry out the numerical prediction method we require a wide and regular network of oceanographic observations in hand.

For the continuous recording of ocean currents, the difference of sea level recorded by tide gauges, and the electric potential differences on submarine cables (C. S. Cox, 1959) are very useful, because they vary in proportion to the currents.

Pattullo and Munk (1955) analyzed the world-wide records of sea levels and showed the steric variation. M. Miyazaki (1953) conducted periodogram analyses of the sea level records along the Kuroshio area and obtained dominant periods of 2, 5-3, 4.5-5, 8-9, and 18-19 months between the peaks of periodogram. K. Wyrzki (1954) analyzed the variations of sea level in the Baltic and found them proportional to the salinity and the southwest component of the wind. D. Shoji (1954) investigated the differences of daily mean sea level between Hatijyo and Miyake Islands and found an oscillatory period of 14 days in the strength of Kuroshio.

### D. Some physical basis of ocean currents

1. From the theories proposed by Stommel, Munk, and Hidaka, the general ocean circulation is maintained by wind stress on the surface. Along the westerly continental boundaries the ocean currents are intensified (e.g. Kuroshio, Gulf Stream, etc.) due to latitudinal variation of Coriolis force. Statistically turbulence tends to dissipate momentum and the kinetic energy of flow. The mass distribution in the oceans adjusts to balance

the flow geostrophically.

2. Kuroshio is a very concentrated strong current similar to a jet stream, and is accompanied by marked temperature gradients (fronts). Such a geostrophic current tends to meander, producing cold and warm eddies. These oceanic eddies are more stable than atmospheric eddies. However offshore eddies, that are not stabilized by land boundaries vary considerably from time to time.

3. The increase of transport and velocity in Kuroshio and the Gulf Stream causes them to contract (Iselin, 1940, Takenouti, 1957). When the volume transport and velocity of Kuroshio decreases, the anti-clockwise gyre of Kumano Nada, and the meander off Honsyu develop simultaneously. The meander of Kuroshio is an unstable oscillation. When the Kuroshio is strong it causes northward spreading of warm surface water (Uda, 1940). When the Kuroshio system shrinks the southward flow of Oyashio increases.

4. Meteorologically, the fluctuations of the Siberian high pressure center, the Aleutian low, Okhotsk high, and the North Pacific high with their related wind systems, are important references for the prediction of Kuroshio and Oyashio in the waters adjacent to Japan (Uda, 1955).

#### E. Secular variation

Climatic changes in the Arctic in relation to plants and animals were discussed in the Rapparts et Procès Verbeaux des Reünions (1949). During the 9 and 10th centuries the Normans colonized in Iceland, Greenland, and Labrador. However, during the colder period 1100 to 1300 they retreated. Between 1720 and 1750 glaciers developed. From 1828 to 1857 there were severe winters. From 1870 to 1900 there was a second warm period when the northern cod fisheries were visited again. With Arctic warming from 1910 to 1946 the cod fishery increased remarkably, the zones of plants and forests moved north, the zone of pack ice shrank, glaciers retreated, and sea level rose. In Oriental waters also such a longterm trend of warming is suggested, (Uda, 1938).

At the time of Nansen's Fram expedition (1893-96) the thickness of the polar ice was 365 cm. During Sedov's expedition (1937-40) it had decreased to 218 cm. During this interval the temperature of the water increased from between  $-1.0^{\circ}$  and  $1.9^{\circ}$  C to between  $0.6^{\circ}$  to  $2.6^{\circ}$  C in the north Polar Sea.

The atmospheric pressure over the seas was reduced so that the gradient between the ocean and western Europe was increased, and the transport of south westerly warm air into high latitudes increased. Since about 1885 there has been a gradual rise of

air temperature. Especially the winter temperature, and the annual mean temperature of the water and air increased. The climate changed, became milder and more oceanic, the amplitude of the fluctuations decreased.

The water temperature along the North American west coast (1919-1954) and the air temperature (1850-1953) have shown cyclic variations. Since 1850-1870 the warm area has extended northward. From 1941 to 1953 it declined, but since 1955 there has been another general temperature rise. (L. Walford, Tully, 1950, Revelle, 1954). Is this the inception of a new period of warming?

Along the coast of Japan there have been cyclic variations

Cool Periods	Warm Periods
1870 - 1917	1917 - 1921
1923 - 1931	1932 - 1940
1941 - 1948	1949 - 1950
1956 - 1958	

These cyclic changes on the east and west sides of the Pacific and Atlantic Oceans, with a phase lag of 2 or 3 years seem to be correlated in a world wide climatic change pattern.

The famous warm water intrusion of "El Nino" occurred in the years 1891, 1925, and 1953 due to a southerly shift of the meteorological pattern. This may be compared to the northerly warm water intrusion along the British Columbia coast in 1936 and 1958. Similar intrusions occurred in the northern Japanese waters in 1936-39, and 1956, and warmer waters prevailed in the Aleutian and Bering areas in 1957.

It will be a very interesting problem to study the relations of oceanic climates between the east and west, and north and south hemispheres in the future. It will require many years of continued study.

Smed (1947) reported the trends of water temperature in the north Atlantic. L. H. N. Cooper (1956) studied the annual variation of dissolved inorganic phosphate from 1922 to 1955 in the English Channel, and explained the cyclic change of biological productivity with reference to plankton (sagitta) and herring larvae. J. B. Tait (1957) discussed long term trends based on observations of a hydrographic section across the Faroe-Shetland Channel from 1927 through 1952. He computed the volume transport of oceanic water (salinity 34.99‰). He concluded that, except in 1947, the Atlantic currents flowed more strongly in the autumn-winter season than in the spring and summer, during the period 1946 to 1952. This is probably applicable to the eastern north Pacific including British Columbia waters.

F. Forecast techniques

Numerical predictions based on physical methods and adequate continued networks of observations may be developed. These data may be processed by electronic devices. In the future the forecast may be given immediately over radio or television.

J. Sugiura (1957) proposed the following classification.

= $\frac{\text{Monthly anomaly}}{\text{Standard deviation}} \times 100$			
very low	-200% or less	(-3°C or less)	1913, 1934
moderately low	-200% to -130%	(-2°C to -2.9°C)	1935, 1941
slightly low	-130% to -60%	(-0.9 to -1.9°C)	1914, 1917, 1918
normal	-60% to 60%	(-0.8 to 0.8°C)	1926, 1929, 1931
slightly high	60% to 130%	(0.9 to 1.9°C)	1920, 1925, 1928 1937, 1938
moderate high	130% to 200%	(2.0 to 2.9°C)	1927, 1930, 1933
very high	200% or more	(3.0°C or more)	1916

J. Fukuoka (1957) has shown that from 1915 to 1956 the sea water temperatures at Departure Bay, B. C. (Hollister) and at Siroyazaki, Japan vary contrary to each other (correlation coefficient - 0.56) both having dominant periods of about 5 and 11 years. This suggests an east-west correlation of sea conditions in the North Pacific. T. Hirano (1957) computed the durability, defined by the conditional probability of occurrence of months warmer or cooler than normal, with the dispersion of the condition. He defined the normal coastal water temperatures within  $\pm 0.5^\circ\text{C}$ , which is about half the standard deviation.

Acknowledgement

These seminars were presented during the period, October, 1958 through January, 1959.

The assistance of Drs. J. P. Tully, J. D. H. Strickland and Mr. H. J. Hollister to prepare the manuscripts, is acknowledged.

- Amemiya, K., K. H. Hibiya, and H. Koyama. 1957. On the abundant driftage and death of fishes along the Pacific Coast of middle Japan due to cold water temperature. Suisangaki Syusei. Univ. Tokyo Press.
- Beklemishev, C. W. and V. A. Burkov, 1958. The relationship between the plankton and the water masses in the frontal region in the N. W. Pacific. Trans. Ints. Oceanogr. Acad. Sci. U.S.S.R., 27.
- Cooper, L. N. H., and D. Vaux, 1959. Cascading over the continental slope of water from the Celtic Sea. J. Mar. Biol. Assoc. U.K. 28.
1955. Deep water movements in the North Atlantic as a link between climate change around Iceland and biological productivity of the English Channel and Celtic Sea. J. Mar. Res. 14 (4).
1955. Hypothesis connecting fluctuations in Arctic climate with biological productivity of the English Channel, Papers in Mar. Biol. and Oceanogr. pp 212-223.
- Cromwell, T. 1953. Circulation in a meridional plane in the Central Equatorial Pacific. J. Mar Res., 12 (2).
- and J. F. Reid, Jr., 1956. A study of Oceanic Fronts. Tellus. 8 (1) .
- Defant, A. 1929. Dynamische Ozeanographic.
1955. Die Ausbreitung des Mittel-Meerwassers in Nordatlanteschen Ozean. Papers in Mar. Biol. and Oceanogr. pp 46 5-470.
- Eggin, J. 1940. The movement of a cold front. Rept. on Norwegian Fishery and Marine Investigations, 6 (5).
- Fofonoff, N. P., and R. B. Montgomery, 1955. The Equatorial Undercurrent in the light of the vorticity equation. Tellus. 4.
- Fukuoka, J., 1955. The variation of the polar front in the sea adjacent to Japan. Oceanogr. Mag. Japan, 6 (4).
- Hanzawa, M. 1952. On some examples of abrupt change of oceanographic conditions at the ocean weather station "Extra" adjacent to the oceanic polar front. Oceanogr. Mag. Japan, 4 (3).
1953. On the eddy diffusion of pumices ejected from Myozia Reef in the Southern Sea of Japan. Oceanogr. Mag. Japan, 4 (4).
1957. Studies on the inter-relationship between the sea and the atmosphere (II) Oceanogr. Mag. Japan, 9 (1).
- and T. Inoue. 1952. Relation between oceanic and atmospheric state in the North Pacific Ocean for the year of the bad and good rice crop. Oceanogr. Rept. Central Meteorol. Office, 2 (3).

- Hayami, S. 1955. On the dynamics of the Kuroshio off the southern coast of Japan. UNESCO Symposium of Physical Oceanography at Tokyo.
- Herlinveaux, R. H. 1954. Surface tidal currents in Juan de Fuca Strait. J. Fish. Res. Bd. Canada, 11 (1).
- Hidaka, K. 1958. Computation of wind stresses over the oceans. Record of Oceanogr. Works in Japan, 4 (2).
- Hirano, T. 1956. On desirability of surface temperature at hydrographical stations of the Pacific coast. II Bull Tokai Reg. Fish. Lab. (17).
1957. The oceanographic study of the sub-Arctic region of the northwestern Pacific Ocean, I, II. Ibid. (15).
1958. The oceanographic study on the sub-Arctic region of the northwestern Pacific Ocean. III. On general condition of the sea in spring and summer, Ibid. (20).
- and C. Boshier, 1957. On durability of surface temperature at hydrographical stations I Ibid. (10).
- Hollister, H. J. 1958. Daily seawater observations on the Pacific Coast of Canada. Proc. Eighth Pacific Sci. Cong. Vol. II.
- Ichiye, T. 1952. On the variation of ocean currents (III), Oceanogr. Mag. Japan, 4 (2).
1953. On the hydrographical conditions around an island. Record of Oceanogr. Works in Japan, 1 (2).
1955. On the variation of oceanic circulation (V) Geophys. Mag. 26 (4).
1956. On the behaviour of the vortex in the polar front region. Oceanogr. Mag. Japan, 7 (2).
1956. On the properties of the isolated cold and fresh water along the edge of the Kuroshio. Ibid., 8 (1).
1956. On the movement of the upper water in the polar front region. Ibid. 8 (1).
- Ishino, M. 1955. Hydrographic survey in the Equatorial Pacific Ocean, the south China Sea and Formosa-Satsuna-Kuroshio region. Records of Oceanogr. Works in Japan, 2 (1).
- Kawai, K. 1955. On the polar frontal zone and its fluctuation in the water to the northwest of Japan (1). Bull. Tohoku Reg. Fish. Res. Lab. (4).

- Kawai, K. 1955. On the Polar frontal zone and its fluctuation in the waters to the Northeast of Japan (II). Ibid. (5).
- Kimura, K. 1943. On the coastal stormy current "Dai Kyutyo", Rept. Central Meteorol. Office, 19 (1).
- Kishindo, S. 1929. On the vortical currents along the south side of the Kuroshio". Proc. Fourth Pacific Sci. Cong.
- Kitano, K. 1958 On the characteristics of the water mass stratification over the frontal zone of "Tohoku Kaiku". Bull. Hokkaido Reg. Fish. Res. Lab., (17).
- 1958 Oceanographic structure of the Bering Sea and the Aleutian waters. Part 1, Part 2. Ibid. (19).
- Knauss, John A. 1957. An observation of an oceanic front. Tellus. 9 (2).
- Koizumai, M. 1955-1956. Researches on the variations of oceanographic conditions in the region of the ocean weather station "Extra" in the North Pacific Ocean (I, II, III, IV, V, VI) Papers in Meteorol. and Geophysics.
1956. Researches on the variation of oceanographic conditions in the region of the ocean weather station "Extra" in the North Pacific Ocean, Ibid. VI, (3-4).
- Koto, K., and T. Fujii. 1958, Structure of the waters in the Bering Sea and Aleutian region. Bull. Fac. Fish. Hokkaido Univ. 9 (3).
- Mao, H-L, and K. Yoshida, 1955. Physical oceanography in the Marshall Island area. U. S. Geological Survey, Professional Paper 260 -5. U. S. Department of the Interior, Washington, D. C.
- Masuzawa, J. 1954. On the Kuroshio south off Shiono-Misaki of Japan, Oceanogr. Mag. Japan, 6 (1).
- 1955 Preliminary Report on the Kuroshio in the eastern Sea of Japan. Records of Oceanogr. Works in Japan, 2 (1). 2 (1)
1956. On the cold belt along the northern edge of the Kuroshio. Oceanogr. Mag. Japan, 8 (2).
1957. An example of cold eddies south of the Kuroshio, Records of Oceanogr. Works in Japan, 3 (1).
- Mischina, S. and S. Nishiuwa, 1955. Report on hydrographic investigations in Aleutian waters and the southern Bering Sea in the early summer of 1953 and 1954. Bull. Fac. Fish. Hokkaido Univ., 6 (2).

- Miller, A. R. 1950. A study of mixing processes over the edge of the continental shelf. J. Mar. Res., 9 (2).
- Miyazaki, M. 1952. The heat budget of the Japan Sea, Bull. Hokkaido Reg. Fish Res. Lab., (4).
1953. Secular variation of the annual sea-level. Oceanogr. Rept. (C. M. O.), 3 (1-2)
- Nakai, Z., 1939. Some information helpful for predicting sardine fisheries in Korea with special references on relationships between the mortality and seismological, meteorological and oceanographic conditions in 1923. Suisan Kentyusui, 34 (4)
- Nakano, M. and S. Unoki, M. Hanzawa, R. Marumo, and J. Fukuoka, 1954. Oceanographic features of a submarine eruption that destroyed the Maiyo maru No. 5., J. Mar. Res., 13 (1).
- Nan'niti, T., 1957. A preliminary study for numerical prediction of oceanic conditions. Oceanogr. Mag. Japan, 9 (1).
1958. A theory of the mechanism of the generation of the cold water region in the offing of Enshūnada. Papers in Meteorol. and Geophysics, VIII (4).
- Nasu, K., 1957. Oceanographic conditions of the whaling grounds in the waters adjacent to Aleutian Islands and the Bering Sea in summer of 1955. Sci. Rept. Whale Res. Inst., (12).
- Neumann, G., 1947. Über die entstehung des aquatorialen gegenstromes. Forschungen und forrchutte, 2 (23).
- Okada, M., 1939. Stationary upwelling and sinking in the sea. Bull. Japanese Soc. Sci. Fish., 8 (3).
- Pickard, G. L., 1953, 1954. Oceanography of British Columbia mainland inlets, I, II, III, Fish. Res. Bd. Canada, Pacific Prog. Rept. Nos. 96, 97, 98.
- Rochford, D. J., 1958. Total phosphorous as a means of identifying east Australian water masses. Deep Sea Research, 5 (2).
- Sawada, T., 1958. A practical method for forecasting ice-area movement. J. Meteorol. Soc. Japan, Series II, 36 (1).
- Schulz, B., 1911. Die Strömungen und die temperatur overhaltcusse des stillen ozeans nördliche von 40° N - Br einschlieschide das Bering Meire. Ann. Hydr. Mar.
- Shoji, D., 1954, Fluctuation of daily mean sea-level and oceanic current. Hydro. Bull. (Tokyo).

- Sigiura, J., 1957. Forecast of water temperature in the south Sea of Hokkaido. Oceanogr. Mag. Japan, 9 (1).
- Suda, K., 1934. On the fluctuation of coastal water along the Japan islands. (Prelim. Rept.) Omoto Sora, 14 (10).
- Tabatu, S., and R. J. Le Brasseur, 1958, Seawater intrusion into the Fraser River and its relation to the incidence of ship worms in Steveston Cannery Basin. J. Fish. Res. Bd. Canada, 15 (1).
- Taguchi, K., 1955. The movement of water masses in the seas of West Aleutian Islands and off east coast of Kamchatka salmon fishing ground. I. Inference from the distribution of water temperature, water colour, and transparency, Bull. Japanese Soc. Sci. Fish., 20 (1).
1956. A report of drift bottle surveys off Kamchatka, U.S.S.R. in 1940 and 1941. Bull. Japanese Soc. Sci. Fish., 22 (7)
- and T. Hirose, 1954. Surface currents and oceanographical conditions in the northern Pacific salmon fishing ground. Ibid. 20 (7).
- and Y. Schoji, 1955. The movement of water masses in the sea of West Aleutian Islands, and off east coast of Kamchatka fishing ground. II. Inference after observation by current meters in two layers. Bull. Japanese Soc. Sci. Fish. 20 (9).
- Tait, J. B., 1955. Long term trends and changes in the hydrography of the Faroe-Shetland Channel region. Papers in Mar. Biol. and Oceanogr., pp 482-498.
- Takenouti, Y., 1957. Long-range oceanographic forecast, historical review and future problem. Oceanogr. Mag. Japan, 9 (1).
- Tully, John P., 1949. Oceanography and prediction of pulp mill pollution in Alberni Inlet, Bull. Fish. Res. Bd. Canada. No. LXXXIII.
1952. Notes on the behaviour of fresh water entering the sea. Proc. Seventh Pacific Sci. Cong., Vol. III.
- and Allan J. Dodimead, 1956. Properties of the water in the Strait of Georgia, B. C. and influencing factors. J. Fish. Res. Bd. Canada, 14 (3).
- Uda, M., 1930. On some oceanographical researches of the seawater of the Kuroshiewo. Records of Oceanogr. Works in Japan (2)
1930. Color of the sea and transparency of the sea water adjacent to Japan. Umuto Sora, (10).

- Uda, M., 1934. Normal monthly sea conditions in the Japan Sea, Yellow Sea, and Okhotsk Sea. J. Imp. Fish. Exptl. Stn. (Tokyo) (5).
1934. Oceanic currents estimated from the records of plying drift nets and long lines in fishing. Bull. Japanese Soc. Sci. Fish., 3 (2).
1935. The origin, movement and distribution of dichothermal water in the Northeastern sea region of Japan. Umito Sora., 15 (12).
11936. Distribution of drifting bodies in the ocean current. Bull. Japanese Soc. Sci. Fish., 4 (5).
1938. Hydrographical fluctuation in the north-eastern sea region adjacent to Japan of North Pacific Ocean. A result of simultaneous oceanographic investigations. J. Imp. Fish. Exptl. Stn., (9)
1940. Relation between the heavy rainfall, dry spell, and oceanographic conditions. Bull. Central Meteorol. Observatory. (16).
1940. On the recent anomalous hydrographical conditions of the Kuroshio in the south waters off Japan proper in relation to fisheries. J. Imp. Fish. Exptl. Stn., (10)
1941. The results of the hydrographic surveys in the China Sea in summer 1939. J. Imp. Fish. Exptl. Stn. (11).
1942. On the problems of oceanic fronts in relation to sea disasters. J. Naut. Soc. Japan.
1949. On the correlated fluctuation of the Kuroshio current and cold water masses. Oceanogr. Mag. Japan, 1 (1).
1950. On the fluctuation of oceanic drift current in Japan Sea, Yellow Sea and East China Sea (Second Report). J. Oceanogr. Soc. Japan, 5 (2-4).
1951. On the fluctuation of the main stream axis and its boundary line of Kuroshio. J. Oceanogr. Soc. Japan, 6 (4).
1952. On the characteristic feature of the yearly variation of coastal water temperature. Umito Sora, 30 (1-2).
1953. Researches on the fluctuation of the North Pacific circulation. I. The fluctuation of Oyoshio current in relation to the atmospheric circulation and to the distribution of dichothermal water masses in the North Pacific Ocean. Record of Oceanogr. Works in Japan, 2 (2).

- Uda, M. 1953. On the stormy current ("Kyutyo") and its prediction in the Sagami Bay. J. Oceanogr. Soc. Japan, 9 (1).
1953. The Kuroshio and its branch currents in the seas adjacent to Hachyo Island in relation to fisheries (I). Record of Oceanogr. Works in Japan, 1 (1).
1955. On the sub-Tropical convergence and the currents in the north-western Pacific. Records of Oceanogr. Works in Japan, 2 (1).
1955. On the sub-Tropical convergence and the currents in the north-western Pacific, Ibid., 2 (1).
1956. Researches on the fisheries grounds in relation to the scattering layer of supersonic wave (Introductory Report). J. Tokyo Univ. Fish., 42 (2).
1957. Hydrographic researches in the Equatorial Pacific waters adjacent to Bikini Atoll in relation to radio-active pollution of fishing grounds. Report from the researches into the effects and influences of the nuclear bomb test explosion.
1958. On the problems of oceanic fronts in relation to sea disasters. J. Naut. Soc. Japan.
1958. On the abyssal circulation in the north-east Pacific area. Geophys. Mag., 28 (3).
1958. (Editor). Report of Tusima warm current areas. I. Fishing conditions and oceanography. Fisheries investigation published by Japanese Fisheries Agency.
- and M. Ishino, 1958, Enrichment pattern resulting from eddy systems in relation to fishing grounds. J. Tokyo U. of Fish., 44 (1-2).
- and M. Y. Morita, and M. Ishino, 1957. Results from the oceanographic observations in the North Pacific (1955-56) with Umitaka maru and Shinyo maru. Records of Oceanogr. Works in Japan (Special No. in 1957).
- and N. Watanabe, 1933. Normal monthly sea conditions in Seto Naikai (Inland Sea). J. Imperial Fisheries Exptl. Stn., (3)
- Watanabe, N. 1955. Hydrographic condition of the North-western Pacific. Part 1. on the temperature change of the upper layer in summer. J. Oceanographic Soc. Japan, 11 (3).
- and T. Hirano, 1955, An attempt to predict the surface temperature of the north-eastern sea adjacent to Japan for the summer 1955. J. Oceanogr. Soc. Japan, 11 (2).

Weidemann, H., 1950. Untersuchungen über hydrographischen Vorgänge in der Beltsee. Kieler Meeresforschungen Bd. VI, (2).

Wüst, G., 1936. Kuroshio and Gulfstream. Veröff des Inst. für Meereskunde.

Wyrzki, Klaus, 1957. Die Zirkulation unter Oberfläche der südostasiatischen Gewässer. D. Hydr. Bd., 10 (1).

Yoshida, K., 1955. Coastal upwelling off the California coast. Record of Oceanogr. Works in Japan, 2 (2).

and H. L. Mao, and P. L. Horner, 1953. Circulation in the upper mixed layer of the Equatorial North Pacific. J. Mar. Res., 12 (1).