OCEAN HYDROCLIMATE: ITS INFLUENCE ON CLIMATE

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THESIS

OCEAN HYDROCLIMATE:

ITS INFLUENCE ON CLIMATE

by

Donald Gene Buchanan

September 1975

Thesis Advisor: Dale F. Leipper

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lithospheric, and atmospheric interactions, as related to SST distributions, ocean currents, upwelling, sea-breezes, and monsoons. SST anomalies as a cause of short period climatic variations are examined. The deep-sea sediment record of past SST conditions is shown to indicate past effects of the ocean on climate. A previously defined numerical index describing oceanicity, a quantitative measure of the ocean's effect on climate, is reviewed. An evaluation of hydroclimatic products most useful to meteorologists was prepared and includes a categorized list and individual evaluations of 62 hydroclimatic products.

Ocean Hydroclimate: Its Influence on Climate

by

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requirements for the degree of

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ABSTRACT

The statistical synthesis of selected oceanographic parameters (SST, SST anomalies, boundary heat exchanges, etc.) over a specified period of time at a given place or over a given area is defined as ocean "Hydroclimate". Research and etymological background leading to the adoption of the term hydroclimate is discussed. Oceanic influence on atmospheric climate is described. In particular, the ocean's role within the earth's hydrologic cycle and heat budget is explained through hydrospheric, lithospheric, and atmospheric interactions, as related to SST distributions, ocean currents, upwelling, sea-breezes, and monsoons. SST anomalies as a cause of short period climatic variations are examined. The deep-sea sediment record of past SST conditions is shown to indicate past effects of the ocean on climate. A previously defined numerical index describing oceanicity, a quantitative measure of the ocean's effect on climate, is reviewed. An evaluation of hydroclimatic products most useful to meteorologists was prepared and includes a categorized list and individual evaluations of 62 hydroclimatic products.

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TABLE OF SYMBOLS AND ABBREVIATIONS

BT	Bathythermograph
CALCOFI	California Cooperative Fisheries Investigations
EASTROPAC	Eastern Tropical Pacific
ESSA	Environmental Science Services Administration
FNWC	Fleet Numerical Weather Central
GARP	Global Atmospheric Research Program
JNWP	Joint Numerical Weather Prediction
MLD	Mixed Layer Depth
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NAVOCEANO	Naval Oceanographic Office
NCAR	National Center for Atmospheric Research
NOAA	National Oceanic and Atmospheric Administration
NODC	National Oceanographic Data Center
NORPAX	North Pacific Experiment
NPS	Naval Postgraduate School
NRC	National Research Council
NSF	National Science Foundation
NWRC	National Weather Records Center
ONR	Office of Naval Research

SIO	Scripps Institution of Oceanography
SST	Sea Surface Temperature
STD	Salinity, Temperature, Depth
UNESCO	United Nations Education, Scientific, and Cultural Organization
USAF	United States Air Force
WHOI	Woods Hole Oceanographic Institution
WMO	World Meteorological Organization
XBT	Expendable Bathythermograph

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I. INTRODUCTION

A. DEFINITION OF STUDY

The intent of this study is to investigate "ocean hydroclimate" and the important role that it plays in the interacting geophysical system composed of the ocean and the atmosphere. Over the centuries a considerable storehouse of information about the ocean and its atmospheric interface has been collected first by mariners, then oceanographers, who described the oceans and the characteristics observed. The compilation of oceanographic data into a statistical product on a large scale was first attempted by Lt. Matthew Fontaine Maury of the U. S. Navy in the 1840's. Since that time many individuals and organizations have collected, studied, and postulated about means and variations of oceanic parameters. Various descriptive titles have been utilized over the years including: climatic oceanography, ocean climatology, hydroclime, etc.

"Hydroclimate" is proposed as a suitable title for the statistical synthesis of selected oceanographic parameters (sea-surface temperature, sea surface temperature anomalies, boundary heat exchanges, etc.) over a specified period of time at a given place or over a given area. Hydroclimate is to be distinguished from "atmospheric climate" which hereafter will be referred to as "climate". Traditionally, climate has

been defined as "the synthesis of all weather", or more rigorously for a specified area as "the statistical collective of its weather conditions during a specified interval of time (usually several decades)" as found in Huschke [1959]. The traditional usage of climate will be followed here.

B. OBJECTIVES OF THESIS

1. The first objective was to conduct a review of oceanographic, meteorological, and climatological literature pertaining to hydroclimate.

2. The second objective was to locate the available hydroclimate products in the form of published tables, charts, atlases, and studies, and unpublished materials.

3. The third objective was to identify, describe, and evaluate hydroclimatic products which are particularly useful to meteorologists. Identification criteria included title, author, publisher, and date. Items of description were: (a) region of coverage; (b) source of data; (c) contributors; (d) format of presentation; and (e) quantity of data. The subjective evaluation pertained to the overall worth of the publication in comparison with other products, and included pertinent comments on the detail of analysis, presentation, and usefulness of the product.

4. The final objective was to recommend areas of improvement and studies which should be conducted within the hydroclimatic field. These recommendations include some basic guidelines for use in development of better hydroclimatic products.

C. APPROACH TO THE PROBLEM

The first step in preparing for this thesis was a thorough literature review of oceanography as pertaining to hydroclimate up to the present time. This oceanographic literature review was supplemented by readings from meteorological and climatological books, journals, and reports. The adoption of an acceptable title for "ocean climate" along with an adequate definition became one of the first tasks to be accomplished.

The effect of the ocean on climate is an essential part of this thesis. A chapter dealing with this subject is included to bring out the historical knowledge pertaining to this subject and to explore the ideas put forth within recent studies that concern the scientific community.

The theme of this thesis focuses on the problem of identifying the location, description, and evaluation of selected hydroclimate products. Locating and identifying hydroclimate products presented no major problem. The location of the Naval Postgraduate School, the Navy's Fleet Numerical Weather Central and Environmental Prediction Research Facility, the National Marine Fisheries Service office, and the Hopkins Marine Station on the Monterey Peninsula provided an abundance of hydroclimatic products. The evaluation of available hydroclimate products required a closer selection of those most relevant for consideration, due to the abundant supply. Hydroclimate products most useful to meteorologists and most closely oriented toward climatic changes were chosen.

II. HYDROCLIMATE

A. BACKGROUND

Extensive literature reviews and discussions with knowledgeable oceanographers, meteorologists, and climatologists revealed the evident lack of an acceptable common focus or title for hydroclimate in the past. Scientists have randomly collected, studied, and published statistical information pertaining to hydroclimate over the years, part of which has been absorbed or lost in the mass of oceanographic literature, with no common denominator or title to locate this information. Hydroclimatic information that has survived and found a niche has been labeled by the various names previously mentioned, none of which has been widely accepted by the scientific community. Meteorologists, oceanographers and climatologists, especially those at the Navy's Fleet Numerical Weather Central and Environmental Prediction Research Facility located in Monterey, California, and at the major oceanographic research centers around the U.S. have labeled historical compilations of oceanic parameters within their studies and models as oceanographic climatologies due to their similarity to atmospheric climatologies in concept and format.

Within the last decade the international scientific, political and social-economical scene has produced conditions such that a concerted.

effort is now being focused upon the development of hydroclimate to aid in the investigations concerning the future of mankind. Major [Newman and Pickett, 1974] droughts, floods, unseasonably warm summers or wet winters have shaken the food production regions of the world as our global population soars higher and higher. Serious [Time, 1974] warnings have been made by UNESCO and others about food shortages occurring now and in the future at the whim of nature, due to climate fluctuations. Because almost everything we do is affected by changes in the weather, the very rise and fall of past civilizations [NAS-NRC Committee on Oceanography, 1959] has been determined in part by changes or shifts in climate. A knowledge of the world's oceans is necessary [NAS-NRC, U.S. Com. for GARP, Panel on Climate Var., 1975] to understand the major processes of climatic change over short and long-periods of time, especially since atmospheric and climatic changes observed are determined to a large, and as yet unknown, extent by what happens in the oceans.

The scientific community [NAS-NRC, Com. on Ocean., 1959] has proposed in the last few years the prediction and possibly the control of climatic changes, but this requires [NAS-NRC, Com. on Ocean., 1960] good hydroclimatic data. A few scientists [Hammond, 1974] have already ventured into the development of circulation models simulating climatic changes through the use of sea-surface temperatures and their anomalies, albedo changes, and other oceanic boundary conditions.

S. Manabe from the Geophysical Fluid Dynamics Laboratory, W. Washington from the National Center for Atmospheric Research, and Jule Charney of M.I.T. working with the model at Goddard Institute of Space Sciences are among the leaders in the development of these climatic models. Manabe et al. and Bryan et al. [1975] published results of their "Global Ocean-Atmosphere Climate Model" in which they attempted to identify the roles of ocean currents in maintaining the climate. These first models developed to understand the role of the oceans in climatic changes are just the beginning, but the accuracy of these models and efforts are limited not only by computer sizes and costs, but also by the quantity and quality of hydroclimatic data.

Since climate involves much longer-range processes [U.S. Congress. House, Committee on Science and Astronautics, 1960] than the transients of weather that may be triggered from purely atmospheric instabilities, the control of climate becomes both significant economically and more possible technologically. Long-range forecasting of climate [NAS-NRC, Com. on Ocean., 1952] depends to a large extent upon an extensive oceanic data collection [Sea Technology, 1975], a better understanding of the fluctuations of oceanic parameters over long periods of time, and better analyses of hydroclimate. Due to the events of the last few years the development of a more extensive oceanic data collection is occurring through various international research projects such as BOMEX [Delnore, 1972], EASTROPAC, NORPAX, and MODE [Berger, 1974],

which are just a part of the overall oceanwide survey program proposed in 1966 [NAS-NRC, 1967] by the National Academy of Sciences-National Research Council. These projects with their associated data have tremendously increased the quality and amount of the hydroclimatic data available for analysis in addition to aiding the scientific community in obtaining a better understanding of the dynamic interactions of the ocean and atmosphere. The basis for a vested interest in hydroclimate has now been established.

B. DEVELOPMENT OF NAME

With an interest in this subject established, a title and definition are required. The proposal of hydroclimate as the title for this subject is both the result of research for such a name and an individual effort to develop such a term from etymological roots of Greek and Latin words related to the statistical characteristics of climate and the ocean. The vast majority of the literature was devoid of any discussion of "ocean climate" and out of those professionals who would have a knowledge of "ocean climate", there was only one who had heard of a semi-established name. References to "hydroclime" [Lyman, 1958], "ocean climatology" [Selfridge, et al., 1968], climatic oceanography (a term used by Gunter R. Seckel, Oceanographer, NMFS), and other titles for this subject always required a definition of what was meant, since the terms were not commonly known or accepted. The only name

that was reported to have been used several times within literature was hydroclime. It was through discussions with T. Laevastu of the Navy's Environmental Prediction Research Facility that this discovery was made. A thorough search of literature came up with only one conflicting word of similar origins, hydroclimate.

In a presentation, "Requirements On Military Oceanography", at a conference in San Diego, Dr. John Lyman [1958] of the U. S. Navy Hydrographic Office suggested the term hydroclime for the climatic average condition of the ocean. Afterwards, T. Laevastu [1960 a, b] corresponded with Lyman concerning hydroclime and referred to the definition of this term in two publications. Hydroclime was selected by Lyman to "indicate the average hydrographical conditions, based on statistical treatment of, for example, monthly data collected over many years." Hydroclimate on the other hand was defined as the study of the influence of climate upon the water of the continents by Walter B. Langbein [1967]. Unfortunately, neither of these terms have been widely promulgated in literature since then. Etymologically, the term hydroclimate is synonymous to hydroclime and both are reasonably acceptable to describe this subject. The word hydroclimate has been adopted and redefined for this thesis as the most acceptable name for this subject.

The Greeks [Ward, 1918] originally used the word klima (from κλίνειν, to incline) to describe the imagined slope of the earth

toward the poles. Klima was commonly used following Aristotle's time with a meaning equivalent to the word zone. It was a mathematical and astronomical term, far removed from its association today with the idea of physical atmospheric climate. The famous geographer, Ptolemy, presented excellent illustrations of the original Greek meaning of the word klima in his discussion of the system of climates. He divided the earth's surface between the equator and the north pole into eleven zones or climates. These eleven climates were distinguished by the length of their longest day, each separated from the other by latitude circles. This subdivision of the earth's surface was simply an astronomical climatic table. A change of climate was noted when travelers ventured from one latitude to another. Changes of this nature gradually with time acquired the meaning of a change in atmospheric conditions as well as a change in length of day.

The word climate today has a meaning that has been altered by common usage over the centuries. Climate no longer means just a change in the length of a day or the change from one latitude to another. It has various definitions dependent on whether one reviews technical glossaries or the common Webster's dictionaries. A few definitions are shown to illustrate the diversity of meanings that climate possesses today:

1) "The prevalent or characteristic meteorological conditions of a place or region, in contrast with weather which is the state of the atmosphere at any time." [U.S. NAVOCEANO, 1966]

2) "Climate - 'The synthesis of the weather' (C. S. Durat); the long-term manifestations of weather, however they may be expressed." [Huschke, 1959]

3) "Climate is the collective state of the atmosphere at a given place or over a given area within a specified period of time." [Landsberg, 1945]

4) "Climate - The prevailing or average weather conditions of a place, as determined by the temperature and meteorological changes over a period of years." [McKechnie, et al, 1970]

5) "Climate - any prevailing conditions affecting life, activity, etc." [McKechnie, et al, 1970]

Climatology, [Ward, 1918] the study of climates, deals with the same atmospheric parameters with which meteorology is also concerned, i.e. visibility; temperature (radiation); moisture (humidity, precipitation, and cloudiness); wind (storms); pressure; evaporation; the composition, and the chemical, optical, and electrical phenomena of the atmosphere. The characteristics of these climatic elements are recorded in a standard numerical format, based on long-term, accurate, systematic, meteorological records that are corrected and compared by well-established methods. The subject of climatology is very closely related to the science of meteorology. It has been described as a "sister" science of meteorology or as an intermediate science between meteorology and geography. When the term [Ward, 1918] meteorology is

properly considered as the complete study of the atmosphere, climatology is largely descriptive.

In the broadest sense of the word, climatology [Huschke, 1959] has various other meanings and subdivisions. In addition to the presentation of climatic data (climatography), it includes the analysis of the causes of climatic differences (physical climatology), and the application of climatic data to the solving of specific design or operational problems (applied climatology). Climatology, like any other major scientific field, can also be subdivided depending on purpose or point of view: agricultural climatology; air-mass climatology, aviation climatology, bioclimatology; dynamic climatology; medical climatology; macroclimatology, mesoclimatology; microclimatology; paleoclimatology; synoptic climatology, upper-air climatology; descriptive climatology; and others.

It was evident from the study of the word climate that there was a vast difference between the original meaning and the accepted form today. The development of a word from Greek and Latin roots required not only words that are etymologically correct but words that will be acceptable today when combined together. The author's past experience in development of names for paleontological specimens aided this project. Dr. Eugene Haderlie, the biological expert of the Naval Postgraduate School's Oceanography Department, was kind enough to loan some of the required texts needed to accomplish the naming and to render helpful guidance on the general acceptance of certain terms.

A search through Dr. Haderlie's texts [Melander, 1940; and Jaeger, 1931] and other resource materials [Marchant and Charles, n. d.; Strong et al., 1970; McKechnie et al 1970; Morris, 1969; Gove, 1961] for relevant words to describe climate, seas, oceans, and statistics produced a list of possible words, prefixes, and suffixes.

Words

mare - L, a sea

pontus - L, the deep, depth, the sea

oceanus - L, the ocean, the sea which encompasses the earth

clime - L, climate

mare clausum - NL, closed sea

mare liberum - NL, free sea

mare nostrum - L, our sea

Prefixes

aelo - Gr, changeful

alima - Gr, pertaining to the sea

aqua - L, water

benth (o) - Gr, depth of the sea

clim - Gr, slope, region

clin (o) - Gr, to incline

hal (i, o) - Gr, sea

hudor - Gr, hydro, water

hydro - Gr, water

hypo - Gr, water

intr - L, inside

intus - L, within

klima - Gr, to incline, sloping surface

neo - Gr, new, recent

pelag (i, o) - Gr, the sea

physio - Gr, nature

pont (o) - Gr, sea

profund - L, deep

sol - L, sun

sphaer (i, o) - Gr, a ball, sphere

sub - L, under, below

thalass (i, o) - Gr, the sea

Suffixes

-ate - possessing (adj), one who (noun), to make (verb)

-ites - Gr, meaning to do with, of the nature of, like, belonging to

-logy - Gr, word or discourse

Many of these words and combinations of prefixes and suffixes were unusable. Some of the combinations meriting consideration were as follows:

thalassoclimate	pelagiclimate
neoceanic climate	pelagoclimate
aquaclimate	subclimate
haliclimate	pontoclimate
haloclimate	mareclimate
marclimate	hydroclimate

Each of these combined words could use either climate or clime, since the two words have identical meanings. The four finalists were thalassoclimate, haloclimate, mareclime, and hydroclimate. The first, although etymologically correct, was thought to be a difficult word to pronounce and quite lengthy. Haloclimate, on the other hand, had the problem of halo- having taken the meaning of sea salt over the years to be associated with halogen salts, such as chlorine, fluorine, iodine, bromine, and astatine. Mareclime or mareclimate presented another problem since marine climate (maritime climate) has been an accepted term for atmospheric climate over ocean regions for many years. The similarity between mareclimate and maritime climate could lead to much confusion. That left the word hydroclimate as the best etymologically correct word that could be easily adopted and accepted by the scientific community. Furthermore, this acceptance would be reasonable because hydrography, [Morris, 1969] the scientific description and analysis of the physical conditions, boundaries, flow, and related characteristics of oceans, lakes, rivers, and other surface

waters, has been a pillar of the scientific community over the centuries. The word hydroclimate is therefore adopted to help focus the attention of the scientific community on a single word for ocean characteristics under the definition: the statistical synthesis of selected oceanographic parameters (sea-surface temperature, sea-surface temperature anomalies, boundary heat exchanges, etc.) over a specified period of time at a given place or over a given area.

III. OCEANIC INFLUENCE ON ATMOSPHERIC CLIMATE

A. INTRODUCTION

The oceans play a dominant role in the determination of climate through the processes of air-sea interaction controlling the exchanges of heat, moisture, and momentum. On the real-time scale the atmosphere and oceans mutually determine these exchanges, but over the longer climatic time scales the oceans predominate. However, the oceans are just one part of a larger "climatic system" consisting of five physical components: the atmosphere; hydrosphere; cryosphere; lithosphere; and biosphere. Within the components of the planet earth's climatic system there exist basic physical properties and processes [NAS-NRC, US Com. for GARP, Panel on Climatic Var., 1975] responsible for the climate and its variations. The world's oceans, as the primary portion of the hydrosphere, play an important role in the process of climatic change, overshadowing the climatic effects of ice masses, land surfaces, or flora and fauna.

Traditionally the earth has been divided into only three components: the atmosphere, hydrosphere and lithosphere. Lithosphere, defined as the outer solid portion of the earth [Huschke, 1959] includes the mountains and ocean basins, together with the surface rock, sediments, and soil [NAS-NRC, U.S. Com. for GARP, Panel on Climatic Var., 1975]. The definition of climatic system above, however, subdivides the first

two traditional categories and creates an altogether new component to cover life on the planet earth. This subdivision is a product of the redistribution of a number of physical states of matter resulting in the development of an additional component referred to as cryosphere. Under this realignment cryosphere takes on the world's ice masses and snow deposits, including the continental ice sheets, mountain glaciers, sea ice, surface snow cover, and ice on rivers and lakes; all of which were formerly considered part of the hydrosphere. Variations within the cryosphere range from seasonal snowfall and ice formation to significant changes in volume and extent of ice fields over millions of years. These long-term variations become important when considering the global balance of the hydrologic cycle and the close tie-in with the changing sea level. The definition of atmosphere incorporates water vapor and cloud droplets leaving the hydrosphere to consist of the liquid phase of water on the earth's surface, including rivers, lakes, oceans, groundwater, and that water tied up within magmatic bodies and mineral structures of the lithosphere. The biosphere, only recently appreciated in a climatic sense, consists of the flora and fauna of the earth found in the air, sea, and on the land, including man himself. These biological elements are sensitive to and influence climatic changes.

The influence of the oceans on the climate has long been recognized. A visualization of this influence first requires a look at the oceans position within the hydrologic cycle and the relationship of the oceans

as found within the heat budget of the earth-atmosphere system. The relative importance of the oceans in the hydrologic cycle and the earth's heat budget serves to emphasize the role the oceans have in climatic changes.

Some features of the ocean that contribute to regional climate are sea-surface temperature distributions in time and space, ocean current systems, and upwelling regimes. The diurnal and seasonal temperature differences between ocean and land surfaces causes another contribution to climate through sea breezes and monsoon circulation systems. These features determine the type of maritime climate found around the world whether on the open ocean or along the coastal margins of the continents. Depending on the exact location and time of year these features produce characteristic atmospheric phenomena that become part of the climate for that region. Local air temperature regimes, some types of fog, local winds, and characteristic cloud patterns are definitely the result of these oceanic features. Physically, these features are a part of the atmospheric interaction with the oceans, but a description of their effect is necessary in understanding the longer climatic scale result.

The climatic effect of the oceans is further described in studies on the sea-surface temperature anomalies, within the natural records of the earth system, and through man's effort to numerically index this effect. Even though the oceans are characterized by changes on a time scale about 100 times as long as that of the atmosphere, studies

by Namias [1975] have shown that sea-surface temperature anomalies play an important role in climate over short periods of time on the order of months and seasons. A natural record of the ocean's past over the years lies within the ocean sediments depicting the oceans as a stabilizing influence on climate [Hammond, 1974]. Oceanicity is the title given to man's efforts to describe, by means of numerical indexes, the influence of the ocean on a point of the earth's surface.

B. HYDROLOGIC CYCLE

Man's awareness of the hydrologic cycle must have had its beginnings prior to recorded history. Biblical writings [New American Standard Bible, 1971] recorded Solomon's observation that "All rivers flow into the sea, yet the sea is not full; to the place where the rivers flow, there they flow again." Today scholars [Hammond, 1975] realize that the earth is unique in its displacement away from the sun, such that all three states of water exist; whereas there is vapor only on Venus, and ice only on Mars due to temperature effect from solar radiation. The earth's hydrologic cycle is depicted as the transfer of water through three distinct phases: solid (ice), liquid (water), and gas (water vapor). The oceans within the hydrologic cycle are described by Davis [1966] as "the immense reservoirs from which all water originates and to which all water returns."

The hydrologic cycle balances different reservoirs of water on the earth in a complex system through various routes as illustrated in Figure 1. Nace [1967] points out that if we assume the amount of water in existence to remain constant during timespans of hundreds to thousands of years, then short-term variations in the volume of the ocean water arrive solely from evaporation, precipitation, and flow of water from the continents. The long-term variations are the result of waxing and waning of icecaps and glaciers. The variation in ocean volume amount is seasonal and on the order of about 0.5×10^{19} cm^3. Averages over all oceanic areas show that evaporation exceeds precipitation by 10 cm/year [McLellan, 1965]. This interaction between the ocean and atmosphere through the processes of evaporation and precipitation is shown in Table 1 for the entire ocean in five degree latitude zones. Since the ocean volume doesn't incur any permanent depletion, then this volume of water must be precipitated over land, to be eventually returned to the ocean reservoirs by surface runoff, rivers, and groundwater flow. Other factors entering into the hydrologic cycle are sublimation of solid ice directly to water vapor, transpiration of water from flora to water vapor, condensation of water vapor into liquid cloud droplets, infiltration of water into the soil and bedrock, and groundwater movement. Two often-neglected parts of the hydrologic cycle, discussed by Davis [1966], are the long-term subtraction of water by marine marine sediments and the periodic addition of small amounts of magmatic water through volcanic activity.

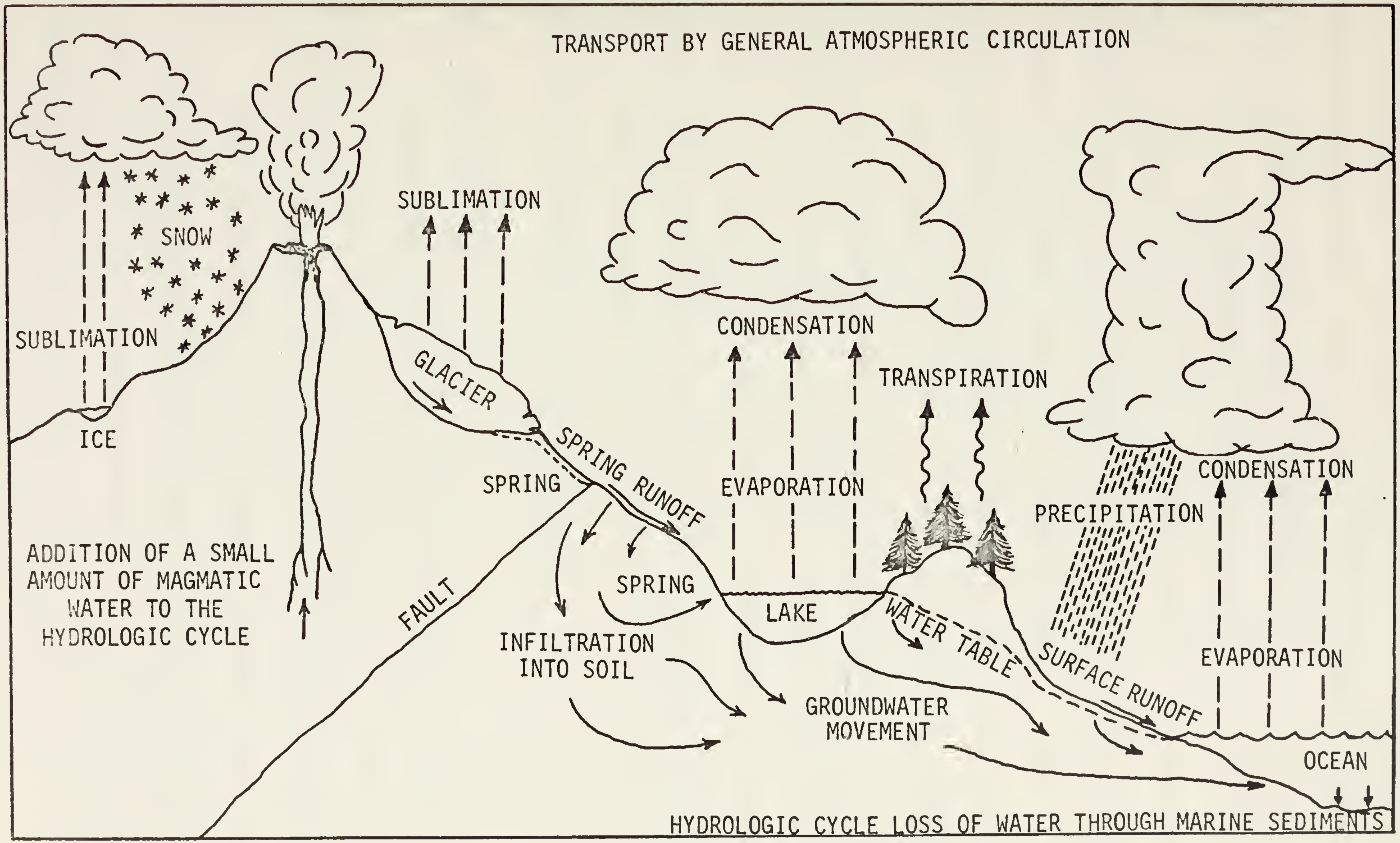

Figure 1. Hydrologic cycle, the transfer of water between the hydrosphere, atmosphere, and cryosphere (modified from Duxbury, 1971, and from Davis, 1966)

The importance of the oceans within the hydrologic cycle and the overall effect that this volume of water has on atmospheric climate becomes evident when one looks at the distribution of the earth's water by volume, shown in Table 2. The vast majority of the earth's liquid water is found within the ocean reservoir, in fact, over 97% [Neuberger and Cahir, 1969]. The distribution of this reservoir shown in Figure 2 covering 70.8 percent of the earth's surface makes it impossible to ignore the influence the oceans have upon climate. The ocean's volume, percent coverage of the earth's surface, and the specific distribution of the oceans and continents combine themselves into a very distinctive influence upon the long-term atmsopheric climate. The effects of the latitudinal and longitudinal distribution of the oceans and continents will be described in a later section. This distribution directly affects the transfer of heat, moisture, and momentum by the oceans and atmosphere in the joint circulation system.

C. HEAT BUDGET

A recent National Academy of Sciences-National Research Council, Panel on Climatic Variation [1975] has emphasized that the oceans not only are the primary source of water in the atmosphere and on the land, as shown in the hydrologic cycle, but they constitute a vast reservoir of thermal energy that influences climate. Scientists [NAS-NRC, Com. on Ocean., 1952] have long observed that solar energy provides the bulk of the heat stored in the oceans through shortwave radiation

Zone in degrees	Precipitation cm/year	Evaporation cm/year	$E-P$ cm/year
70–65 N	34	12	−22
65–60 N	65	20	−45
60–55 N	77	34	−43
55–50 N	105	55	−50†
50–45 N	112*	66	−46
45–50 N	102	84	−18
40–35 N	86	108	22
35–30 N	74	125	51
30–25 N	63	132	69
25–20 N	57†	137*	80*
20–15 N	70	135	65
15–10 N	103	132	29
10– 5 N	187*	126	−61†
5– 0 N	146	113†	−33
70– 0 N	101.0	110.6	9.6
0– 5 S	105†	125	20
5–10 S	109*	137	28
10–15 S	94	139*	45
15–20 S	76	137	61
20–25 S	68	133	65*
25–30 S	65†	123	58
30–35 S	70	110	40
35–40 S	90	96	6
40–45 S	110	78	−32
45–50 S	117*	56	−61
50–55 S	109	39	−70
55–60 S	84	12†	−72†
0–60 S	91.45	102.1	10.7

* Maxima
† Minima

Table 1. Mean values of precipitation, evaporation, and the difference between them (E-P) for the entire ocean, including adjacent seas (McLellan, 1965, according to Wüst, 1954).

Table 2. Distribution of the earth's water by volume, km^3 (Original table from Duxbury, 1971, altered by information from Schell, 1967)

Water vapor and condensate in the atmosphere	15.3×10^3
Rivers and lakes	510.0×10^3
Groundwater	$5,100.0 \times 10^3$
Glacial, sea, and land ice	$22,995.0 \times 10^3$
Oceanic water	$1,369,305.0 \times 10^3$

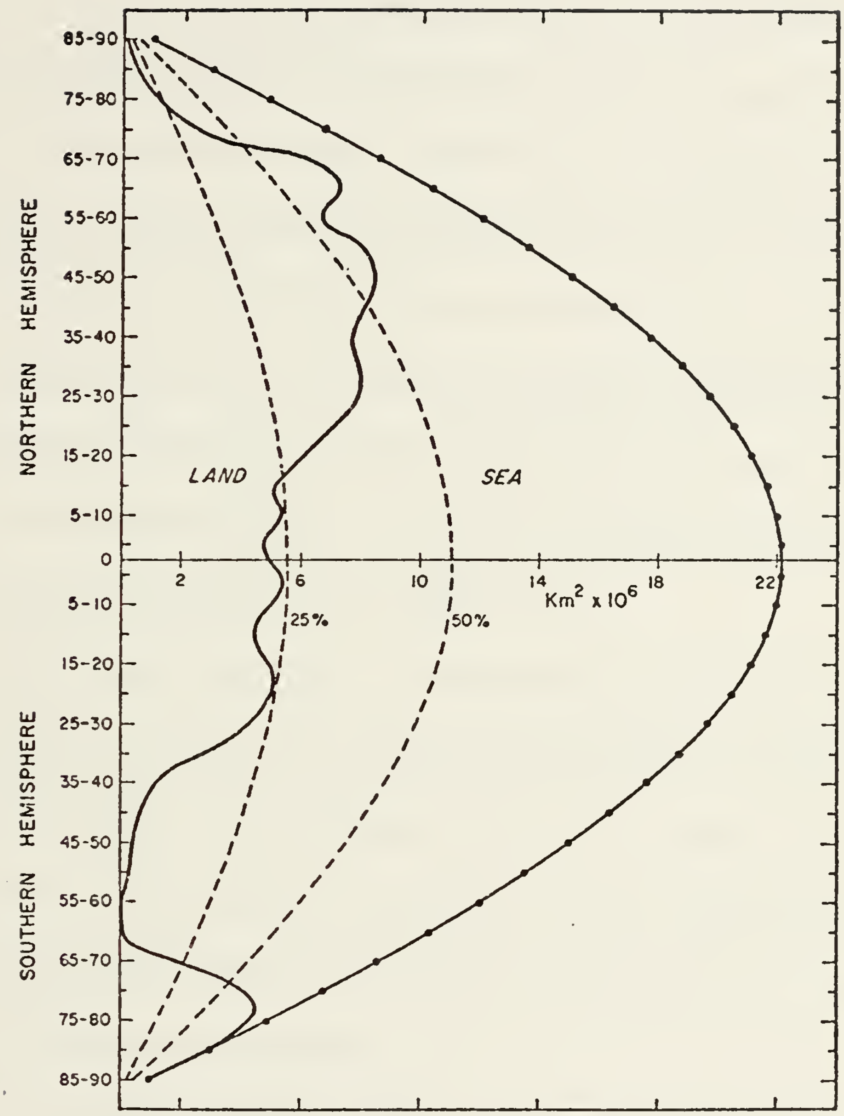

Figure 2. Distribution of water and land in five-degree zones (McLellan, 1965).

penetrating the transparent waters to several hundred meters [McLellan, 1965]. In May 1969, during the Barbados oceanographic and meteorological experiment (BOMEX), airborne measurements of the total heat flux from the sea revealed that a total of 1021 calories of solar energy is stored in the top 30 meters of the world's oceans during the daylight hours of an average day [McAlister, McLeish, and Corduan, 1971]. This represents the total energy available to the marine atmosphere from the sea surface, thus having a direct bearing on the resultant climate. It is left up to the heat budget of the earth system to balance the incoming short-wave solar radiation absorbed by the atmosphere, the oceans, and the land against the long-wave radiation into space from the entire system [Sverdrup, et al., 1942a].

Sverdrup's [1942a] description of the general earth heat budget points out that there is more heat received in the lower latitudes than is lost by back radiation and reflection and just the reverse in the higher latitudes. These statements are quantified in Table 3 for the heat budget of the earth as a whole with the heat transfer from the lower to higher latitudes at 10° latitude increments.

There is an annual net gain of heat in the equatorial regions as compared to a net loss in the polar regions, shown in the table, resulting in a mean annual temperature in different latitudes on the earth showing very little change from year to year. This small change is due to the oceans and atmosphere jointly transporting heat from lower to

higher latitudes to balance the heat received and heat lost by radiation. This transport is accomplished through ocean currents and atmospheric circulation [Sverdrup et al., 1942a]. The distribution of heat received by the earth and the methods of heat transport is of the greatest concern in climatic changes. The role of ocean currents in this transport becomes quite apparent as evidence will be presented later, but first the heat budget of the ocean provides an entirely different picture that needs some explanation.

The heat budget of the ocean involves more than the balance of radiation. The complete heat balance equation for any specific region of the ocean in a temporal sense according to Sverdrup [1942a] is written:

$$Q_s - Q_b - Q_e - Q_n - Q_r + Q_\theta = 0$$

where the incoming solar radiation Q_s is of primary importance. The balance of these terms directly affects the overlying atmospheric motions and the resultant climatic regimes. In specific regions, local heat variations are taken into account. When heat is brought into or out of a region by ocean currents or by processes of mixing the Q_r term must be evaluated. Likewise, during specified intervals of time the net amount of heat used locally for changing the temperature of the sea water is represented by Q_θ. The heat budget of the oceans as a whole is a balance of the back radiation from the ocean, Q_b, the conduction of sensible heat to the atmosphere, Q_h, and evaporation from the sea surface, Q_e, against the incoming shortwave radiation.

In this discussion, the processes of heat transfer from the oceans that affect climate are of major concern, yet the processes that heat the ocean waters are of interest for comparison. The primary source of heat radiation comes from the sun and the sky, yet there are several minor sources that are often ignored due to the large magnitude of difference between solar energy and other sources. These minor sources of energy with some representative values include: the convection of geothermal heat through the ocean bottom from the interior of the earth, estimated at 50-80 langleys per year by Laevastu [1960b]; the transformation of kinetic energy from the dissipation of wind and tidal energy into heat with the wind energy estimated by Sverdrup [1942b] to be about one ten-thousandth of the energy from incoming solar radiation and tidal energy varying with locality on the order of 500-1000 langleys/year [Lane, 1965]; and the heat released by chemical processes (mainly photosynthesis) within the ocean waters, estimated to be 235 langleys/year by Laevastu [1960b]. Three other sources of heat without estimated values, but of negligible value in the heat budget, are: the convection of sensible heat from the atmosphere, the release of latent heat by condensation of water on the ocean surface, and the heat transferred by freshwater runoff.

The oceans influence the climate by the amount and distribution of heat that is pumped into the atmospheric system from the heat reservoir stored in the ocean below. As mentioned, this is accomplished by back

radiation from the ocean surface, convection of sensible heat to the atmosphere, and evaporation from the ocean surface. The ocean surface emits long-wave heat radiation to the atmosphere at a rate that approximates that from a black body, due to the relative closeness of the ocean's emissivity to unity. The back radiation Q_b formula for a black body is governed by the Stefan-Boltzmann law

$$Q_b = \sigma T^4$$

where σ is the Stefan-Boltzmann constant with a value of 5.735×10^{-5} ergs/sec cm^2 degree^4, and T is the temperature in degrees Kelvin [McLellan, 1965]. The ocean surface in addition to emitting long-wave radiation, is also a receiver of long-wave radiation [Sverdrup et al., 1942a]. Water vapor and other absorptive materials in the atmosphere absorb solar shortwave radiation, and re-radiate it in the form of long-waves, part of which reach the ocean surface. The bulk of this incoming long-wave radiation is absorbed in the top few millimeters of the water surface due to high absorption coefficients. The effective back radiation from the ocean surface that affects climate then is the difference between the outgoing long-wave heat radiation of the ocean surface due to its temperature and the incoming longwave radiation from the atmosphere. Thus, this effective back radiation depends on the sea surface temperature and the water vapor content of the atmosphere.

Angstrom published some classical empirical observations of effective back radiation in 1920. This effective back radiation is shown in Figure 3 [Sverdrup et al., 1942a] as a function of sea-surface temperature and of surface relative humidities between 100 and 70 percent. The sparse data in this figure induce some error in the evaluation, but it is interesting that the effective back radiation decreases slowly with increasing sea-surface temperature and that at a given temperature the effective back radiation decreases with rising humidity. Since the diurnal and annual variations of sea-surface temperatures and of the relative humidity over the oceans when compared to temperatures and humidities in the atmosphere over land are relatively small, the effective back radiation under a clear sky becomes nearly independent of the time of the day or the season of the year. On the other hand, at a given surface location solar radiation is subjected to large diurnal and seasonal variations. Cloudiness significantly cuts down the effective back radiation from the ocean surface. In this way the diurnal or other temporal variations in cloudiness directly affect the amount and occurrence of effective back radiation. The diurnal variation of cloudiness over the oceans is very small on the average and can be sometimes neglected. The annual variation of cloudiness, on the other hand, is considerable and can play a significant role. A simple empirical relation [Sverdrup et al., 1942a] between effective back radiation is written as

Table 3. Heat budget of the earth as a whole and heat transport from lower to higher latitudes (Sverdrup, Johnson, Fleming, 1942a).

Latitude (°)	Heat received (g cal/cm²/min)	Heat lost (g cal/cm²/min)	Surplus or deficit (g cal/cm²/min)	Heat transport across parallels of latitude (10^{16} g cal/min)	Heat transport across every centimeter of parallels of latitude (10^{7} g cal/cm/min)
0..........	0.339	0.300	0.039	0.00	0.00
10..........	0.334	0.299	0.035	1.59	0.40
20..........	0.320	0.294	0.026	2.94	0.78
30..........	0.297	0.283	0.014	3.58	1.07
40..........	0.267	0.272	−0.005	3.96	1.30
50..........	0.232	0.258	−0.026	3.34	1.32
60..........	0.193	0.245	−0.052	2.40	1.20
70..........	0.160	0.231	−0.071	1.20	0.88
80..........	0.144	0.220	−0.076	0.32	0.46
90..........	0.140	0.220	−0.080	0.00	0.00

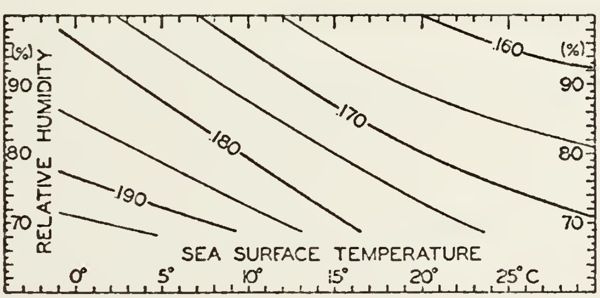

Figure 3. Effective back radiation in gm cal/cm^2/min from the sea surface to a clear sky. Represented as a function of sea-surface temperature and relative humidity of the air at a height of a few meters (Sverdrup, Johnson, Fleming, 1942a).

$$Q = Q_o (1 - 0.083C)$$

where Q_o is the clear sky back radiation and C is the cloudiness on a scale from 1 to 10. This equation only applies to average conditions though, since the attenuation of the effective back radiation due to clouds depends upon the thickness of the clouds and their altitude.

The total incoming radiation, including solar and diffuse radiation, is both reflected by and absorbed at the ocean surface. The portion of the total incoming radiation lost by reflection from the ocean surface is called the albedo. Lane [1965] points out that the albedo varies with the time of day, time of year, latitude, state of sea surface (rough or smooth), and the turbidity of the atmosphere. It is therefore evident that the albedo is dependent upon atmospheric and oceanic conditions at any particular place and time. Lane [1965] estimates the total possible range of daily mean values of reflection in mid-latitudes over a year to vary between 4 and 20 percent. Traditionally, reflection lost from the ocean surface has been related to the altitude of the sun. Table 4 [Sverdrup, 1942a] contains approximate percentage values of solar and diffuse sky radiation reflected from a smooth water surface on a clear day at different altitudes of the sun. On a smooth water surface the

Table 4. Percentage of total incoming radiation from sun and sky which on a clear day is reflected from a horizontal water surface at different altitudes of the sun (Sverdrup, Johnson, Fleming, 1942a).

Altitude of the sun (^{o})	5	10	20	30	40	50	60	70	80	90
Percentage reflected	40	25	12	6	4	3	3	3	3	3

Table 5. Average amounts of radiation from sun and sky, expressed in gram calories per square centimeter per minute, which every month reaches the sea surface in the stated localities (Sverdrup, Johnson, Fleming, 1942a, after Kimball, 1928).

Locality		Month											
Latitude	Longitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
60°N...........	7°E- 56°W	.002	.053	.125	.207	.272	.292	.267	.212	.147	.074	.006	0
60 N...........	135 -170 W	.005	.078	.155	.208	.269	.260	.242	.185	.127	.077	.015	0
52 N...........	10 W	.048	.089	.148	.219	.258	.267	.251	.211	.160	.104	.062	.041
52 N...........	129 W	.053	.091	.135	.185	.246	.250	.230	.214	.158	.097	.058	.039
42 N...........	66 - 70 W	.094	.138	.212	.272	.306	.329	.302	.267	.230	.174	.115	.086
42 N...........	124 W	.100	.151	.210	.286	.331	.360	.320	.274	.231	.174	.113	.092
30 N...........	65 - 77 W	.146	.165	.238	.285	.317	.310	.301	.282	.239	.188	.169	.142
30 N...........	128 -130 E	.141	.153	.199	.241	.258	.238	.256	.260	.219	.178	.153	.135
10 N...........	61 - 69 W	.254	.276	.299	.305	.272	.276	.285	.292	.287	.269	.248	.239
10 N...........	116 E- 80 W	.226	.257	.292	.278	.255	.239	.240	.242	.247	.237	.224	.219
0.............	7 - 12 E	.239	.248	.244	.230	.210	.196	.188	.194	.220	.240	.239	.235
0.............	48 W & 170 E	.261	.265	.282	.297	.309	.300	.300	.340	.366	.362	.339	.278
10 S...........	14 E; 36- 38 W	.329	.328	.301	.254	.219	.206	.232	.278	.312	.324	.317	.320
10 S...........	72 -171 E	.290	.308	.315	.289	.266	.253	.269	.306	.332	.313	.301	.303
30 S...........	17 and 116 E	.452	.406	.340	.254	.186	.148	.166	.214	.274	.362	.401	.430
30 S...........	110 W	.380	.330	.260	.209	.162	.130	.145	.176	.237	.321	.340	.390
42 S...........	73 W; 147 E	.343	.297	.223	.154	.101	.085	.092	.135	.187	.261	.310	.318
52 S...........	58 W	.289	.237	.167	.112	.062	.039	.049	.097	.150	.222	.273	.302
60 S...........	45 W	.213	.171	.105	.056	.011	0	.003	.054	.111	.156	.204	.221

lost radiation on a clear day varies from 3 to 40 percent, but the picture changes with the development of wave conditions or presence of cloud cover. Sea surface waves cause the reflection loss to be somewhat increased with a low altitude sun, especially in high latitudes [Neumann and Pierson, 1966]. Powell and Clarke [1936] observed that on overcast days when all radiation reaching the surface is diffuse the reflection loss is limited to about 8 percent. The larger portion of the incoming radiation absorbed in the surface layer of water is distributed by mixing to form an upper layer of warmed water varying up to several hundred meters in thickness. This energy is stored in the heat reservoir of the ocean to be released to the atmosphere during periods when the atmosphere is colder than the ocean surface. In this way the oceans act as a thermostatic control on climate.

The transfer of sensible heat from the oceans affecting the climate is by conduction of heat into the overlying atmosphere when the ocean surface is warmer than the air above. The air immediately above the sea surface is heated sufficiently to induce turbulence and create instability [Sverdrup et al., 1942a]. Intense heating from below under certain conditions leads to violent thunderstorms. The amount of heat transported in unit time by conduction from the sea surface through a unit area is

$$Q_h = - C_p A \left(\frac{\partial \theta}{\partial z} + \gamma \right)$$

where C_p is the specific heat of air, A is the eddy conductivity,

is the observed atmospheric lapse rate (positive when the temperature decreases with height), and γ is the adiabatic lapse rate. The air lapse rate $\partial\theta/\partial z$ dominates the relationship near the air-sea interface overshadowing the effect of the adiabatic lapse rate. Due to the turbulence of heat transfer across the air-sea interface caused by conduction which is usually upwards, the term $C_p A$ applies rather than the molecular coefficient of heat conductivity.

In all latitudes the ice-free oceans receive a surplus of radiation as shown in Table 5. Thus, although there are exceptions to the rule, sea-surface temperatures, on the average, are higher than the air temperatures above and therefore the ocean transfers sensible heat by conduction to the atmosphere at all latitudes. Yet conduction accounts for only about 10% of the heat surplus transferred to the atmosphere. The larger part of the heat stored in the oceans is transferred by evaporation of water vapor into the overlying air [Sverdrup et al., 1942a]. This transfers latent heat into the air column.

The mechanics of evaporation are found in most meteorological or oceanographical texts. The importance of evaporation in its effect on climate will be the concern here. There are two general cases to be considered that depend on the temperature relationship between the ocean surface and the overlying air column. Sverdrup et al., [1942a] points out that vapor pressure over salt water is 98% of that over fresh water, thus when the water surface is sufficiently warmer than the air,

the vapor pressure at the ocean surface stays greater than that in the air. This allows evaporation to occur. Evaporation is greatly aided by the unstable turbulent conditions created by the upward transfer of sensible heat. The greatest evaporation occurs when cold dry air masses flow over warm water. When the air is much colder than the ocean surface, water vapor saturates the air to form steam fog. If under these conditions the atmospheric pressure gradient is strong, then the resultant winds carry the moisture upward in streaks or columns called "sea smoke". This is primarily a coastal phenomenon as the large temperature differences rapidly disappear over the open oceans due to ocean modification of the air temperature above.

D. HYDROSPHERIC, LITHOSPHERIC, AND ATMOSPHERIC INTERACTIONS

The configuration of continents and oceans exercises a profound influence upon the atmospheric circulation and the resultant climate regime distribution [Neumann and Pierson, 1960]. A comparison of the percentages of water and land distribution over the earth's surface as shown in Figure 2 illustrates the vast difference between the northern and southern hemispheres. The distribution is asymmetrical in that the northern hemisphere represents a "land hemisphere" and the southern hemisphere, a "water hemisphere". The influence of the oceans becomes evident when it is known that even in the land hemisphere 53% of the area is covered by water. Differences of weather and climate in the southern hemisphere from that in the northern hemisphere can be attributed to the fact that

90% of the southern hemisphere is water [Neumann and Pierson, 1966].

The effect of the ocean and continent configuration on the air temperature distribution is well indicated on world wide sea level isotherm diagrams, especially in the northern hemisphere where the largest contrasts between land and ocean environments occur. Figures 4 and 5 depict the January and July mean isotherms in degrees Fahrenheit at sea level. Generally the summer sea level isotherms exhibit a trough of cool air over the oceans extending toward the equator, whereas over the continents a ridge of warm air extends toward the poles. Cold equatorward flowing ocean currents causing lower air temperatures are clearly reflected in the summer isotherms along the western coastlines of the major continents. In the winter the isotherm orientation is altered, such that the sea level isotherms over the oceans rise toward the polar regions, whereas over continents the isotherms dip equatorward. The effect of warm ocean currents are now quite observeable in the winter isotherms stretching toward the polar regions, especially in the eastern portions of the northern hemisphere oceanic basins.

The atmosphere and ocean circulation patterns as influenced by the distribution of continents and oceans produce the resultant climate regimes. The interaction of the atmosphere and the ocean is complex and has been difficult to describe. The ocean circulation is driven by the atmospheric winds above and by density differences within, while the

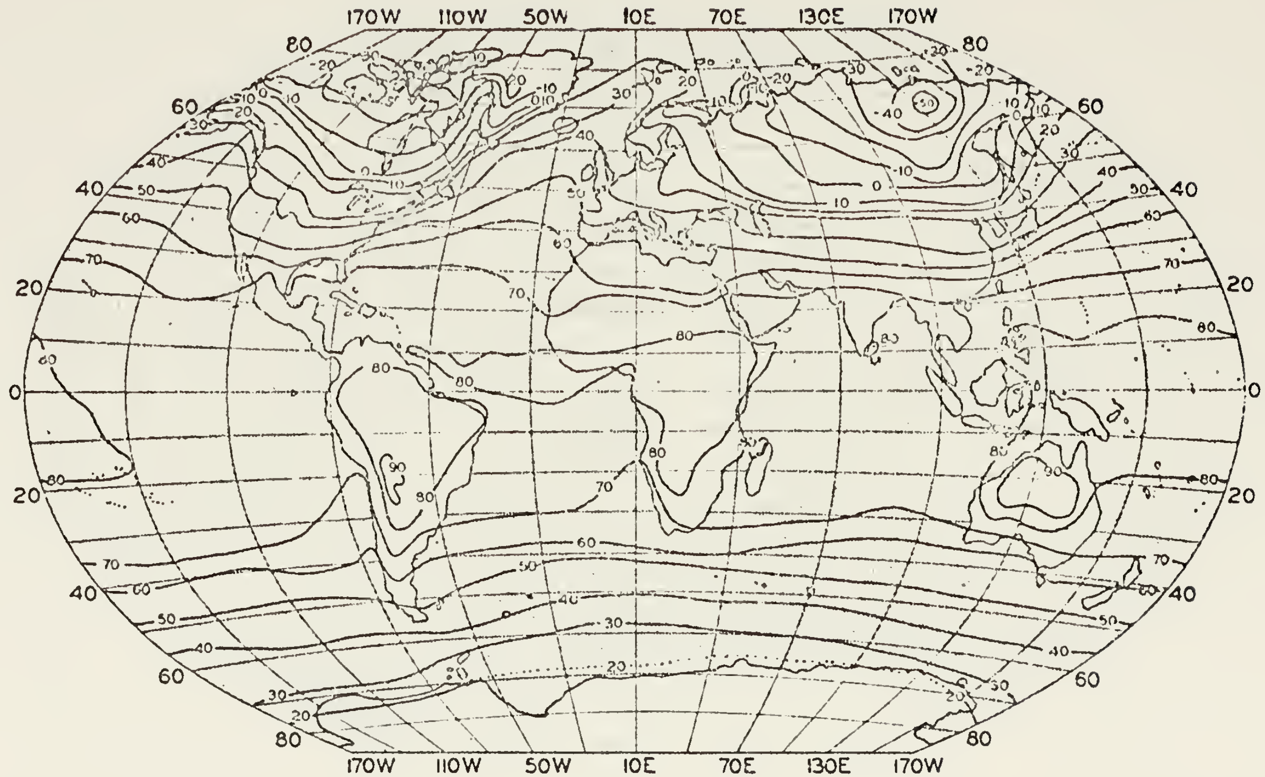

Figure 4. Mean air isotherms (^{o}F) at sea level during January (Landsberg, 1945)

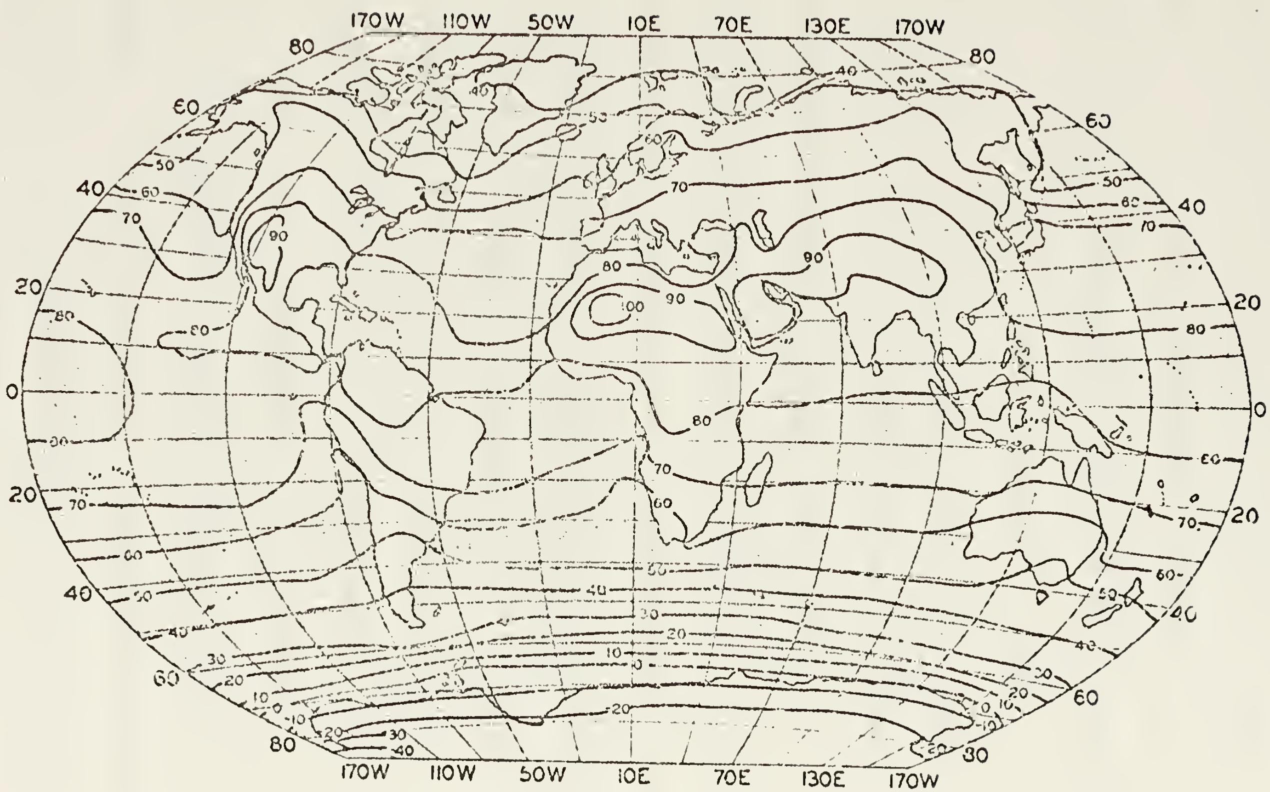

Figure 5. Mean air isotherms (^{O}F) at sea level during July (Landsberg, 1945).

atmospheric heat engine above is driven primarily by the thermal reservoir of the oceans.

The interaction of the ocean with the general circulation of the atmosphere influences the development of regional climate around the earth. The atmosphere and ocean together constitute a complex geophysical system that, traditionally, scientists have retained as two distinct fields of study [U.S. Dept of Commerce-NOAA, 1972]. Only recently have the techniques and instrumentation become available to investigate more thoroughly the air-sea interactions that bind the two fluids. The long-term behavior of either the atmosphere or the ocean in the development of climate cannot be understood or predicted without reference to the other [U.S. Dept. of Commerce-NOAA, 1972].

Several distinctive oceanic-atmospheric interactions directly influence the regional climates of the world. To begin with, the primary oceanic features that aid in the transfer of heat, moisture, and momentum into the atmosphere, besides those processes mentioned in the hydrologic cycle and heat budget, are the ocean current systems and their distribution. A second, but more regional, climatic influence of major concern, is oceanic upwelling. Then there are the diurnal and seasonal superpositions of air currents upon the general circulation of the atmosphere caused in part by thermal contrasts between the continents and oceans. Diurnal sea and land breezes are active thermal-pressure solenoidal circulation systems positioned over coastal regions, which act as boundaries

separating the pure oceanic and continental climates. An infinitely more spectacular scaled-up model of this same thermal-pressure circulation is the monsoon circulation, but on a seasonal cycle rather than diurnal. Together with the current systems and upwelling regimes these thermal circulations created by the interaction of the ocean and atmosphere imprint distinctive climate patterns upon the various regions of the earth.

1. <u>Sea-Surface Temperature Distributions</u>

The distribution of sea-surface temperatures is primarily a function of the latitude, the season, and the character of the ocean currents. Year round, the latitude effect generally dominates, as evidenced by the gradual decrease of temperature toward higher latitudes. In some areas of the world and in certain seasons these general rules break down due to the effects of ocean currents in altering the orientation of the sea-surface isotherms. The influence of the oceanic temperature changes are quite widespread though. This is partly due to the oceans covering 70.8% of the earth's surface, but is also due to the transport of water temperature character far from the region of origin [Neumann and Pierson, 1966] by ocean currents. The seasonal values of sea-surface temperatures shown in Figures 6 and 7 illustrate the points just discussed.

The sea-surface temperature has the effect of dampening and distorting the normal temperature variations of air masses overlying

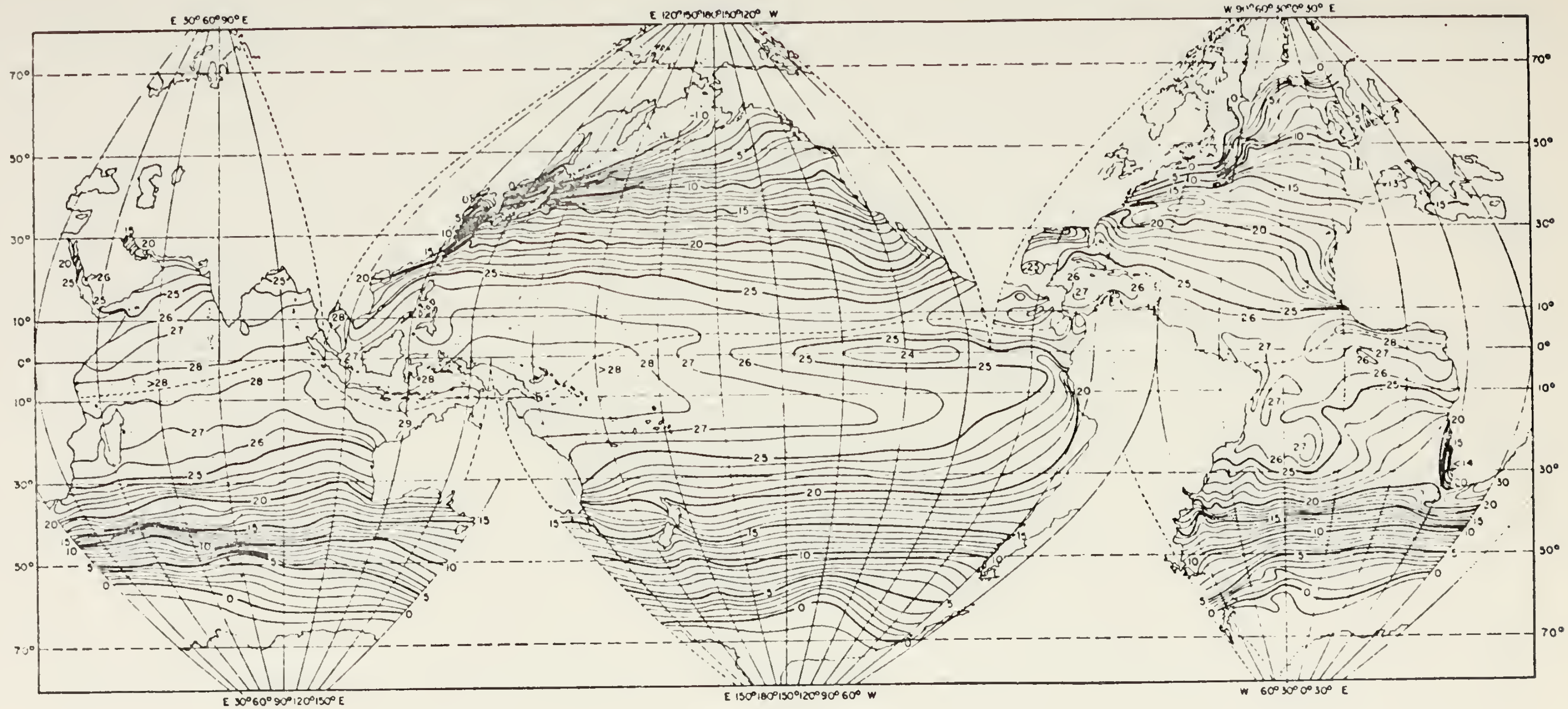

Figure 6. Sea-surface temperature (°C) of the world oceans for February (McLellan, 1965).

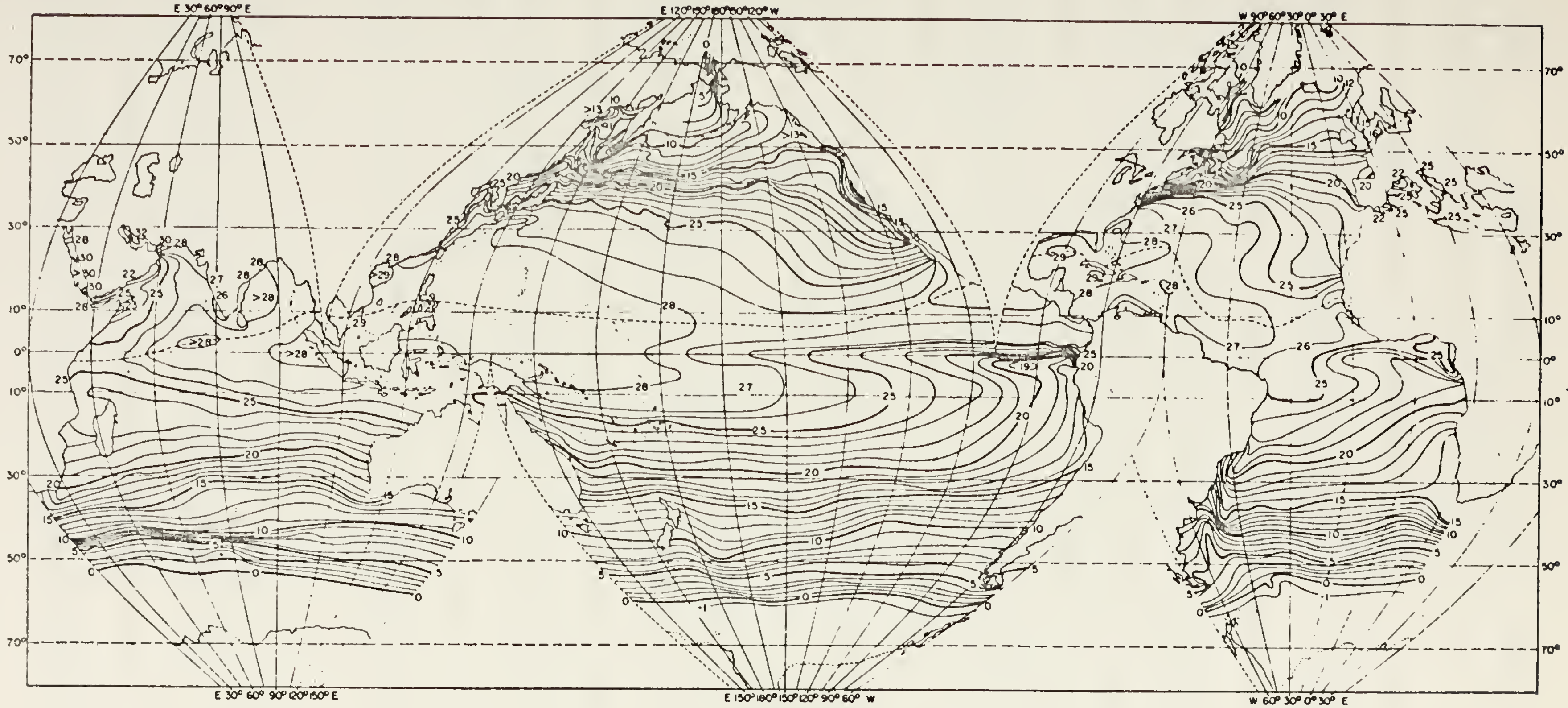

Figure 7. Sea-surface temperature (^{o}C) of the world oceans for August (McLellan, 1965).

oceanic regions. The daily amplitude and annual range of air temperature varies considerably less over the oceans than over land. The diurnal fluctuation of near surface air temperature over the oceans as described by Landsberg [1945] is generally on the order of 2° to 3°F. Moving inland, the coastal regions, acting as a buffer between purely oceanic and continental regions, experience mean diurnal ranges of 8° to 12°F. Inland areas, on the other hand, have mean diurnal ranges of air temperature from 12° up to 40°F. in certain extremes. A good example of coastal and continental mean diurnal temperature ranges during January in the United States is shown in Figure 8. In addition to the dampening effect of the ocean surface temperatures, there is over the ocean an air temperature lag of extremes behind the occurrence of maximum and minimum radiation intensity greater than that which occurs over land. The lag of temperature extremes is normally about one month longer over the oceans than over land due to the heat storage capacity within the oceans and the slower release of heat by the oceans as compared to land. The oceans and coastal areas generally experience their warmest month in August and the coldest in February due to this influence by the oceans.

The modification of air masses by the oceans is another factor discussed by Landsberg [1945] in ocean induced climate. The ocean is effective in reducing the interdiurnal temperature variations normally caused by alternation of air masses. Air masses flowing from land

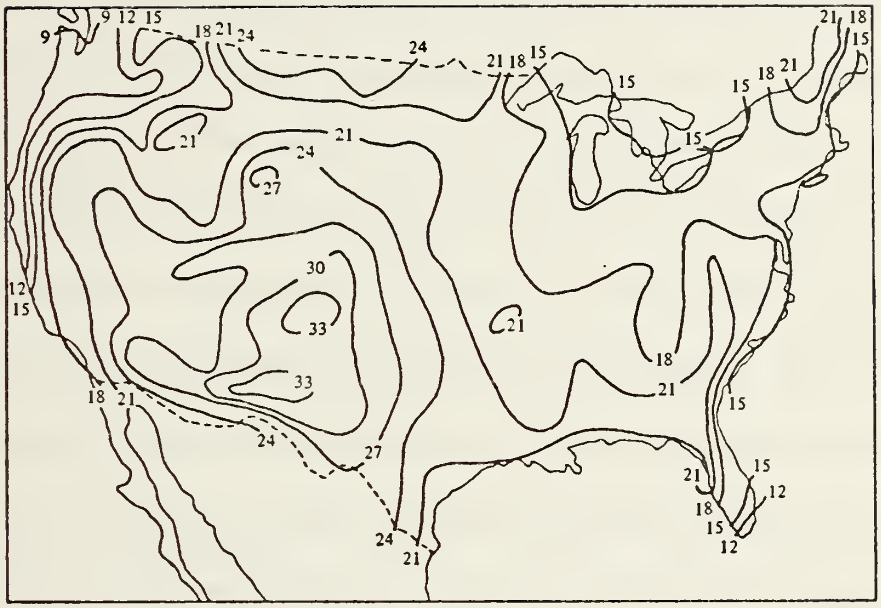

Figure 8. Mean diurnal air temperature range in January ($^{\circ}F$) at land surface (Miller and Thompson, 1970).

out over ocean regions rapidly lose their original character near the air-sea interface because of the influence of the sea-surface temperature. The characteristic large interdiurnal temperature variations derived over the continents are dampened out.

2. Ocean Currents

Ocean currents are one of the relatively permanent factors [Huschke, 1959] which govern the general natural climate over portions of the earth's surface. Haurwitz and Austin [1944] went so far as to say that next to insolation, the ocean currents are the principal factors controlling the water temperature of a region and the water temperature as mentioned has a direct effect on the resultant climate. The climatologist Trewartha [1937] was not the first to label ocean currents as a climatic control, but he was able to expound upon their importance to climate. To most of mankind the best evidence of climatic control lies along coastal regions where the ocean currents flow affecting daily activities. The temperature of the ocean water present in these currents alters the lower boundary layer of the atmosphere, especially the temperature and pressure patterns along the coastal regions. The presence of latitudinally warmer or cooler winters, more or less evaporation, fog and low stratus, and coastal steppes and deserts are the most noticeable climatic products of the interaction of the ocean currents with the atmosphere.

When examining the ocean currents and the influence that they exert upon climate it is necessary to remind ourselves of the total environmental picture. Stommel [1972] has pointed out that warm, cool, or cold ocean currents relative to the temperatures of ocean waters on either side or of the coastal margins are just part of a larger dynamic circulation system driven by density and thermal differences within the ocean. These differences are created by the distribution of solar radiation and influenced by the rotation of the earth about its axis. As the ocean surface currents flow rhythmically around the ocean basins their intensity, volume of transport, and climatic effect are determined by the changing character of the major oceanic gyres. Solar radiation fluctuations which deepen or raise the thermocline within these gyres produce changes in the character of the ocean currents on their boundaries. These fluctuations are the ultimate source of the climatic changes experienced.

Ocean currents in their interaction with the general circulation of the atmosphere can influence the routes of cyclonic storms and the general climatic character of coastal regions along which they flow. Trewartha [1937] has discussed this indirect climatic effect of ocean currents. Their influence upon the climate occurs on both windward and leeward coasts. When relatively high regional air temperatures and associated low pressures due to air expansion are produced over warm currents, observations have shown that cyclonic systems are influenced toward a more equatorial route. A classic case illustrating this interaction

occurs along the principal northern hemisphere storm track crossing the North American continent into the North Atlantic. When the Gulf Stream temperatures off the south Atlantic Coast of the United States are warmer than normal, air pressures are consequently lowered. This situation allows cyclonic storms to migrate into more southerly routes along the eastern seaboard, producing abnormally cold and snowy winters. On the other hand, the situation of lower temperatures than normal in the Gulf Stream leads to a lesser decrease in the density of overlying air causing more subsidence and higher air pressures over the coastal areas. This results in a shift of the storm tracks farther to the north and a milder, less severe winter for the eastern seaboard area.

In most regions the climatic influence of the oceanic interaction with the atmosphere is directly affected by the wind direction over the ocean currents according to Trewartha [1937]. For an ocean current to have a direct and marked effect upon the climate of a coastal area the associated wind system must be predominantly onshore. The westerly wind belt in the northern hemisphere provides a good illustration. Westerly winds fetching across the North Atlantic and Pacific are modified by the high temperatures of the North Atlantic Drift and the North Pacific Current respectively. The coupling of these westerly winds with the underlying warm waters of the northern hemisphere in the north-eastern oceanic regions [Stratton, 1969] causes a northward shift of the warmer climatic regions. According to Landsberg [1967] this increases

precipitation and produces milder air temperatures especially in the winter, than normally experienced at this latitude. Air temperatures which are higher on the order of 15 - 40°F are experienced along the European coastal regions from northern Spain to northern Russia as as evidenced in Figures 4 & 5. There are milder air temperatures well into the interior of northwestern Europe and North America. These temperatures are much higher than those at the same latitude along the northeast coasts of the United States and Japan where the winds are generally offshore.

Other climatic latitudinal and longitudinal changes produced by warm ocean currents and onshore wind are seen along the southwest coast of Iceland and the northwestern European continent. The Gulf Stream System flows across the North Atlantic as the North Atlantic and Irminger currents. These currents act as the northern boundary of the larger subtropical gyre of warm ocean water to the south. Bowditch [1966] noted that the warming effect of the northern boundary currents causes Reykjavik, Iceland to experience a higher average winter temperature than New York City, approximately 950 miles to the south. He went on to observe that even though Great Britain and Labrador are at about the same latitude, Great Britain and the whole of northwestern Europe have milder winters than experienced in Labrador due to the warming of the atmosphere in those regions by these ocean currents.

Even the coastal regions of northern Russia experience this climatic warming effect. Haurwitz and Austin [1944] mention two port cities near or bordering on the Arctic Ocean along the northern Russian coast that are icebound only during 5 to 8 months of the year. Archangel, on the inland White Sea is blocked by ice for eight months during an average year, yet at Aleksandrovsk, 300 miles to the north on the Murmansk coast, the warming effect of this northward extension of warm water results in icebound conditions in the harbor that are rarely longer than 5 months.

In a similar fashion the degree of influence upon continental climate of a cool or cold current paralleling the continents is dependent on the direction of the prevalent winds in the regions. Trewartha [1937] emphasized that whether the currents along a coast are warm, cool, or cold, if the winds are predominately onshore the climate of a region is modified extensively. On the other hand, offshore winds significantly reduce the effect of these ocean currents on adjacent coastal areas except during those synoptic events where the atmospheric wind directions are changed, usually only for brief periods of time.

Warm ocean currents flowing poleward are found along the western portions of all oceans except in the North Indian Ocean. The volume of water returning equatorward flows as cool ocean currents along the eastern ocean boundaries. These two types of current systems

are evident between the equator and 40° latitude influencing and being influenced by the subtropical anticyclonic wind circulations. These vast ocean currents have a profound influence on the climate as mentioned due to the properties of the water surface and their effects in modifying the overlying air masses. Observations shown in Figures 4 & 5 indicate that from the tropical latitudes to about 40° there are higher surface air temperatures over the western portions of the oceans than over the eastern sections due to this interaction. In addition, where warm currents lie offshore they tend to amplify the atmospheric humidity and to increase the rainfall due to increased evaporation over warm waters [Trewartha, 1937]. The lower air temperatures along the eastern portions of the oceans produce some climatic advantages. In both hemispheres the maritime tropical air near the western shores of the continents is more stable during the summers with considerably less humidity as a result of the cooling of air masses over the cool coastal waters [Haurwitz and Austin, 1944]

The longitudinal climatic warming in the northeastern oceanic regions beyond 40° latitude is a northern hemisphere phenomenon due to the distribution of the continents and oceans. In the southern hemisphere south of 40° latitude there are only minor longitudinal temperature differences due to the absence of continents in the middle to higher latitudes and the tendency toward zonal ocean currents [Haurwitz and Austin, 1944].

The warm currents are distinguished by their inherent property of having higher surface water temperatures than the water masses through which they flow as seen in Figures 9 & 10. Their extensions longitudinally across the higher latitudes do not necessarily have this same distinct property, even though they do carry warm water to higher latitudes. These extensions are not so much warm currents as higher latitude limits of warm waters found in the large oceanic gyres equatorward. The thermal properties of warm currents are illustrated in cross-sections of the Gulf Stream System in Figures 9 & 10. In addition to the high surface temperatures the current flow at depth borders a zone of steeply sloping isotherms. The northern hemisphere warm currents include the Gulf Stream and the Kuroshio Current found on the western portion of the Atlantic and Pacific Oceans respectively.

A seasonal warm current called the Davidson Current surfaces off the California coast during November, December, and January [Bowditch, 1966]. This normally subsurface flow of warm water flows poleward as far as 48°N. Similar poleward undercurrents surfacing near the west coasts of the continents when seasonal upwelling dwindles have been observed in the Peru-Chile and Benguela regions [Neumann and Pierson, 1966]. In the southern hemisphere the warm western oceanic currents are comprised of the Brazil Current, the Agulhas Current, and the East Australian Current as found in the South Atlantic, the South Indian Ocean, and the South Pacific Ocean respectively. An

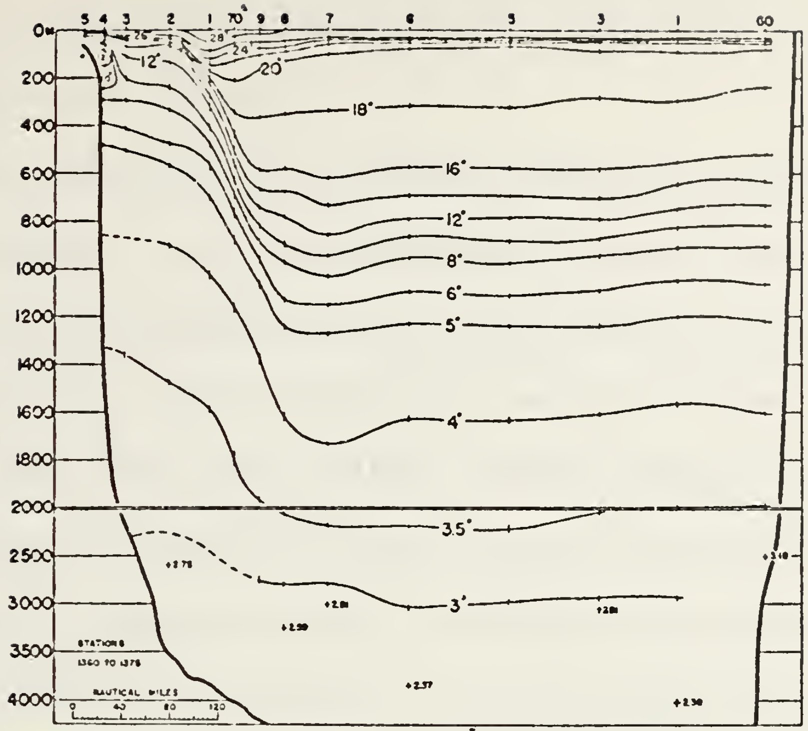

Figure 9. Temperature section across the Gulf Stream, Chesapeake Bay to Bermuda, August 28-September 3, 1932 (Stommel, 1972).

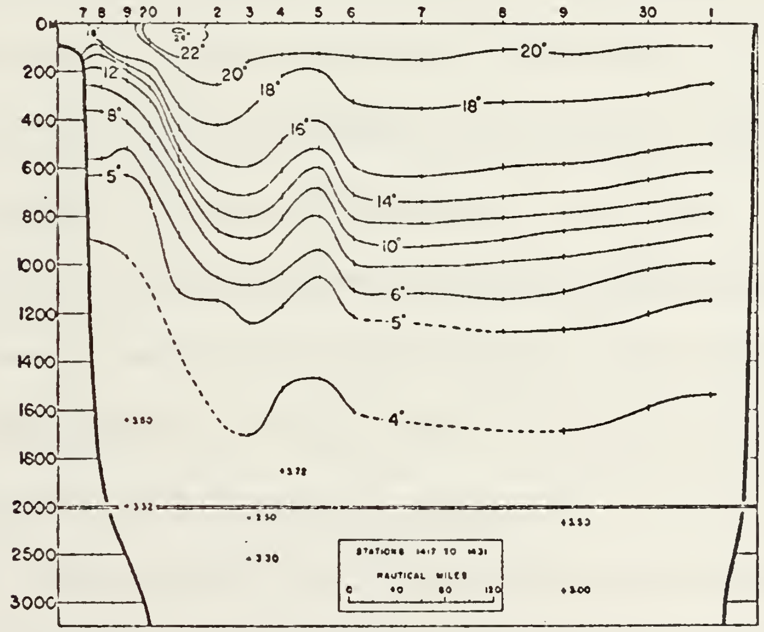

Figure 10. Temperature section across the Gulf Stream, Chesapeake Bay to Bermuda, November 30-December 5, 1932 (Stommel, 1972).

ocean current circulation depicted in Figure 11 shows the primary currents over the earth's surface.

The contrast between the climatic temperature regimes of the western and eastern ocean areas [Landsberg, 1945] is further reinforced by the equatorward flowing high latitude cold currents in the western portion of the oceans. High latitude ocean waters are colder and denser than those in the tropics due to the solar radiation imbalance on the earth's surface; their flow thus creates a constant exchange of waters between polar and equatorial regions. Although the subsurface flow of this cold, dense water is voluminous and important in the total oceanic circulation, the surface distribution of ocean waters is of more importance to climatic control. In the northern hemisphere the easterly winds on the north side of the Icelandic and Aleutian regions [Haurwitz and Austin, 1944] produces a flow of cold water westward and then southward. These cold water flows are the Labrador and Oyashio currents flowing south off the northeast coasts of North America and Japan respectively. Similarly, the Falkland Current flows northward in the southern hemisphere on the western border of the South Atlantic. This latter current derives its primary source of energy from the westerly wind belt rather than the easterlies as in the northern hemisphere.

Cold currents stamp a distinctive climate on the oceanic regions through which they flow. These currents influence the temperature of the environment around them, the pressure patterns of the boundary

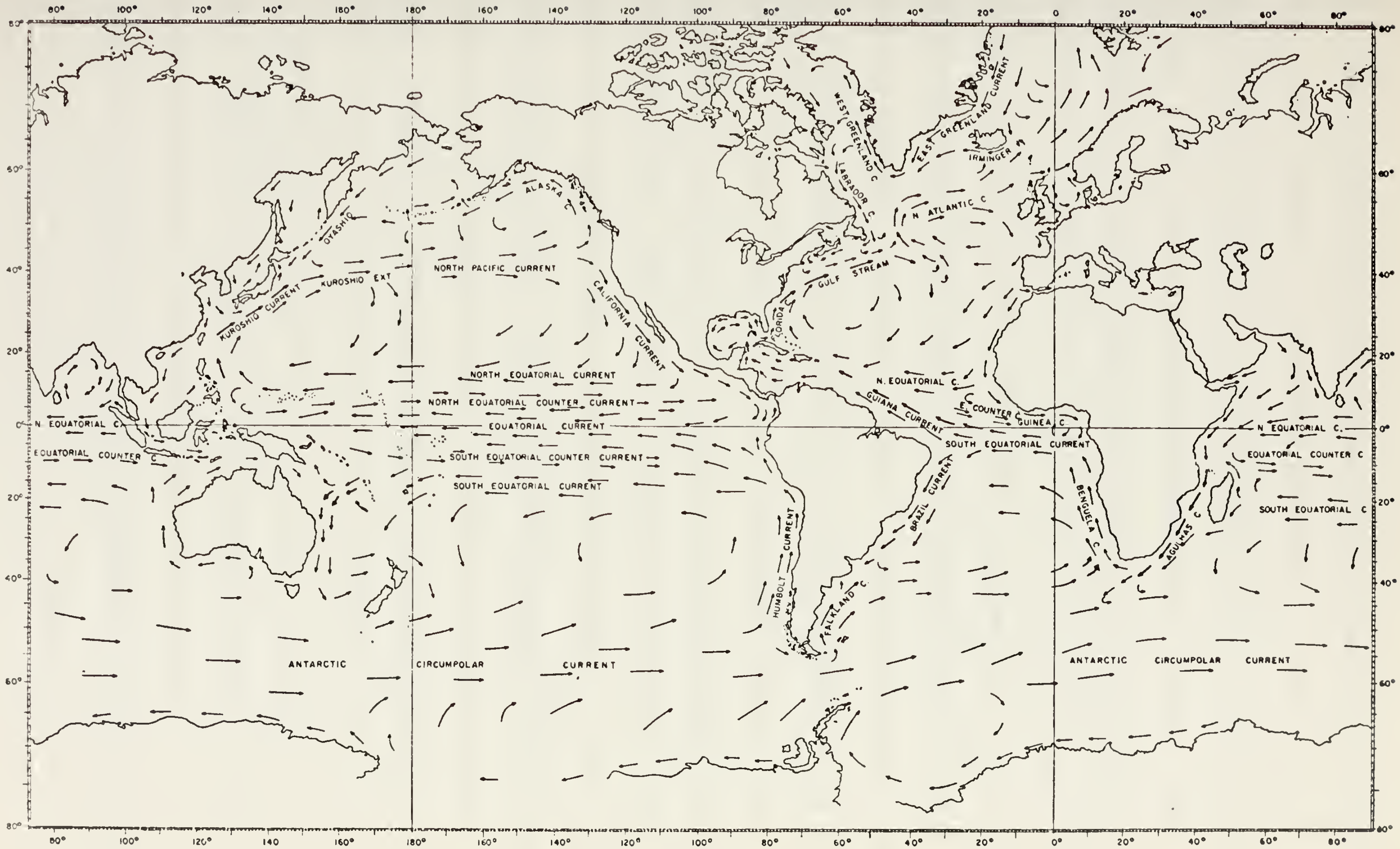

Figure 11. Major features of the surface circulation of the oceans (McLellan, 1965).

layer, and are instrumental in the formation of immense fog banks over the open ocean waters. In the mid-latitudes from 40 - 60^{o} along the eastern coastlines where the winds are onshore the low temperatures of the surface water in these currents influences the air climate of the coastal regions. As the currents flow equatorward the wind belts gradually shift to the predominant westerly direction, producing offshore winds which significantly reduce the influence on coastal climates. The currents then become more important as instruments to change the prevailing atmospheric pressure patterns. The air overlying the cold current contracts [Bowditch, 1966] as it is cooled or expands as it is warmed. Wintertime polar air [Haurwitz and Austin, 1944] flowing equatorward off the mid latitude continents is generally slightly colder than the sea surface. This results in a heating of the cold air, which increases the instability of the air column when cyclonic systems pass off the continental margins. The westerly wind influence becomes less dominant during the summer as the subtropical anticyclone intensifies over the open ocean. During this season, in the presence of the cool coastal waters the wind circulation is most favorable for fog formation. Fog results from the cooling of either maritime or continental air masses as warm moist air is advected over the cold ocean currents. Warm, moist air trajectories over the cold ocean currents produce a cooling of the air by conduction [Bowditch, 1966], increasing the relative humidity of the air. Together these processes create an advection fog due to the

air cooling below its dew point. This type of fog can be quite thick and often persists over relatively long periods of time making ocean navigation hazardous.

The cool ocean current is also of significance to climate production. The cool equatorward moving current is found on the eastern edges of the subtropical anticyclones between the equator and about 40° latitude. Classical cool currents include the Canaries Current of the North Atlantic, the Benguela Current of the South Atlantic, the California Current of the North Pacific, and the Peru (Humbolt) Current of the South Pacific. Although many reputable atlases and scientific texts continue to identify the West Australian Current of the South Indian Ocean as a cool current, J. Gentilli [1971] emphasized again the absence of a definite cool current along the western coast of Australia. With this exception, cool currents are found flowing along all mid-latitude western coasts from higher to lower latitudes. The water temperature, even though it rises while moving equatorward, lags behind the temperature of the environment. This results in relatively cooler water within these currents.

3. Upwelling

The influence of cool currents is often coupled with the effect of upwelling along these same coasts to give nearly a year-round oceanic climate influence to these regions. Westerly winds with polar components in each hemisphere cause seasonal displacements of warm surface water

away from the west coast that is replaced by an upwelling of colder water near shore. The combination of these events causes the west coasts of the continents to experience relatively low average air temperatures over the total year as compared to the normal temperature of the continental regions inland at the same latitude. Warm moist maritime air flowing across these cool current and upwelling conditions rapidly loses its identity. The air temperatures of the region are lowered and this frequently leads to the development of extensive advection fog and low stratus cloud banks along the coasts extending hundreds of miles latitudinally. The combination of these events creates a relatively cool summertime climate [Landsberg, 1967] inducing a low rainfall and a comparatively small range [Bowditch, 1966] of average monthly temperatures.

In addition to the production of cool marine climate along the western coasts, Trewartha [1937] points out that these cool current and upwelling conditions produce a latitudinally restricted contradictory climate characterized by the juxtaposition of fog and desert conditions (coastal steppes and deserts). The fog and low temperatures usually are confined to a narrow coastal boundary, but the dry desert climate may extend inland for hundreds of miles. The lower air temperature over the coastal zone is more noticeable in the summer when the inland areas become conspicuously warmer. Since the hot surface of the continent induces a lower pressure than over the oceans, the winds

during the summer have a slight onshore component produced by the pressure gradient. This amplifies the effect of the cool ocean currents on the temperature in the coastal area. The aridity inland is the result of a rapid increase in temperature with distance from the coast, a decrease in relative humidity, and the fact that the marine air with associated fog generally doesn't travel inland much farther than 60 to 70 km, as will be discussed in the sea breeze section. Latitudinally, this desert climate is extensive. In western Peru the desert conditions, created by the effects of the cool Peru Current, extend to within 5° of the equator. A similar coastal desert occurs along the coast of southwestern Africa caused by the cool Benguela Current.

Classical coastal upwelling regimes as discussed by Neumann and Pierson [1966] are associated with the cool currents on the eastern boundary of the subtropical regions. They are the product of an offshore surface water displacement caused by coastal winds. The coastal upwelling is generally confined to a narrow band, usually less than 100km, near the coast. The water coming to the surface replacing the displaced surface water rises from a depth of only about 100 to 200 meters. The regions influenced by the coupling of cool currents and upwelling conditions are characterized by special climatic conditions as previously described. These regions were classified by Köppen [1934] as a "humid desert climate" (desert climate with fog). The occurrence of upwelling under similar atmospheric events in other areas of the world is possible,

but on a smaller scale. In the Caribbean Sea there is a relatively small region of the Venezuela coastline where a humid desert climate exists. It lies nestled in a belt of tropical rain forest with a bordering tropical savanna climate and is caused by localized upwelling of cool coastal waters within a predominantely warm surface water region. Another similar occurrence of upwelling lies off the coast of Brazil near Cape Frio. In figure 12, a cross section across the region of upwelling in the cool Benguela Current off the coast of SW Africa illustrates the ocean temperature distribution along a coastline experiencing upwelling conditions.

Lane [1965] carried out a study of the climate and heat exchange in the oceanic region adjacent to Oregon where upwelling is evident seasonally producing some very interesting results. The measurable upwelling effects observed on the climate are a suppression of the summer and autumn air temperatures with an increase in relative humidity despite a reduced evaporation. Climatological data during the summertime upwelling season clearly shows a lowering of the air, sea, and wet bulb temperature with a layer reduction in the vapor pressure difference, $e_s - e_a$, in the nearshore regions, with the converse true during the winter (non-upwelling period). In addition, upwelling affects the heat budget by slightly reducing the back radiation, greatly reducing conduction from the ocean to the atmosphere, and greatly reducing the heat loss due to evaporation. In fact, suppression of nearshore evaporation by

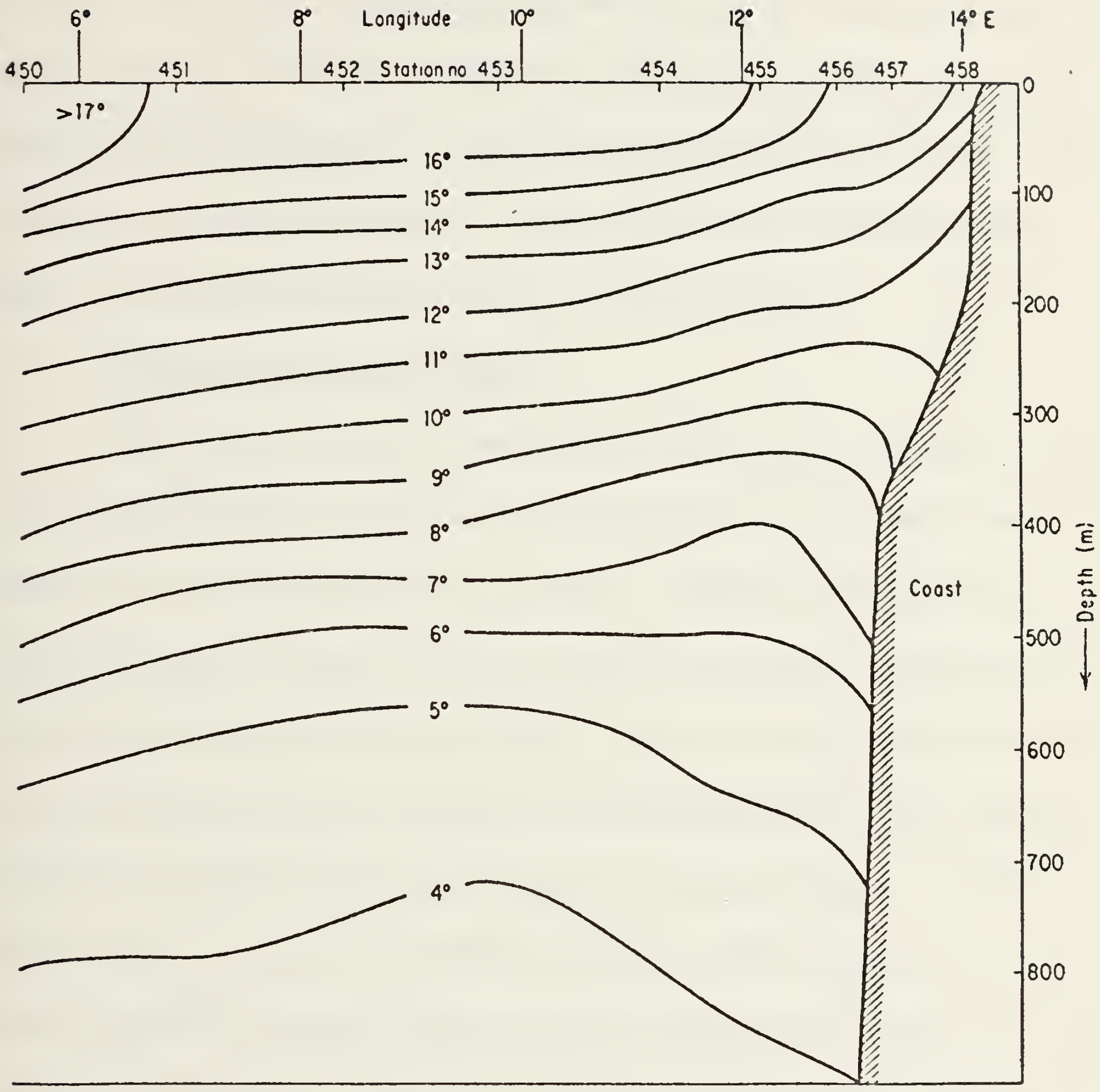

Figure 12. Cross-section of upwelling region in the Benguela Current off the coast of SW Africa, showing the temperature distribution between about 6° E and the coast during October (Neumann and Pierson, 1966).

upwelling causes a reduction of water transfer to the atmosphere on the order of 2 inches a month in the summer and early winter months. The reader is referred to Smith [1968] for a general review of the classical processes associated with coastal upwelling, to Mooers and Allen [1973] for a summary of the observational knowledge and present theory of coastal upwelling dynamics, and to O'Brien [1975] for a review of the modeling of coastal upwelling. These conclusions, found by Lane, appear to hold true in most coastal upwelling regions.

4. Thermal Circulation Cells

The superposition of sea breeze and monsoon thermal circulation cells upon the general atmospheric circulation is proposed by Landsberg [1945] to be climatically quite important. Coastal climates and in many cases the adjacent inland climates around the world are influenced by one or both of these thermal circulations. The circulation cells are induced by the thermal contrast across the coastal boundaries due to unequal heating of the atmosphere by the ocean and land surfaces. The [Landsberg, 1967] marine air transported into the coastal regions by the sea breeze produces a cooling effect that is an important climatic factor for local human comfort. In addition, [Miller and Thompson, 1970] the sea breeze aids coastal cities which generate air pollution, such as found in the Los Angeles basin. The marine air is predominantly swept inland at times clearing the pollutants from the coastal region. The land [Huang, 1972] breeze, on the other hand, especially on semiarid coasts, sometimes

produces unpleasant dusty conditions to the dismay of the coastal population.

a. Sea Breezes

The sea breeze regime [Neuberger and Cahir, 1969) in effect is nothing more than the diurnal reversal of onshore and offshore winds created by the differential heating of the ocean and land surfaces. The ocean-atmosphere interface [Miller and Thompson, 1970] rarely exhibits more than a $2^{\circ}C$ diurnal change, whereas land surfaces heat and cool on the order of 20 to $40^{\circ}C$ within the same time frame. Defant [1951] points out that the cause of the relatively small air-sea temperature variations is due to the turbulent mixing of the water by winds and waves producing a continuous downward transport of surface heat through large masses of water. The large diurnal temperature variations due to the heating of the land surface on the other hand, is caused by the complete absorption of radiant heat within the surface layers of the ground and a rapid loss of heat at night as well as a much weaker influence of this form of energy on the deeper layers [Defant, 1951]. The heating of the land surface [Miller and Thompson, 1970] during the daytime while the sea surface temperature remains almost constant causes the formation of a thermal gradient from land to sea drawing a sea breeze inland. This onshore flow is [Landsberg, 1945] additionally supported by a thermally induced daytime low pressure cell with associated pressure gradients inland of the coastal region. The general flow pattern of the sea breeze regime is shown in Figure 13.

The characteristics of sea breezes vary from place to place, but usually the breeze begins to develop 3 to 4 hours after sunrise lasting through early evening [Miller and Thompson, 1970]. At its peak during early afternoon, the circulation cell normally extends both inland and seaward about 20 km, although in some localities it has been known to extend inland as much as 60 - 70 km. In the Los Angeles basin the author has observed the sea breeze on occasion to reach out into the desert as far as Palm Springs, nearly 100 miles inland. The surface winds associated with this circulation are usually quite irregular in direction and magnitude. Sea breeze [Fairbridge, 1967] velocities at the surface are normally between 10 to 20 knots, with gusts to 25 knots not uncommon. On cloudy days [Neuberger and Cahir, 1969] or when other atmospheric features are present, the sea breeze may be entirely absent. In regions where the air flow is generally offshore, as on the eastern seaboard of the United States, the sea breeze raises the daytime relative humidity and cloudiness by its vapor transport inland and cooling. Figure 14 illustrates the diurnal variation of temperature, relative humidity, and wind at Boston on a cloud-free day caused by the sea breeze. The onset of the sea breeze occurs between 9 and 10 o'clock in the morning as the northerly winds decrease and the wind direction changes. The marine air causes a rise in the relative humidity and interrupts the normal temperature rise by the advection of cool air from the sea.

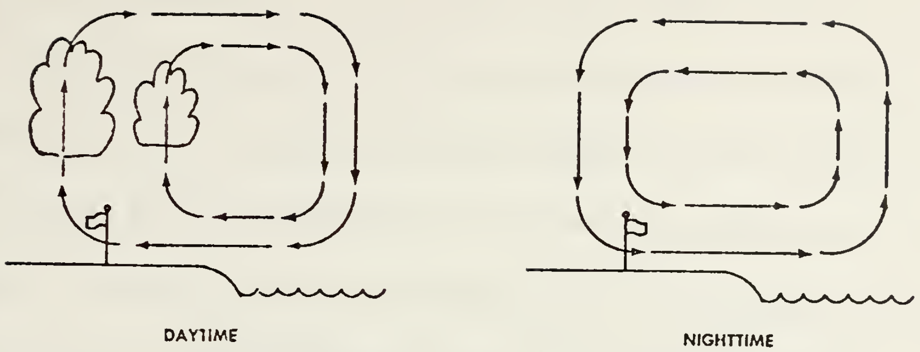

Figure 13. Sea breeze-land breeze diurnal circulation patterns (Williams, Higginson, Rohrbough, 1968).

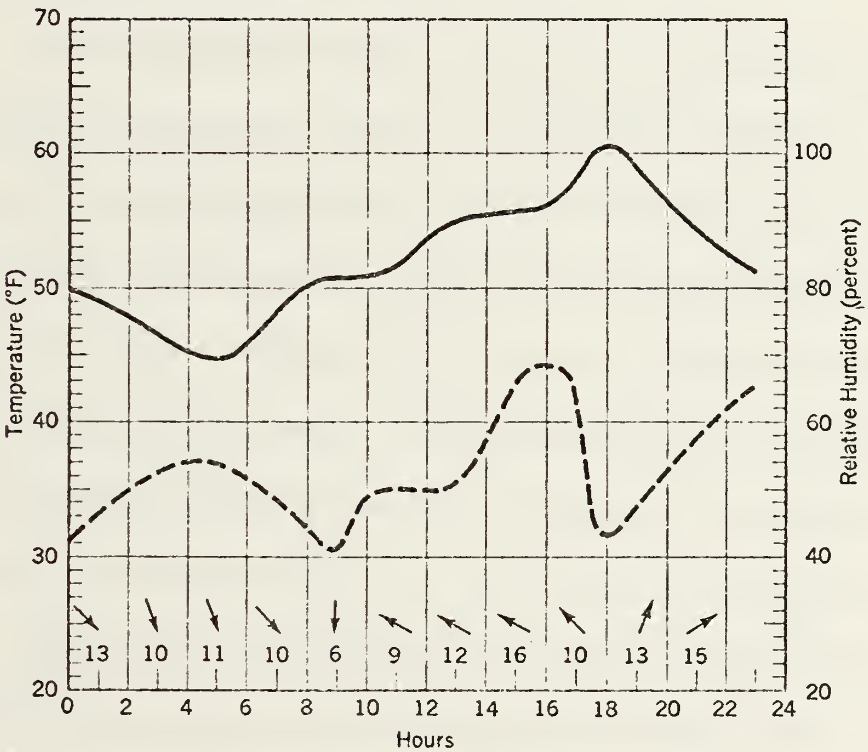

Figure 14. Diurnal variation of temperature (solid curve), relative humidity (dashed curve), and wind at Boston on 21 May 1964. The arrows below fly with the wind; speeds below arrows are given in knots (Neuberger and Cahir, 1969).

The land breeze [Miller and Thompson, 1970] is primarily a nocturnal phenomenon. As the land cools in the evening, the intensity of the sea breeze drops off and the thermal pressure gradients reverse. Basically weaker in both intensity and extent, the land breeze normally begins shortly before midnight and reaches its maximum development near dawn. Surface velocities average about 5 to 15 knots with the breezes seldom reaching farther than a few miles out to sea. While the land breeze tends to return the marine air toward the ocean, due to its lower wind velocities and shorter duration, the net effect is a general influx of marine air over coastal area.

The sea breeze regime [Landsberg, 1945] is basically a shallow boundary phenomenon with the thermal solenoidal [Byers, 1959] circulation cell including the upper return flow being normally less than 1 km deep [Miller and Thompson, 1970]. The vertical depth [Huang, 1972] of the sea breeze starts with only a few meters, building in thickness up to its maximum depth by evening. In the tropics [Miller and Thompson, 1970] this circulation system is much more active as it achieves heights of as much as 3 to 4 kms as shown in cross-section for Batavia in Figure 15. This cross-section gives a more detailed illustration of the depth, intensity, and time of occurrence of sea breezes within a typical tropical circulation cell. The sea breeze [Fairbridge, 1967] characteristically blows normal to the shore early in the day, but as the regime builds in depth and distance from the coast the Coriolis effect causes the wind direction to gradually swing to an oblique angle by evening.

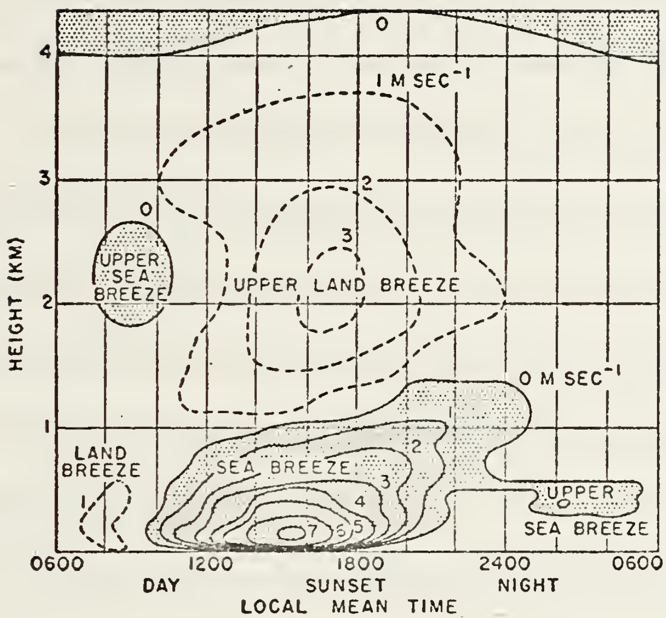

Figure 15. Velocity isopleths for the land and sea breezes in Batavia (Defant, 1951).

Sometimes the sea breeze regime [Miller and Thompson, 1970] is associated with coastal fog or low stratus clouds. Where there are cool offshore currents or upwelling conditions, such as off California, Peru, northwestern and southwestern Africa, the occurrence of coastal fog and low stratus clouds carried inland by the sea breeze is seasonally quite common. In other areas marine air carried by the sea breeze commonly induces cloudiness as it is forced upward adiabatically over the inland slopes, but again this influx of marine air is generally not associated with rainfall. One exception [Neuberger and Cahir, 1969] to this rule occurs on the Florida Peninsula. A zone of convergence in the low level winds along the coast is produced by the sea breeze resulting in convective activity that leads to localized maximum precipitation from showers and thunderstorms.

The regional occurrence [Defant, 1951] of sea and land breezes extends from the equator to the poles. In tropical regions, the breezes exist almost year-round, due to the large diurnal temperature variations over the land, predominantely clear skies, and the usually weak air circulation. The only major exception occurs in India where the land breeze is totally obscured by the dominant summer monsoon from May through September. Outside the tropics [Neuberger and Cahir, 1969] the sea breeze regime is strongest in the late spring and early summer, when the temperature contrast between the ocean and land is maximum. In the middle latitudes, [Defant, 1951] as evidenced by the

shores of the Baltic Sea, the sea breeze regime occupies not more than twenty percent of the summer days. In the polar regions this local wind phenomenon disappears almost completely except on a rare clear summer day.

b. Monsoons

A thermal circulation similar to the sea breeze regime, but of a seasonal nature, is the monsoon circulation. The name monsoon as derived from the Arabic word mausin - a season [Williams et al., 1973] denotes its seasonal nature. Climatic effects of the monsoon are principally felt in the tropical and subtropical latitudes [Neuberger and Cahir, 1969], especially so with the well developed monsoons in India, southeast Asia, Australia, and those parts of Africa bordering the Arabian Sea. Here, even the lowliest laborer in the rice fields is aware of the monsoon, depending on its rainfall to save him from famine [Byers, 1959]. The economy of the area, living habits of the people, and ocean currents are attuned to the onset of the monsoon winds and rains [Williams et al., 1973]. The Indian Monsoon Current in the northern Indian Ocean affected the early Arabian trade with Africa and India. During the winter monsoon season the dhows sailed the Arabian Sea with northeast winds from October to May, and as the winds reversed in the summer they sailed with south to southwest winds from June to September [Williams et al,, 1973].

Traditionally, monsoons have been described as a simple thermal solenoidal cell where the atmospheric air flow responded to the

seasonal thermal contrasts between oceans and continents. This type of monsoon circulation driven by differential heating of land and water masses was proposed by Halley in 1686 [Palmén and Newton, 1969]. The annual air temperature range over the oceans' surface as shown in Figure 16 varies considerably less than over land surfaces. Therefore, in the winter when the middle to high latitude land radiation losses cause air to become intensely cold, especially in areas such as Siberia, the contrast between air temperatures over land and oceans sets up a thermal gradient. The extreme coldness of land areas is exemplified by Oimekon, Siberia where the unofficial record for the northern hemisphere low temperature is recorded at $-108^{\circ}F$ [Williams et al., 1973]. Subsidence over cold land areas develops high surface pressures resulting in a large-scale outflow of adiabatically dried air at the surface toward the ocean. Turning under the influence of the coriolis force this outflow of dry air either reinforces [Landsberg, 1945] or weakens the planetary atmospheric circulation. In the summer, while ocean waters warm slowly, solar radiation heats up land surfaces more rapidly, producing high air temperatures, as shown in Figure 5, and associated low pressures. The resultant thermal-pressure gradients superimposed [Landsberg, 1945] upon the general atmospheric circulation cause a reversal of air flow to an onshore flow of moist warm [Williams et al., 1973] air from the oceans bringing summer monsoon precipitation.

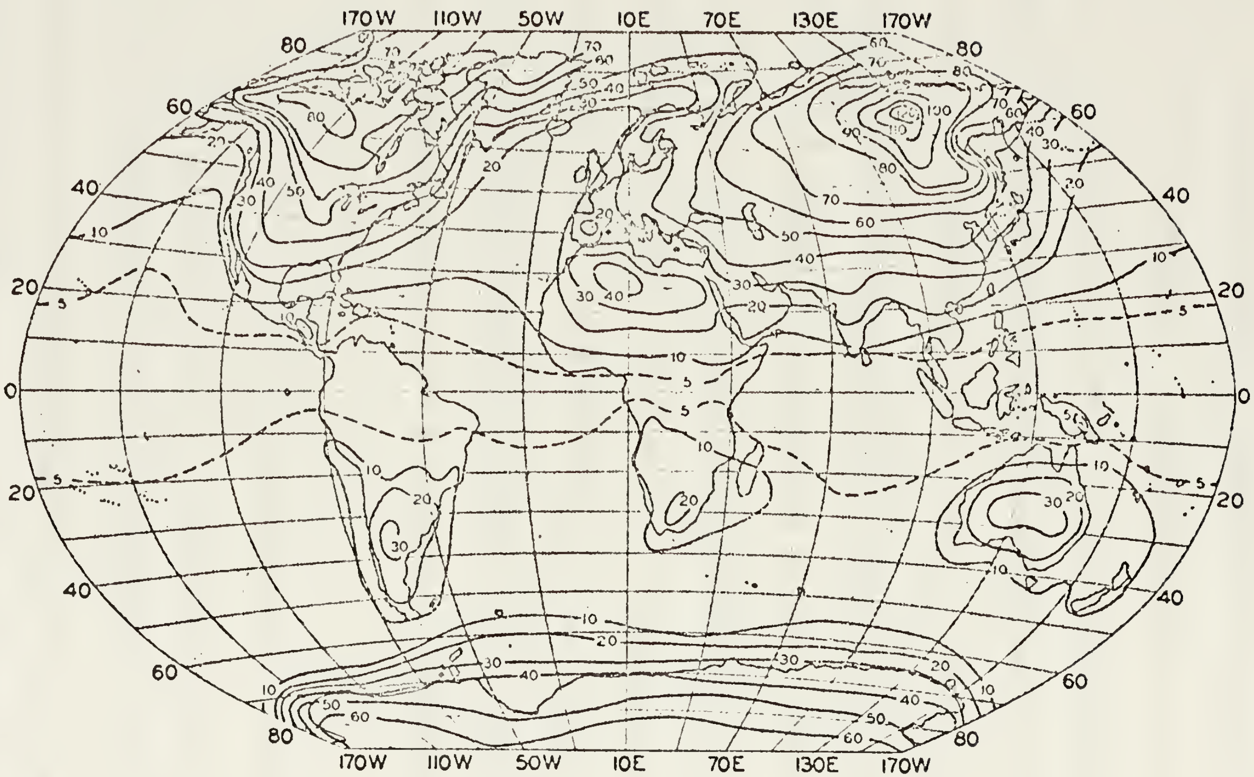

Figure 16. Isopleths of equal annual range of air temperature in ^{o}F (Landsberg, 1945).

More recently, theorists [Neuberger and Cahir, 1969] have attempted to explain the irregularity of the observed monsoons by means of the less regular seasonal shift in the dynamic Hadley cell circulation. The Hadley regime is composed of two major circulation cells, one in each hemisphere. The tropical cells tend to migrate seasonally, lagging anywhere from a month to two months behind the sun. The normal 30° north and south latitude boundaries usually are extended as far as 40° poleward in the summer hemisphere, transporting poleward the Intertropical Convergence Zone (ICZ) with its associated cloudiness and rainfall. This migration of the ICZ is partially related to the classical monsoons of Asia, Africa, and Australia [Neuberger and Cahir, 1969]. A more technical discussion of the monsoon circulation can be found in Palmén and Newton [1969]. Modern theorists have linked the thermal effects of the continents and oceans with the dynamic effects of the subtropical high pressure cells on both hemispheres in explaining the monsoon circulation.

The climatic effect of monsoons varies from sheer dominance of the general circulation within a region to a slight deflection of local winds. The tropical and subtropical latitudes [Neuberger and Cahir, 1969] feature the classical well-developed monsoons. Here the pressure pattern of the general circulation is distorted by the ocean-land thermal contrast sufficiently to produce summer onshore and winter offshore air flow [Landsberg, 1945] which are closely linked to the

seasonal precipitation of these regions [Miller and Thompson, 1970]. As the lands heat during the summer the warm moist oceanic air flows inland. Summer monsoon rainfall is partially developed from direct [Byers, 1959] convection, but the heaviest rainfall occurs with the convergence of the monsoon flow and the normal westerlies. The most pronounced summer monsoon rains are produced by the convergence over northern India between the south to southwest winds from over the northern Indian Ocean [Miller and Thompson, 1970] and a counter northwest flow from the Arabian Sea. The warm moist oceanic air rises adiabatically up the mountainous slopes [Williams et al, 1973] of Nepal, Tibet, and China, reducing saturation vapor pressure, inducing extensive cloudiness, and producing large rainfalls along the route. As a consequence, Cherrapunji, India at 4455 ft on the south slope of the Khasi Hills in northeastern India has the reputation of being the wettest spot on earth. Cherrapunji receives an average of 426 inches of rain annually, but primarily during the summer monsoons [Byers, 1959]. Its record rainfall in one year sits at 1042 inches and the record for one single month is 366 inches [Williams et al., 1973].

Summer monsoon rainfall [Neuberger and Cahir, 1969] is produced almost entirely by showers and thunderstorms, which are sporadic and irregular, although widespread over a large area. A substantial amount of rainfall additionally is generated by synoptic disturbances migrating through the ICZ and by local orographic effects. The

poleward progression of monsoon rainfall peaks and the associated reductions in air temperature is shown in the mean monthly temperature and precipitation charts at four stations in the Indian Monsoon region illustrated in Figure 17. The rainfall peaks occur at Colombo in May, farther north at Mangalore in July, and in August they have reached Jodhapur. The mean monthly temperature charts point out that those stations affected by the monsoon winds have their highest temperatures in the spring or early summer prior to the rainy season due to the reduction of the summer temperature by cloudiness and precipitation. The lack of observed monsoon rainfall and the overall lower annual rainfall at Madras (48 inches) as compared to Mangalore (137 inches) is attributed to the depletion of the moisture supply on the lee side of the local mountains. The higher rainfall peaks experienced at Colombo and Madras at the end of the year are primarily caused by tropical storms over the Bay of Bengal [Neuberger and Cahir, 1969].

The presence or absence of monsoon rains is a life and death matter on the Asian continent. Indian meteorologists have emphasized over the years that monsoon rains are not a steady phenomenon, but vary greatly from year to year and from one region to another. Even the day-to-day and regional variations are flexible enough to confuse the most experienced forecaster. The source of all this precipitation lies within the ocean waters and the mechanism of air-sea water exchange. The role of the oceans in this ocean-atmosphere exchange in the last

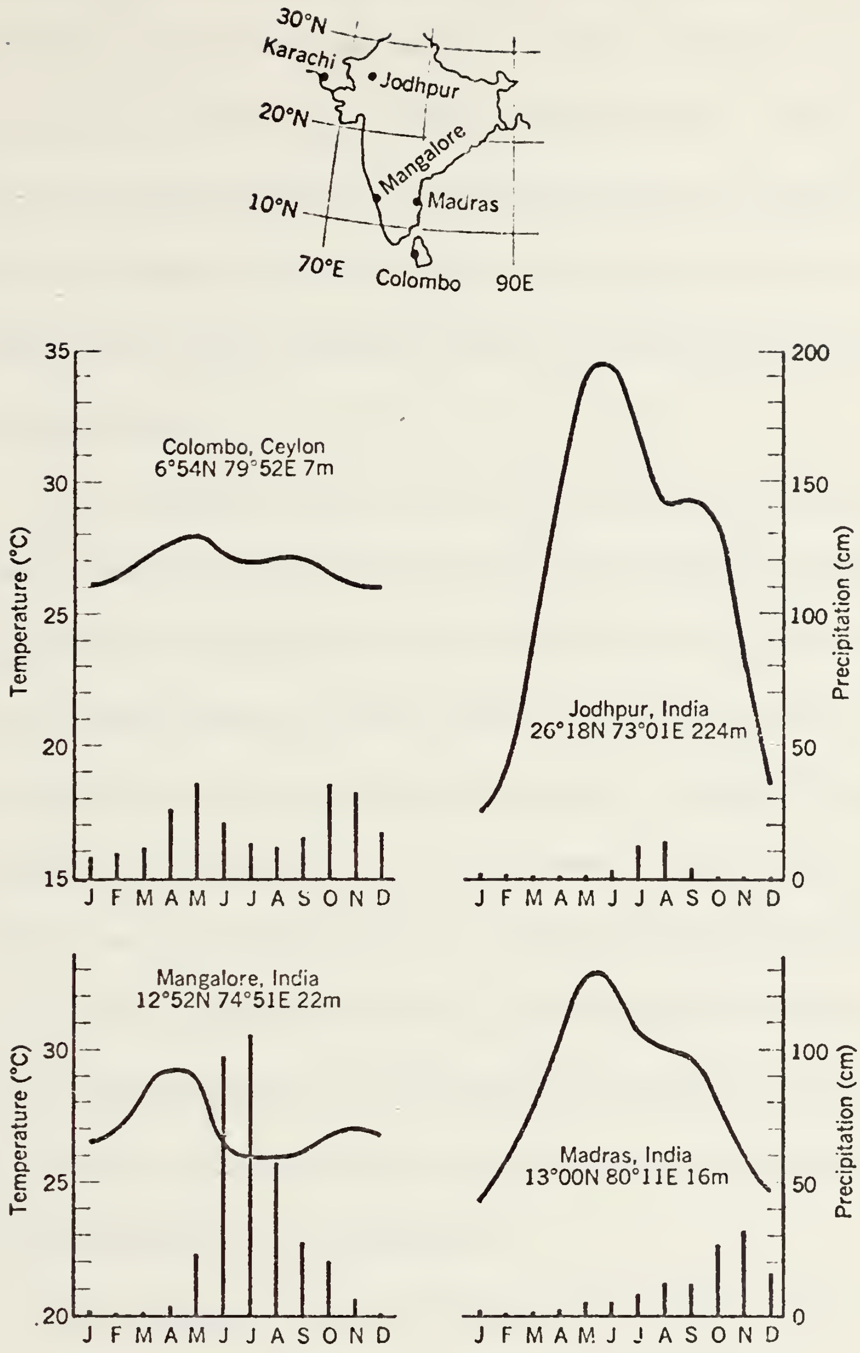

Figure 17. Mean monthly temperatures and precipitation at four stations in the Indian monsoon region (Neuberger and Cahir, 1969).

decade has gained international attention as major drought conditions in the Asian-African areas have focused the world's attention to sources of climatic change that affect the world's food production. Stratton [1969] published the fact that there were scientists at that time hypothesizing that climatic variations, such as long-term droughts, may be caused by shifts in positions of major ocean currents or in positions of sea-surface temperature anomalies.

The climatic effects of the Asian winter monsoons are limited primarily to the populations living on the offshore islands of eastern Asia and even there they are interrupted by cyclonic storms. The subsiding dry continental air flows outward from the continent over the warm ocean surface picking up moisture rapidly. Initially dry and stable, this air produces no rainfall over the continent. The offshore islands of Japan, Taiwan, and the Philippines are sufficiently distant that the moisture-laden air deposits heavy rain on the Asiatic sides of these islands. The climate [Byers, 1959] below the Himalayas and west of the mountains of Burma and Indo-China is dry and hot in comparison due to the clear skies produced by subsidence.

The climatic effects of monsoons in other parts of the world are generally obscured by the strong pressure gradients of the general circulation of the atmosphere or by the fact that the continent's size is so small that the only evidence of monsoons is nothing more than an additional wind component [Landsberg, 1945]. The North American

[Miller and Thompson 1970] continent experiences some monsoon effects, but normally the monsoon is obscured by migratory synoptic systems. In the eastern United States [Neuberger and Cahir, 1969] there is evidence of a weak monsoon with winter west to northwest winds reversed in the summer to southwestern winds. More dramatic summer monsoon conditions prevail in the southwestern part of the United States and northern Mexico in the form of frequent intrusions of moist tropical air, especially during July and August [Hales, 1974]. The author has observed the hot desert regions of the southwest and the summertime flow around the 700mb high pressure ridge over this region transporting moisture from the Gulf of Mexico and the Gulf of California. The moisture surge northward from the Gulf of California is controlled primarily by a thermal pressure gradient in the lower troposphere rather than the general atmospheric circulation. Traditionally, it has been accepted that the total moisture supply for this summer monsoon was derived through a broad band of southeast winds from the Gulf of Mexico. Hales [1974] pointed out that the importance of the Gulf of Mexico as a moisture source is minimal for the area west of the Continental Divide. The monsoon flow can be observed occasionally during the summer in upper air and surface weather charts with its daily progression of moist air flow, showers, and thunderstorms across Texas, New Mexico, Arizona, and eventually to southern Nevada and California or from the Baja and west-central Mexico northward to the same region. To a lesser extent monsoon

conditions [Williams, et al, 1973] have been observed in other areas of the world including Spain, Africa, and Chile.

E. SST ANOMALIES - CAUSE OF SHORT PERIOD CLIMATIC VARIATIONS

The oceans have been thought to be a stabilizing influence on climate over the centuries because the ocean undergoes changes on a time scale about 100 times as long as that of the atmosphere [Hammond, 1974]. Recent observations of the uppermost layer of the ocean however, have shown that sea-surface temperature (SST) anomalies play an important role in short period climatic variations. Between the fall of 1957 and the spring of 1958 a dramatic environmental event occurred, whereby SST's were observed to be as much as 3°C higher than the long-term normal values over much of the eastern North Pacific and off the South American coast [Huang, 1972]. Prior to this time the westerly wind system had been characterized by particularly low monthly index states during the winters of 1956 and 1957 [White and Barnett, 1972]. For a full detailed account and discussion of the anomalous phenomena occurring during this period, the reader is referred to the proceedings of the interdisciplinary conference of the Marine Research Committee [1960] or to a critical review by Isaacs and Sette [1960] of the special symposium on this subject at the 1958 California Cooperative Fisheries Investigations Conference.

Anomalous atmospheric and SST phenomena occurring in the Pacific basin first in 1956-58, then 1962-63, and again in 1968-69 led J. Namias [1959, 1963, 1965, 1969, 1970, 1971, 1974] to publish an extensive series of

articles on the subject. Namias has shown that air-sea interaction processes can play an important role in determining the thermal structure and circulation characteristics of the atmosphere and the SST characteristics of the ocean on monthly and seasonal time scales. He has demonstrated that anomalous thermal or circulation patterns in either medium can create, amplify or destroy anomalous patterns in the other and that these interactions occur on a contemporary or lag basis in time and over large (oceanwide) spatial scales [Clark, 1972]. The Panel on Climatic Variation, a part of the U.S. Committee for the Global Atmospheric Research Program, recently concurred with these observations. In their recent publication [NAS-NRC, U.S. Com. for GARP, Panel on Climatic Var., 1975] it is stated that a perturbation of the ocean surface temperature may modify the transfer of sensible heat to the overlying atmosphere, and thereby affect the atmospheric circulation and cloudiness. These changes may in turn affect the ocean surface temperatures through changes in radiation, wind-induced mixing, advection, and convergence and may subsequently affect the deep ocean temperature through geostrophic adjustment to the convergence in the boundary layer. These processes may result in either the enhancement or reduction of the initial anomaly of SST. Namias [1970], well known as the founder and long-time former director of the Weather Bureau's extended range prediction effort, suggests that the observed high coherence of SST's over long periods increases the importance of understanding these interaction processes

before meaningful long-range forecasting of atmospheric and oceanic properties can be accomplished.

The publication of Short Period Climatic Variations - Collected Works of J. Namias 1934 through 1974, Volume I and II - provides a unique opportunity to observe the step-by-step development of Namias' efforts on studying SST anomalies in addition to his other accomplishments. Namias [1959] gathered together a large amount of evidence to explain descriptively the anomalous events observed in the eastern North Pacific during 1957-58 based upon the mutual interaction of anomalous SST fields and the sea level pressure patterns. This basic study and subsequent articles led Namias to the conclusion that anomalous atmospheric conditions, together with associated surface heat exchanges, result in the development of anomalous warming or cooling of surface waters of the oceans. Based upon his collective work, Namias [1959, 1963, 1965, 1969] has correlated the anomalous SST variations in the North Pacific Ocean with abnormal atmospheric circulation patterns and climatic changes in eastern North America. Further work on SST observations and corresponding sea-level pressure data taken during the 20-year period from 1947 to 1966 led Namias [1970] to observe that the average sea-surface temperatures for the entire North Pacific Ocean exhibit fluctuations having persistence through lags from 0 to 8 seasons. Having no counterpart in the atmosphere, this conservation of heat as indicated by SST's illustrates the large heat capacity of the mixed layer of the oceans.

In a more recent publication, Namias [1971] showed that the abrupt anomalous variation in the North Pacific Ocean during the period 1957-58 marked a break between two roughly decadal climatic regimes, with the decadal mean atmospheric patterns differing materially off the west coast of North America [Huang, 1972]. Namias [1974] went one step further to illustrate an example of continuity in monthly means that lasted almost a year involving a coupled air-sea-continent system. Maps spanning the period from September 1972 through July 1973 showed an eastward progression of an atmospheric mean trough from mid-Pacific to the east coast of North America. The trough was associated with anomalous SST contrasts during its Pacific migration, such that anomalously warm water was found ahead of the trough and cold water behind. Displacement computations of the anomalous surface waters advected with normal surface currents indicated eastward motion of the cold and warm waters. Namias' work has increasingly shown an interrelationship within the ocean-atmosphere geophysical system that becomes more intriguing as the investigations continue. What cannot be ignored is the fact that SST anomalies do play an important role in short-period climatic variations and that a far better understanding of the air-sea interaction processes is necessary.

Namias was not the first nor the last to study the large scale interaction between the ocean and the atmosphere. It has been almost a half century since Helland-Hansen and Nansen [1920] carried on their

pioneering work on large-scale air-sea interactions. Namias [1969] relates that they were beset by obstacles in obtaining adequate records of SST and meteorological variables, by slow and cumbersome methods of data processing, and by fragmentary knowledge of the general circulation and heat budgets of both media preventing them from completing much of their work based on many sound ideas. Since then the problem has been investigated by Jacobs [1951], Bjerknes [1962], and Namias [1975]. Further studies by Bjerknes [1966, 1969] established atmospheric teleconnections from large-scale air-sea interactions in the tropical regions with other parts of the world. Using the concepts of the variable Hadley and Walker circulations, Bjerknes correlated anomalous weather patterns in the mid-latitudes with the equatorial SST anomalies. He observed that the mid-Pacific equatorial ocean during 1963-67 exhibited a sequence of rhythmic changes of temperature of approximately 2-year periodicity. The atmospheric Hadley Circulation responded with increased intensity when the equatorial waters were at their highest temperature. The inherent increase of the strength of the extratropical westerlies was demonstrated by Bjerknes [1969, 1972], Bjerknes [1974] went one step farther to describe the tropical SST rhythms in more detail.

A few other scientists took the same basic information as Namias, but worked at it with a different approach. Most of Namias' studies presented qualitative and statistical results in defining the nature of air-sea coupling, although several of his reports [1959, 1963, 1965] and

those of Eber [1961], Clark [1967], and Jacobs [1967] described techniques that attempted to explain quantitatively the changes that occur in SST anomaly patterns on monthly and seasonal time scales. Clark [1972] went on to show that these observed SST anomalies are related to well-known, large-scale air-sea interaction processes using empirical methods. White and Barnett [1972] using the same geophysical data base developed by the North Pacific Study Group at Scripps Institution of Oceanography as used by Namias, established a theory describing a large-scale feedback mechanism (servomechanism) between the mid-latitude ocean and atmosphere to explain the beginning of the anomaly activity that dominated the mid-latitude North Pacific from 1956-58. The theory involving a mutual feedback of vorticity between the ocean and atmosphere, such that the oceanic vorticity between the ocean and atmosphere, such that the oceanic vorticity (and hence distribution of heat) is altered by the wind stress curl and the atmospheric vorticity is altered by the Laplacian of the heat flux at the subarctic frontal zone. A significant amount of historical data supports this theory and it appears the servomechanism theory may play an important role in the generation of ocean-atmosphere anomalies over the entire Pacific basin.

F. SEDIMENT RECORD OF PAST SST CONDITIONS

The natural history of the ocean's influence on climate lies recorded in the earth's rocky surface and within the sediments lying beneath the sea [Donn, 1972]. The climate of the earlier stages of the earth's history

is discernible within this geological assemblage, but the details of climatic changes have been sometimes obscured and effaced through the geologic ravages of time. To understand the nature of the stabilizing influence of the oceans on climate it is most advantageous to concentrate on the more recent period of geologic time, that is the latter portion of the Cenozoic Era. The late Cenozoic climate has by far its most complete record in the cores of sediments raised from the floor of the deep sea. An extremely slow and continuous rain of fine mineral particles and hard parts of temperature sensitive microorganisms [Ericson and Wollin, 1968] has been going on for millions of years with little disturbance. Under normal conditions this sedimentation rate in the deep ocean has been estimated to vary from 1.5 to 3 cm in 1000 years [Wollin, et al, 1971]. This sediment found over much of the ocean floor provides an ideal recording mechanism. Analysis of layers [Sears, 1974] of sediment laid down in this manner has provided indicators of how the temperature of the surface waters varied during climatic changes of the past. This record of sea-surface temperatures within the sediments beneath the oceans provides a unique hydroclimate source for evaluation, especially with the important influence of sea-surface temperatures on climate.

The pioneer work of Wolfgang Schott [1935] on sediment cores collected during the oceanographic cruises of the Mereor, 1925-27, in the Atlantic equatorial regions opened up a new approach to the study of climate and the ocean. Schott concluded that vertical variations in the

abundance of the planktonic foraminiferans Globorotalia menardii in the cores probably corresponded with the moderating of climate at the end of the last ice age [Ericson and Wollin, 1968]. This conclusion led to the hope that a legible record of all the major climatic events of the Pleistocene lay within the deep-sea sediments. Over the years since this observation was made the scientific community has extensively studied and restudied cores of the ocean sediments in the determination and refinement of climatic changes and their relationship to sea-surface temperatures. Lamont Geological Observatory alone has collected over 5000 deep-sea sediment cores obtained in more than 50 expeditions from all the oceans [Ericson and Wollin, 1968]. The Deep Sea Drilling Project within the last decade has exponentially expanded the rate of collection and study of deep-sea cores.

Several techniques have been utilized to estimate Pleistocene paleotemperatures in surface ocean waters. One method proposed by Urey [1947] utilizes the temperature dependence of oxygen-isotope fractionation in the carbon dioxide-water-calcium carbonate system [Emiliani, 1966]. Oxygen, 0^{16}, is far more common than is its heavier isotope, 0^{18}, which is normally found at about 1 part in 500 [Donn, 1972]. The amount of 0^{18} taken up for the carbonate of a shell varies with temperature (decreases as temperature increases) and salinity of the ocean, both of which vary with climate. The oxygen-isotope geochemistry

method has been applied extensively to Mesozoic belemnites and Cenozoic mollusks and foraminifera.

Emiliani's [1966] analysis of deep-sea cores from the Caribbean Sea using oxygen-isotope technique shows a range of about 8° C (14°F) between maximum and minimum points on the temperature-time graph shown in Figure 18. . A comparison graph in the same figure from a different core in the Caribbean Sea shows the variation in abundance of a warm-water species of protozoa with time, with the intervals of very low abundance interpreted as glacial climates. The diverse data for these cores from different localities are remarkably similar in the analysis of climatic trends for the past 500,000 years. The magnitude of the temperature range is moderated by the enormous volumes of water that must be heated or cooled before an average temperature change of even one degree could be expected throughout the oceans [Sears, 1974]. This moderation of temperature ranges by the ocean's volume definitely influences climate and the rate of climatic change.

G. OCEANICITY

A quantitative measure of the ocean's effect on climate is found in the form of a numerical index titled oceanicity. The Glossary of Meteorology [Huschke, 1959] defines oceanicity as "the degree to which a point on the earth's is in all respects subject to the influence of the sea" and goes on to say that oceanicity "refers to climate and its effects."

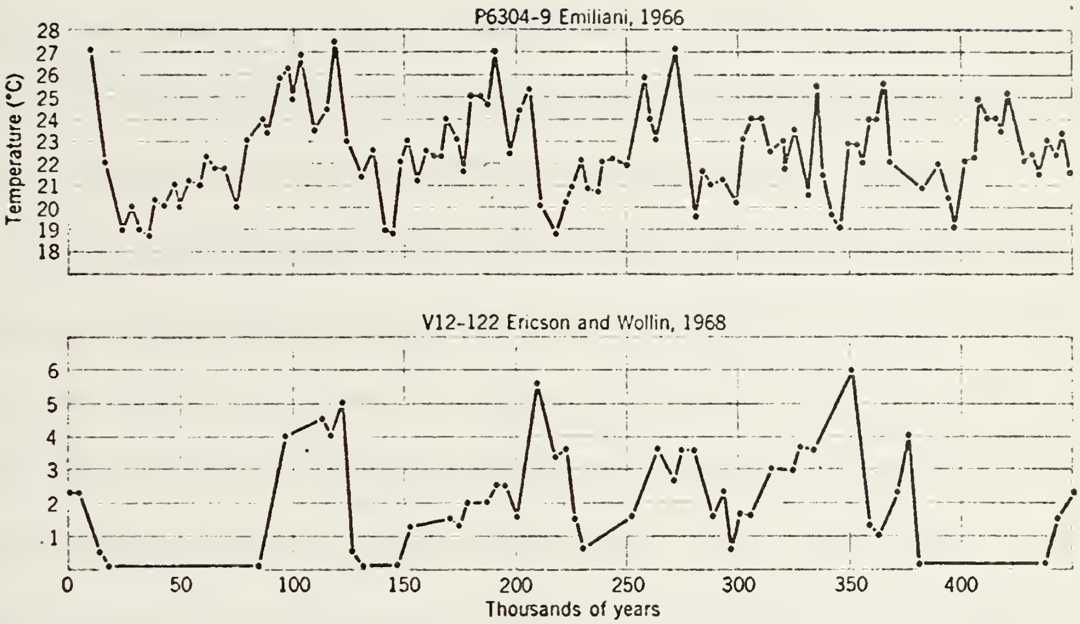

Figure 18. Comparison of temperature curves from two Caribbean cores which indicate the climate chronology deduced from the curves. Time is given on the horizontal scale. In the lower core amount of warm and cold water species is the criterion; in the top, temperature is deduced from O^{18}/O^{16} ratio (Donn, 1972, after Emiliani, 1966).

Oceanicity is contrasted to continentality and the effects of land on the climate. Oceanicity could be redefined as the degree to which the climate at any point on the earth's surface is influenced by the sea. Ignoring the biosphere and cryosphere momentarily, the lithosphere and hydrosphere are the two primary sources of atmospheric climate change on the earth's surface. Land and ocean masses pitted against each other across boundary areas regulate the development of climate at any given region.

On continental land masses and islands of large size, the oceanic influence under prevailing onshore winds dominates the coastal area and up to 100 miles inland under extreme conditions. Offshore winds, on the other hand, allow the continental influence to extend seaward, but with much less intensity or extent, traditionally stated in literature to be held within one or two miles from the coast. Several field investigations conducted by the U. S. Navy's Environmental Prediction Research Facility in September of 1972 help to determine the range of coastal influence off the California coast. Laevastu and Hamilton [1974] observed that the properties of the sea surface and air come to typical oceanic equilibrium conditions anywhere from 15 to 60km away from the coast dependent upon the synoptic conditions of the atmosphere, the time of the year, and time of the day. The continental influences are well illustrated by the sea and land breeze circulation as mentioned before. Under certain atmospheric conditions, localized land winds, especially along mountainous coastal areas where local winds are channeled into jet-effect winds, are felt up

to 100 miles out to sea [Huschke, 1959]. These jet-effect winds, are short-time occurrences, only lasting from 1 to 4 days. However, they are a distinctive part of the climate in certain localities around the world. Two such dramatic winds described by Huschke [1959] in the Glossary of Meteorology are the Tehuantepecer and the Düsenwind. The Tehuantepecer is a violent winter-time wind that blows out into the Gulf of Tehuantepecec, found south of southern Mexico in the Pacific Ocean. Similarly, the Düsenwind passes through a narrow mountain gap in the Dardanelles between the Black Sea and the Aegean Sea, caused by a ridge of high pressure over the Black Sea. This east-northeast wind swoops down on the coastal seas to be felt as far as the island Limnos, approximately 50 miles out into the Aegean Sea.

The development of the oceanicity index has been approached in two distinct methods. One measure of oceanicity as discussed by Landsberg [1945] has been the contrast between maritime and continental air masses. An index of this type uses the ratio of the frequencies of air masses of maritime (M) and continental (C) origin, thus

$$0 = M/C$$

where 0 is oceanicity. The M/C ratio for an average year on the eastern seaboard of the United States is about .83, indicating a more continental than maritime influence on this coastal area, which agrees with previous discussions of prevailing winds and the effect of current systems in that area. Western Europe on the other hand, registers a 3.3 ratio denoting

a large maritime air mass influence on the climate of this region as a result of the coupling of the ocean-atmosphere influences.

A second technique using a numerical index was defined as a thermo-isodromic ratio by F. Kerner in 1905. Landsberg [1964] explains this statistical determination of oceanicity using the Kerner concept. Kerner's numerical index was developed from observations over a long period of time that the spring months in maritime climates are much colder than the corresponding autumn months. This empirical evidence led to an oceanicity equation

$$0 = 100 \quad \frac{T_o - T_a}{A}$$

where T_o, T_a are the monthly mean temperatures for October and August, and A is the annual range of temperatures. Selected values of oceanicity shown in Table 6 illustrate Kerner's formula for oceanicity. Verkhoyansk, USSR, in the Taiga climatic zone exemplifies an extreme continental influence as compared to Honolulu, Hawaii, a station with a very high oceanic influence. This second type of oceanicity index could have a larger use as the scientific community becomes more aware of the role of the oceans in climatic changes today.

Table 6. Kerner's Oceanicity Index for selected stations (Landsberg, 1964).

Station	T_o	T_a	T_w	T_c	A	O %
Verkhoyansk, USSR..	−14.6	−12.1	16.5	−46.2	62.7	− 4
Bismarck, N. D.......	6.9	6.2	21.1	−12.7	33.8	2
Winnipeg, Manitoba..	4.8	3.2	19.1	−19.9	39.0	4
Bergen, Norway......	7.5	5.6	14.3	1.1	13.2	14
Tokyo, Japan........	15.8	12.5	25.4	3.0	22.4	15
New York, N. Y......	13.2	9.2	23.1	− 0.8	23.9	17
San Diego, Calif......	17.3	14.6	20.2	12.2	8.0	34
San Francisco, Calif...	14.9	12.4	15.5	9.7	5.8	43
Honolulu, Hawaii	24.9	22.8	25.8	21.5	4.3	49

IV. REVIEW OF HYDROCLIMATIC PRODUCTS USEFUL TO METEOROLOGISTS

A. PROCEDURE

The collection of selected hydroclimatic products for evaluation was a dusty task. Atlases and charts by the nature of their subject and presentation are ordinarily large cumbersome publications stored away in some hidden bookshelf, cabinet, or back room. The publications used in this thesis for review were derived from sources at, near, or co-located with the Naval Postgraduate School (NPS), Monterey, California. The libraries and collections from which a portion of these publications were borrowed for review are as follows:

1. NPS Dudley Knox Library
2. NPS Oceanography Department Collection
3. NPS Meteorology Department Collection
4. Environmental Prediction Research Facility (EPRF) Technical Library
5. Hopkins Marine Station Library

In addition there were many publications generously loaned by individuals to make this review more complete. These people included: T. Laevastu, Head, Oceanography Department, EPRF; Prof. Dale F. Leipper, Chairman, NPS Oceanography Department; Gunter R. Seckel, Oceanographer, National Marine Fisheries Service; Prof. Willem Van der Bijl, Assoc. Prof. of Meteorology, NPS; and Roger A. Bauer, Compass Systems, Inc.

The evaluation of hydroclimatic products required a subjective selection of those most relevant for consideration due to the abundant supply of materials available. Hydroclimatic products most closely oriented toward climatic changes and of interest to the meteorologist were chosen as the most desirable for a better understanding of the ocean's role in climatic changes.

The evaluation of many different hydroclimatic products facilitated the development of a review form for standardization, ease of comparison, and that would be most useful to meteorologists. Besides the normal identification by title, author, publisher, and date, there were five additional descriptions and one subjective evaluation. These five descriptions included: (1) the region of coverage, with name of geographical ocean and latitude-longitude boundaries; (2) the source of data, such as from BT's, ship injection temperatures, Nansen casts, STD's, weather observations, etc.; (3) contributors, whether the data came from military or merchant ships, weather ships, different institutions, universities, or countries, etc.; (4) format of presentation, with the type of projection map used and the form of analyses, whether isopleth, arrows, current roses, etc.; and (5) quantity of data, when given. The last criteria was a personal subjective evaluation of the hydroclimatic products. This pertained to the overall worth of the publication in comparison with other products and pertinent comments about the detail of analysis, presentation, and usefulness of the product.

The selection of hydroclimatic products with oceanic parameters relevant to climatic changes focused attention on sea-surface temperatures (SST), subsurface temperatures, air temperature minus SST differences, surface currents, and other pertinent information related to these four. By far the most important aspect of hydroclimate influencing climatic changes is sea surface temperature. The mean, minimum, and maximum SST along with SST anomaly analyses were regarded as the primary hydroclimatic parameter to evaluate. The presentations of this parameter varied considerably. SST were analyzed monthly, seasonally, (February, May, August, November), semi-annually (winter-summer), annually, and occasionally with a depiction of seasonal or annual range. Normally the publications presented the SST with isotherm or isopleth analyses, but there were exceptions with printed or tabular forms of SST. The degree of detail in analyses ranged widely from .1°F to 10°F or from .1°C to 5°C with most analyses using a 1°C contour interval.

The subsurface temperature analyses, with related information on the top of the thermocline, the average layer depth, and the mixed layer depth (MLD), as found in different atlases, provided valuable information on the heat content of the ocean. Analyses of subsurface temperatures on horizontal levels were done in a manner similar to SST. The isopleth analyses of the top of the thermocline, the average layer depth, and mixed layer depth were generally done at 50-foot contour intervals, although finer contour intervals were used in some restricted regions.

This subsurface information along with isopleth analyses of the heat exchanges (loss and gains) at the sea surface provide a world of information to the meteorologist on the heat content of the ocean at the surface and below.

Air temperature minus SST difference is an old tool, that although it is not truely a hydroclimatic parameter, it is of significant interest to a better understanding of the ocean's influence on the atmosphere and climate. The charts with this information provide a generalized picture of the average stability or instability of the lower layers of the atmosphere immediately above the sea surface. Generally found in meteorological publications, there was a bias toward seasonal analyses based on atmospheric temperature extremes rather than oceanic temperature extremes. Therefore, in addition to the monthly isopleth analyses when the data is plentiful, the analyses were centered on the mid-months of the atmospheric seasons (January, April, July, October) rather than oceanic seasons.

The surface current circulations, their prevailing and resultant directions, and velocities are another hydroclimatic parameter of interest. The analyses of surface currents were normally done on a monthly basis, but there were exceptions with annual, semi-annual (winter-summer), and seasonal (both January, April, etc., and February, May, etc.) analyses. The most common form of presenting surface currents was by the use of a solid black arrow for general direction of the current and

with velocities printed in nautical miles or miles per day and knots. Prevailing currents were often depicted by current roses. Various other forms of presentation were utilized including: isopleth analyses of velocities, variable length of arrows for frequency of current, barbs on arrow shafts for velocities, etc.

All hydroclimatic products were divided into categories for ease of comparison. The first division placed the products into the major ocean they represented. Products were then evaluated as to whether they possessed temperature or surface current information or both. A third category of separation divided those products that represented the major ocean or some restricted region. The major ocean groups included the world oceans, the polar seas, the Indian Ocean, the Pacific Ocean, and the Atlantic Ocean. Based upon the idea that SST, subsurface temperature, air temperature minus SST, and surface currents were the most important selected parameters of evaluation, in that order, a listing of the best or most useful products was made on a subjective basis. Restricted region products are at the end of each list for the major oceans, not because they aren't the most useful, but because they do not represent the whole ocean basin. Following the summary listing of major hydroclimatic products by the categorization scheme described above, and a list of additional useful publications, there is a detailed coverage of each listed product with complete publishing data.

B. LIST OF MAJOR HYDROCLIMATIC PRODUCTS

World Oceans

1) WORLD ATLAS OF SEA SURFACE TEMPERATURES H. O. Pub. No. 225

2) U. S. NAVY MARINE CLIMATIC ATLAS OF THE WORLD VOL III, NAVAER 50-1C-54

3) THE TIMES ATLAS OF THE WORLD VOL I WORLD, AUSTRALASIA & FAR EAST ASIA

4) ATLAS OF WORLD PHYSICAL FEATURES

5) ATLAS OF CLIMATIC CHARTS OF THE OCEANS NAVAER 50-11OR-25 (W.B. No. 1247)

Polar Seas

1) U. S. NAVY MARINE CLIMATIC ATLAS OF THE WORLD VOL VIII ANTARCTIC NAVWEPS 50-1C-50

2) OCEANOGRAPHIC ATLAS OF THE POLAR SEAS PART I-ANTARCTIC H. O. Pub. No. 705

3) OCEANOGRAPHIC ATLAS OF THE POLAR SEAS PART II-ARCTIC H. O. Pub. No. 705

Indian Ocean

1) MONTHLY CHARTS OF MEAN, MINIMUM, AND MAXIMUM SEA SURFACE TEMPERATURE OF THE INDIAN OCEAN SP-99

2) GEOGRAPHIE des INDISCHEN UND STILLEN OZEANS

3) U. S. NAVY MARINE CLIMATIC ATLAS OF THE WORLD VOL III INDIAN OCEAN NAVAER 50-1C-530

4) CLIMATIC SUMMARIES FOR MAJOR SEVENTH FLEET PORTS AND WATERS NAVAIR 50-1C-62

5) ATLAS OF SURFACE CURRENTS INDIAN OCEAN H. O. Pub. No. 566

6) ATLAS OF PILOT CHARTS South Pacific and Indian Oceans H. O. Pub. No. 107

7) CURRENTS IN THE SOUTH CHINA, JAVA, CELEBES, AND SULU SEAS H. O. Pub. No. 236

8) METEOROLOGICAL ATLAS OF THE INTERNATIONAL INDIAN OCEAN EXPEDITION VOL I - THE SURFACE CLIMATE OF 1963 & 1964

9) OCEANOGRAPHIC ATLAS OF THE INTERNATIONAL INDIAN OCEAN EXPEDITION

10) U. S. NAVY REPRINT - WIND AND WEATHER, CURRENTS, TIDES, AND TIDAL STREAMS IN THE EAST INDIAN ARCHIPELAGO NAVAER 50-1R-39

Pacific Ocean

1) MONTHLY CHARTS OF MEAN, MINIMUM, AND MAXIMUM SEA SURFACE TEMPERATURE OF THE NORTH PACIFIC OCEAN SP-123

2) MONTHLY MEAN CHARTS SEA SURFACE TEMPERATURE NORTH PACIFIC OCEAN 1949-62 CIRCULAR 258

3) GEOGRAPHIE des INDISCHEN UND STILLEN OZEANS

4) ATLAS OF MONTHLY MEAN SEA SURFACE AND SUBSURFACE TEMPERATURE AND DEPTH OF THE TOP OF THE THERMOCLINE NORTH PACIFIC OCEAN

5) ATLAS OF NORTH PACIFIC OCEAN MONTHLY MEAN TEMPERATURES AND MEAN SALINITIES OF THE SURFACE AND SUBSURFACE LAYERS

6) FAR EAST CLIMATIC ATLAS

7) MONTHLY MEAN CHARTS SEA SURFACE TEMPERATURE NORTH PACIFIC OCEAN CIRCULAR 134

8) U. S. NAVY MARINE CLIMATIC ATLAS OF THE WORLD VOL V SOUTH PACIFIC OCEAN NAVAER 50-1C-532

9) MONTHLY THERMAL CONDITIONS CHARTS FOR THE NORTH PACIFIC OCEAN H. O. Pub. No. 762

10) CLIMAT - NORTH PACIFIC OCEAN 14ND - FWC - P 26

11) U. S. NAVY MARINE CLIMATIC ATLAS OF THE WORLD VOL II NORTH PACIFIC OCEAN NAVAER 50-1C-529

12) ATLAS OF TEMPERATURE, SALINITY AND DENSITY OF WATER IN THE PACIFIC OCEAN

13) OCEANOGRAPHIC AND METEOROLOGICAL OBSERVATIONS IN THE CHINA SEAS AND IN THE WESTERN PART OF THE NORTH PACIFIC OCEAN NAVAER 50-1R-173

14) ATLAS OF SURFACE CURRENTS NORTHEASTERN PACIFIC OCEAN H. O. Pub. No. 570

15) ATLAS OF SURFACE CURRENTS NORTHWESTERN PACIFIC OCEAN H. O. Pub. No. 569

16) ATLAS OF SURFACE CURRENTS SOUTHWESTERN PACIFIC OCEAN H. O. Pub. No. 568

17) CLIMATOLOGICAL AND OCEANOGRAPHIC ATLAS FOR MARINERS VOL II NORTH PACIFIC OCEAN

18) ATLAS OF MONTHLY MEAN SEA SURFACE AND SUBSURFACE TEMPERATURES IN THE GULF OF CALIFORNIA, MEXICO

19) OCEAN CURRENTS IN THE VICINITY OF THE JAPANESE ISLANDS AND CHINA COAST H. O. Pub. No. 237

20) CURRENTS IN THE SOUTH CHINA, JAVA, CELEBES, AND SULU SEAS H. O. Pub. No. 236

21) EASTROPAC ATLAS CIRCULAR 330 VOLUMES 1, 3, 5, 7, &9

22) OCEANIC OBSERVATIONS OF THE PACIFIC 1955 - THE NORPAC ATLAS

23) OCEANOGRAPHIC ATLAS OF THE PACIFIC OCEAN

Atlantic Ocean

1) OCEANOGRAPHIC ATLAS OF THE NORTH ATLANTIC OCEAN SECTION II PHYSICAL PROPERTIES Pub. No. 700

2) GEOGRAPHIE des ATLANTISCHEN OZEANS

3) SERIAL ATLAS OF THE MARINE ENVIRONMENT Folio 16 Mean Monthly Sea Surface Temperatures and Zonal Anomalies of the Tropical Atlantic

4) SERIAL ATLAS OF THE MARINE ENVIRONMENT Folio 2 North Atlantic Temperatures at a Depth of 200 Meters

5) CLIMATOLOGICAL AND OCEANOGRAPHIC ATLAS FOR MARINERS VOL I NORTH ATLANTIC OCEAN

6) ENROUTE WEATHER GUIDE

7) U. S. NAVY MARINE CLIMATIC ATLAS OF THE WORLD VOL I NORTH ATLANTIC OCEAN NAVAER 50-1C-528

8) U. S. NAVY MARINE CLIMATIC ATLAS OF THE WORLD VOL IV SOUTH ATLANTIC OCEAN NAVAER 50-1C-531

9) OCEANOGRAPHIC ATLAS OF THE NORTH ATLANTIC OCEAN SECTION I TIDES AND CURRENTS Pub. No. 700

10) ATLAS OF SURFACE CURRENTS NORTH ATLANTIC OCEAN H. O. Pub. No. 571

11) ATLAS OF PILOT CHARTS CENTRAL AMERICAN WATERS AND SOUTH ATLANTIC OCEAN Pub. No. 106

12) ATLAS OF PILOT CHARTS NORTHERN NORTH ATLANTIC OCEAN H. O. Pub. No. 108

13) THE ENGLISH CHANNEL PART I OCEANOGRAPHY VOL IV No. 2

14) MONTHLY MEAN SEA SURFACE AND SUBSURFACE TEMPERATURE AND DEPTH OF THE TOP OF THE THERMOCLINE: MEDITERRANEAN, BLACK AND RED SEAS TECH NOTE No. 73-3

15) Monatskarten der Oberflächentemperatur für die Nord und Ostsee und die angrenzenden Gewässer Nr. 2336

16) Monatskarten der Temperatur der Nordsee, dargestellt für verschiedene Tierfenhorizonte

17) ATLAS OF MONTHLY MEAN SEA SURFACE AND SUBSURFACE TEMPERATURE AND DEPTH OF THE TOP OF THE THERMOCLINE GULF OF MEXICO AND CARIBBEAN SEA

18) THREE-DIMENSIONAL DIGITAL OCEAN CLIMATOLOGY FOR THE WESTERN NORTH ATLANTIC

19) SERIAL ATLAS OF THE MARINE ENVIRONMENT Folio 7 Surface Circulation on the Continental Shelf Off Eastern North America between Newfoundland and Florida

20) SERIAL ATLAS OF THE MARINE ENVIRONMENT Folio 21 Average Monthly Sea-Water Temperatures Nova Scotia to Long Island

21) ENVIRONMENTAL ATLAS OF THE TONGUE OF THE OCEAN, BAHAMAS

22) SERIAL ATLAS OF THE MARINE ENVIRONMENT Folio 1 Sea Surface Temperature Regime in the Western North Atlantic 1953-1954

23) SERIAL ATLAS OF THE MARINE ENVIRONMENT Folio 15 Monthly Sea Temperature Structure from the Florida Keys to Cape Cod

C. LIST OF ADDITIONAL USEFUL PUBLICATIONS

1. Coastal Upwelling Ecosystems Analysis, CUE-I Meteorological Atlas, v One, by J. J. O'Brien, 309 pp, October 1972

2. Coastal Upwelling Ecosystems Analysis, CUE-I Meteorological Atlas, v Two, by R. D. Pillsbury, J. J. O'Brien, and A. Johnson, Jr., 229 pp, September 1974.

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NOTE: "THE SOVIETS HAVE PUBLISHED A NEW ATLAS OF THE PACIFIC OCEAN. In a Pravda interview, deputy director of the Oceanographic Institute, Doctor of Geographical Sciences A. M. Muromtsev, said that the new book, which is part I of a three-part work titled The Atlas of the Oceans, deals with such physical measurements as the depths of water to 5,000m and the atmosphere to an altitude of 16-18 km. The most important expeditions which contributed to geographic discoveries are shown, as well as descriptions of the bottom, climate, hydrography; epicenters of strong underwater earthquakes, volcanos and tsunamis; charts of the chemical structure of water; temperature and salinity of the water; speed of sound on the surface and in the depths; tides and winds. All charts are based on observations made by Soviet and Western research ships." Taken from Ocean Science on Station by J. R. Botzum (editor), v17, 25 July 1975.

D. INDIVIDUAL HYDROCLIMATIC REVIEWS

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: WORLD ATLAS OF SEA SURFACE TEMPERATURES H. O. Pub. No. 225

AUTHOR: Scripps Institution of Oceanography

PUBLISHER: Hydrographic Office, United States Navy

DATE: 1944 2nd ed (reprinted 1969)

REGION OF COVERAGE: World Oceans - Atlantic, Pacific, and Indian Oceans 90°S-90°N

SOURCE OF DATA: SST information collected by U. S. Hydrographic Office with additional information provided by 41 sources cited in reference.

CONTRIBUTORS: The major contributors include the U. S. Hydrographic Office, Scripps Institution of Oceanography, Japan, Germany, Norway, USSR, Canada, Denmark, Great Britain, the Netherlands, and the U. S. Coast Guard.

FORMAT OF PRESENTATION: The world oceans were divided into regions on an equal area map projection from 90°S to 90°N latitude portraying the Atlantic, the Eastern Pacific, the Western Pacific, and the Indian Oceans each with a 12 month series of average sea surface temperature charts. Solid isotherms were shown for intervals of 5°F, except in the regions of small horizontal temperature gradients where 2.5°F dashed contour intervals were used. In areas of sparse data dash-dot isotherms were interpolated. Ice limits were added whenever possible by mean, extreme, and interpolated symbols.

QUANTITY OF DATA: Millions of correlated individual observations taken from the files of the U. S. Hydrographic Office and other sources.

SUBJECTIVE EVALUATION: This atlas was described at the time of publication as the most accurate compilation pattern of sea surface temperatures of the world to date (1944). More extensive data collections within new atlases have improved little on this atlas for the broad scale picture, except in the polar regions and the Indian Ocean where concentrated efforts in recent years have made up for past neglect. Newer atlases are concentrating on presenting each ocean with finer detailed analyses than found here to complement this classical presentation.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: U. S. NAVY MARINE CLIMATIC ATLAS OF THE WORLD VOL VIII NAVAER 50-1C-54

AUTHOR: Dr. H. L. Crutcher and Mr. O. M. Davis of NWRC

PUBLISHER: U. S. Government Printing Office

DATE: 1 March 1969

REGION OF COVERAGE: World's oceans 75°S-75°N lat, 30°E-45°E long

SOURCE OF DATA: Data derived over 100 years from many institutions and countries by way of ship observations.

CONTRIBUTORS: U. S. Navy and Merchant Marine, Germany, Britain, Netherlands, France, Norway, Canada, Japan, Argentine, Australia, Chile, Denmark, New Zealand, Union of South Africa, and the USSR were some of the major contributors.

FORMAT OF PRESENTATION: Mercator map projection with isotherm analyses. The monthly SST's are analyzed at 10°F isotherm contour intervals from a 30°F low to 80°F high.

QUANTITY OF DATA: 20 million surface marine weather observations.

SUBJECTIVE EVALUATION: Over ninety-five percent of this atlas is meteorological, with only one type of information having to do with ocean hydroclimate. This type of SST analysis is good only for the broad scale features since no detail has been provided.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: THE TIMES ATLAS OF THE WORLD VOL I WORLD, AUSTRALASIA & EAST ASIA MID-CENTURY EDITION

AUTHOR: John Bartholomew

PUBLISHER: The Times Publishing Company LTD, Printing House Square, London, England

DATE: 1958

REGION OF COVERAGE: World, Australasia & East Asia

SOURCE OF DATA: Not stated.

CONTRIBUTORS: Not stated.

FORMAT OF PRESENTATION: Lotus conformal projection used to illustrate continuity of ocean flow around the world. Mean SST shown for July and January using a 10^{o}F isotherm contour interval and color shading, with ice fields depicted by symbols. SST analyses on map projection with scale 1:250,000,000. Larger map, scale 1:80,000,000, used to depict ocean surface currents. Solid red arrows used for warm currents, dashed arrows used for cold currents. Arrows in Indian Ocean, China Sea and off the West Coast of Central America have a circle in the middle of the shaft to indicate N.W. and S.W. Monsoon Drift during the northern winter, simple shaft for summer conditions of S.W. and S.E. Monsoon Drift. Areas of convergence shown by dotted line.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The atlas provides a good description of the broad features of the ocean surface currents and SST patterns for the casual observer using an unique projection.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: ATLAS OF WORLD PHYSICAL FEATURES

AUTHOR: Rodman E. Snead

PUBLISHER: John Wiley & Sons, Inc.

DATE: 1972

REGION OF COVERAGE: World's oceans

SOURCE OF DATA: Not stated.

CONTRIBUTORS: Not stated.

FORMAT OF PRESENTATION: Mercator Projection with seasonal isotherm analyses for August and February at a 9°F isotherm interval presented on one chart. Each season has a different color for isotherm analysis.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: Atlas is primarily set up for more geological and geographical features than oceanic parameters. Best used for illustration of seasonal differences. The contrasting colors used for seasonal analysis aids the individual in picturing the annual cycle of temperature changes over the ocean.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: ATLAS OF CLIMATIC CHARTS OF THE OCEANS NAVAER 50-110R-25 (W.B. No. 1247)

AUTHOR: Willard F. McDonald, U. S. Weather Bureau

PUBLISHER: U. S. Government Printing Office

DATE: 1938

REGION OF COVERAGE: Atlantic, Pacific, & Indian Oceans 60^{o}S-67^{o}N lat, 60^{o}W-80^{o}W long

SOURCE OF DATA: Derived directly and exclusively from original weather observations in the files of the U. S. Weather Bureau from ships at open sea positions over a 50-year period between 1885 and 1933, 90% of which has air and sea temperatures. Most SST's taken from bucket supplies, but a small part based on condenser intake water, obtained a few meters below the surface.

CONTRIBUTORS: Ships from the United States of America, Great Britain, Netherlands, France, Germany, and Japan were the major contributors.

FORMAT OF PRESENTATION: Equatorial Cylindrical map projection with isopleth analyses of temperature difference between air and sea surface temperatures and printed averages of air and sea surface temperatures. Ninety-five percent of the atlas pertains to meteorological parameters of climatic interest presented on a monthly or seasonal basis. Average temperatures of the air and sea surface and sea-air temperature difference charts are limited to the Pacific and Atlantic Oceans from 10^{o}S to 67^{o}N latitude and from 120^{o}E to 10^{o}E longitude. The monthly average temperature values to a tenth of a degree Fahrenheit are printed for each 5^{o} lat. long. quadrange. Upper figures in red are averages of dry bulb thermometer readings as observed on the ship's bridge. Lower figures in gray are mean sea surface temperatures. The sea-air temperature difference charts are represented seasonally (December-February, March-May, etc.) in degrees Fahrenheit. Isopleth

analyses with shading describe temperature differences (black for positive, red for negative) with 1°F contour intervals except near zero change, where 0.5°F positive and negative values were used.

QUANTITY OF DATA: Approximately 5.5 million observations.

SUBJECTIVE EVALUATION: The atlas is definitely meteorologically oriented with the SST information presentation considered to be different, but not too useful. The printed average SST temperatures, even with their degree of accuracy, present no visual image of a smooth isotherm field. There is a good picture provided for influence of ocean surface conditions on overlying air temperatures in the temperature difference charts, but here again lies a hidden problem. The seasonal extremes for ocean temperatures lag the air temperature extremes by one month, so that the seasonal presentation of these charts is biased toward the atmosphere as compared to the oceans.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: U. S. NAVY MARINE CLIMATIC ATLAS OF THE WORLD VOL. VII NAVWEPS 50-1C-50

AUTHOR: Naval Weather Service

PUBLISHER: U. S. Government Printing Office

DATE: 1 September 1965

REGION OF COVERAGE: Antarctic Ocean $90^{\circ}S$-$40^{\circ}S$-$20^{\circ}S$ lat in corners of diagram.

SOURCE OF DATA: Sea surface temperatures adapted from Oceanographic Atlas of the Polar Seas Part I. Antarctic H. O. Pub. No. 705, with additional data added.

CONTRIBUTORS: U. S. Weather Bureau, NWRC, United States of America, Germany, Netherlands, Britain, USSR, and Japan plus other station data from additional countries.

FORMAT OF PRESENTATION: Polar azimuthal projection with various isopleth analyses, bar graphs, tables, cumulative frequency diagrams, and other forms of presentation for meteorological and oceanographic parameters. The mean SST analyses are seasonal (February, May, August, November) with a $2.5^{\circ}F$ isotherm contour interval.

QUANTITY OF DATA: Over 1 million weather observations for ocean and sea areas. 70,000 observations for selected ocean areas.

SUBJECTIVE EVALUATION: The atlas presentation of SST analyses shows much improvement over the previous publication, extending much farther north in latitude. More improvement in the future could be accomplished with monthly analyses rather than seasonal and at a finer scale, such as $1^{\circ}C$. This type of atlas can only be improved with a much larger data base upon which to make the evaluations. The atlas as a whole is a meteorological atlas with only one set of hydroclimatic charts of interest.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: OCEANOGRAPHIC ATLAS OF THE POLAR SEAS PART I - ANTARCTIC H.O. Pub. No. 705

AUTHOR: U. S. Navy Hydrographic Office

PUBLISHER: U. S. Navy Hydrographic Office

DATE: 1957 (reprinted 1970)

REGION OF COVERAGE: Antarctic Ocean 90°S-50°S lat, 360° long

SOURCE OF DATA: Compiled from punch card deck based on H. O. H 1-9 Current Report Forms for years 1904 to 1945 and from additional data given by the U. S. Weather Bureau.

CONTRIBUTORS: List of 91 references representing many countries and institutions.

FORMAT OF PRESENTATION: Polar azimuthal projection centered on the south pole, 90°S. Average SST analyses shown at 2.5°F contour intervals for representative seasonal months (February, May, August, November). These charts also depict mean ice limits by hatching and cumulative frequency diagrams of air-sea temperature differences at selected locations where at least 30 observations were available for analysis. An additional chart shows the comparative SST conditions for points equidistant from the continent illustrated by the use of shading where the temperature difference (°F) is shown between mean SST and February mean SST's computed along lines equidistant from the continent. General surface current circulation pattern depicted by solid arrows for areas of adequate data and dashed arrows for areas of sparse data. Printed numbers located randomly indicate current speed to the tenth of a knot.

QUANTITY OF DATA: Not stated

SUBJECTIVE EVALUATION: The atlas provides a realistic picture of the SST properties in the Antarctic Ocean areas especially with the limited data available. The SST analyses are representative of the upper 350 to 150 feet of water rather than the surface

conditions above, due to the isothermal nature of the surface water layers, so this fact must be taken into consideration. The use of cumulative frequency diagrams instead of an isopleth analysis of the air-sea temperature difference represents the sparcity of data in this region. The diagrams do aid the observer in determining the stability or instability of the atmosphere over these selected locations. The comparative SST chart shows those longitudes at which relatively warm or cold waters persist around Antarctica.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: OCEANOGRAPHIC ATLAS OF THE POLAR SEAS PART II - ARCTIC H.O. Pub. No. 705

AUTHOR: U. S. Navy Hydrographic Office

PUBLISHER: U. S. Navy Hydrographic Office

DATE: 1958

REGION OF COVERAGE: Arctic Ocean 90°N-65°N lat, 360° long

SOURCE OF DATA: Oceanographic knowledge of the Arctic prior to IGY 1957 58. Atmospheric data obtained from U.S. Weather Bureau.

CONTRIBUTORS: List of 124 references representing many countries and institutions.

FORMAT OF PRESENTATION: Polar azimuthal projection centered on 90°N. Average SST analyses prepared for representative seasonal months (February, May, August, November) at a 2.5°F isotherm contour interval. Cumulative frequency curves of air-sea temperature differences for selected locations are shown on the same type of projection for seasonal months also. The SST charts have dashed isopleth representing the zone bounded by the extent of the mean 1/10 ice coverage whereas the air-sea temperature difference charts have hatching to indicate the mean limit of ice ≥ 5/10 coverage. One additional chart depicts average subsurface temperature at 300 feet with 2.5°F isotherm intervals. Surface current circulation depicted by black arrows with randomly printed speed values to the tenth of a knot for the entire Arctic region and seven additional restricted straits and seas.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The atlas is undoubtedly restricted by lack of data. The broad-scale features are evident in the analyses for SST and surface currents, although refinements are definitely possible. SST analyses limited for all seasons except August

to the regions around central to southern Greenland, the Norwegian and Barents Seas, all south of 80°N. August analysis is the most extensive, but again limited primarily to the coastal regions of the continents and islands surrounding the Arctic Ocean. The cumulative frequency curves offer information for the selected locations but give no broad scale regional view of the oceanic influence on the stability of the atmosphere immediately above the sea surface. The 300-foot average temperature offers a look at the heat content of the subsurface waters. More extensive effort needed to provide amount of data required for monthly analyses rather than seasonal, and extention to evaluation of means, minimum, and maximum isotherm analyses with a finer scale, such as 1°C.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: MONTHLY CHARTS OF MEAN, MINIMUM, AND MAXIMUM SEA SURFACE TEMPERATURE OF THE INDIAN OCEAN SP-99

AUTHOR: U. S. Naval Oceanographic Office

PUBLISHER: U. S. Naval Oceanographic Office

DATE: 1967

REGION OF COVERAGE: Indian Ocean 50°S-30°N lat, 20°E-150°E long

SOURCE OF DATA: Ship injection temperature data collected over 100 years, from 1854-1961 and maintained by NWRC.

CONTRIBUTORS: U. S. Navy & Merchant Marine, Japan, Denmark, Britain, Netherlands, and German ships

FORMAT OF PRESENTATION: The Equatorial cylindrical map projections with monthly mean, minimum, and maximum SST charts are analyzed at 2°F isotherm intervals except in areas of weak temperature gradients where a 1°F dashed isotherm interval was used. Each 10°F isotherm interval is darkened for easy reading. Gray shading of 1° quadrangles shows areas of data observations of 25 or more. Monthly variability of SST in 49 selected regions of the Indian Ocean are presented for further study.

QUANTITY OF DATA: 6,467,349 ship injection temperature observations.

SUBJECTIVE EVALUATION: Excellent statistical presentation of SST properties over a long period of time. It would be hard to improve on this product. A 1°C analysis, in fact, would possibly cause more trouble than it would benefit as isotherm packing develops.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: GEOGRAPHIE des INDISCHEN UND STILLEN OZEANS

AUTHOR: Gerhard Schott

PUBLISHER: Verlag Von C. Boysen, Hamburg

DATE: 1935

REGION OF COVERAGE: Indian & Pacific Oceans 90°S-90°N lat, 10°E-70°W long

SOURCE OF DATA: Oceanographic and other scientific observations collected from all major oceanic cruises up to 1933. Additional information collected from regional studies by various institutions and countries.

CONTRIBUTORS: Some of the major contributing countries include Germany, Britain, Russia, Norway, United States of America, Portugal, Denmark, Canada, France, and Spain.

FORMAT OF PRESENTATION: Azimuthal equal area map projection with isopleth analyses for many oceanic and atmospheric parameters. Other parameters depicted by arrows, course tracks, and color shading. Scale 1:90,000,000. Map centered on 150°E. Tables XX-XXIII depict seasonal (February, May, August, November) SST's at 1°C isotherm intervals with every 5°C isotherm darkened. The thermal equator position is indicated on each chart as well as color shading from low (green) to high (red) temperatures to aid the observer. Table XXIV shows the mean annual range of SST's in a 1°C isopleth analysis. Color shading enhances changes from low to high positive variations with ranges from 1°C to 25°C. Tables XXV and XXVI show the temperature anomalies of SST's at 1°C contour intervals with color shading again (positive-red and negative-blue) for the winter (February) and summer (August). Tables XXIX and XXX show winter and summer (northern hemisphere) surface currents for the region by black arrows, with the length and width of arrows indicating duration and speed. Speed of currents is given by nautical miles per day. The major currents are labeled and regions of convergence or divergence are shown in the tropics, subtropics, and subpolar areas by different

symbols. In addition, limits of sea ice and pack ice (southern hemisphere), and upwelling areas are indicated by sybols in a contrasting green color. Tables XXXI & XXXII depict the subsurface temperatures at 200 and 400m depths with $1^{\circ}C$ isotherm intervals and color shading to enhance the presentation.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: Basically a geography text that covers all phases of the geographical area in the Pacific and Indian Oceans, especially oceanographic, meteorological, biological, and geological aspects. The thirty-seven tables at the end of the text present some very interesting hydroclimatic products, especially in the statistical analysis of SST's, temperature anomalies, and surface currents. The seasonal SST isotherm analyses are useful, although monthly analyses would have been more useful. Considering this atlas was prepared in 1935, a $1^{\circ}C$ isopleth analysis for SST's, temperature anomalies, and annual ranges presents a detailed series. Additional emphasis on ocean surveys in the Indian Ocean area since the preparation of these tables could provide a more reliable analysis of features presented. The presentation for surface currents is good although current roses at selected locations would have provided additional detail if presented on a separate companion chart. The subsurface temperature charts completed a classical package, allowing one to look at the heat content of the world's oceans in this region.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: U. S. NAVY MARINE CLIMATIC ATLAS OF THE WORLD VOL. III INDIAN OCEAN NAVAER 50-1C-530

AUTHOR: Naval Weather Service

PUBLISHER: U. S. Government Printing Office

DATE: 1 September 1957

REGION OF COVERAGE: Indian Ocean 55°S-32°N lat, 25°E-180°E long

SOURCE OF DATA: Charts are based almost entirely on observations made by observers employed by or cooperating with foreign meteorological services and collected at the U. S. Weather Bureau, National Weather Records Center, Asheville, N.C.

CONTRIBUTORS: Union of South Africa Weather Bureau prepared most of the southern hemisphere information. Netherlands, United Kingdom, Germany, and the United States provided surface data.

FORMAT OF PRESENTATION: Mercator map projection with monthly isopleth analyses of air temperature minus SST. Positive values shown by red isopleths indicating air warmer than sea surface. Blue isopleths for negative values where air is colder than sea surface. Isopleth interval is 2°F on odd numbers. Contours dotted where data sparse.

QUANTITY OF DATA: 4, 600, 000 observations for whole Indian Ocean area.

SUBJECTIVE EVALUATION: The atlas is principally a meteorological climatic presentation. The one hydroclimatic series is of little value, showing only a generalized picture of the average stability or instability of the lower layers of the atmosphere immediately above the sea surface. Considerable sparsity of data south of 40°S latitude.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: CLIMATIC SUMMARIES FOR MAJOR SEVENTH FLEET PORTS AND WATERS NAVAIR 50-1C-62

AUTHOR: Naval Weather Service Environmental Detachment, Asheville, N. C.

PUBLISHER: U. S. Government Printing Office

DATE: November 1973

REGION OF COVERAGE: Portions of Indian and Pacific Oceans 10^{o}S-45^{o}N lat, 65^{o}E-154^{o}E long

SOURCE OF DATA: U. S. Naval Weather Service Command's "Summary of Synoptic Meteorological Observations" (SSMO) series was the primary source. U. S. Navy Climatic Atlases of the World Vol. II, III, and V.

CONTRIBUTORS: Japan, Netherlands, U. S. Navy, and U. S. Air Force (ETAC).

FORMAT OF PRESENTATION: Equatorial cylindrical map projection with monthly isotherm analyses of mean air temperature and mean SST show on the same chart. SST analyzed at 2^{o}F contour intervals, shown by broken isotherms. Air temperature drawn with solid lines at 5^{o}F contour intervals. Dotted line used for areas where spacing is large and 1^{o}F isotherms are necessary.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The atlas presents a region of the world that is usually not shown except on world ocean charts and then not with this detail. The SST analysis at 2^{o}F intervals is excellent, but would have been better if the air temperature analysis had been placed on another chart or in a contrasting color. The clash of solid and broken black lines leads to confusion.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: ATLAS OF SURFACE CURRENTS INDIAN OCEAN H.O. Pub. No. 566 (Formerly H.O. Misc. 10057)

AUTHOR: U. S. Navy Hydrographic Office

PUBLISHER: U.S. Navy Hydrographic Office

DATE: 1st Ed. 1944 (reprinted 1950, 1958, 1966, 1970)

REGION OF COVERAGE: Indian Ocean 50°S-26°N lat, 10°E-130°E long

SOURCE OF DATA: Information used in preparation of this atlas was compiled from observations during the month for all years prior to 1935.

CONTRIBUTORS: Cooperating observers of the Hydrographic Office

FORMAT OF PRESENTATION: Equatorial cylindrical map projection used to portray monthly isotherm analyses of mean sea surface temperatures at 5°F contour intervals, current roses of prevailing currents, and black arrows of resultant currents. The eight-point current roses graphically picture the frequency of direction and the average drifts within the directions for each area outlined by heavy brown lines, approximately 5° quadrangles. Resultant currents in each 1° quadrangle are depicted by black arrows showing mean direction and magnitude. The number of observations and the strength of the surface currents are printed above and below each arrow. Interpolation was used in areas of sparse date shown by broken isotherm contours as compared to the normal solid-line isotherm analysis.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The atlas is primarily prepared with surface current information on both prevailing and resultant currents, of which the presentation is easily read and understood. The broad scale temperature field is a secondary feature with the 5°F isotherm analysis leaving a lot to be desired.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: ATLAS OF PILOT CHARTS South Pacific and Indian Oceans H. O. Pub. No. 107

AUTHOR: U. S. Navy Hydrographic Office

PUBLISHER: U. S. Navy Hydrographic Office

DATE: 2nd edition 1955 (reprinted 1960)

REGION OF COVERAGE: South Pacific and Indian Oceans 60°S-31°N lat, 10°E-160°E long

SOURCE OF DATA: Oceanographic data collected over the years by the U. S. Navy Hydrographic Office and the U. S. Weather Bureau.

CONTRIBUTORS: Cooperating observers of the U. S. Navy Hydrographic Office and U. S. Weather Bureau.

FORMAT OF PRESENTATION: Equatorial cylindrical map projection with monthly analyses of surface currents shown by small blue arrows. Figures printed randomly indicate the average velocity in miles per day. In addition, there are seasonal charts (December-February, March-May, etc) with surface currents shown by small blue arrows and velocities for both minimum and maximum drift shown by whole value numerals.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The atlas has a very poor presentation of surface currents, not only lacking in detail, but almost totally obscured by the maze of colored wind roses, streamlines, etc. The Atlas of Surface Currents Indian Ocean has a much more detailed analysis and presentation for the larger portion of this region. The seasonal charts do provide some additional information to supplement the latter atlas.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: CURRENTS IN THE SOUTH CHINA, JAVA, CELEBES AND SULU SEAS H.O. Pub. No. 236

AUTHOR: U. S. Navy Hydrographic Office

PUBLISHER: U. S. Navy Hydrographic Office

DATE: 1945

REGION OF COVERAGE: South China, Java, Celebes, and Sulu Seas $9^{o}S$-$25^{o}N$ lat, $99^{o}E$-$127^{o}E$ long

SOURCE OF DATA: Observations collected by the Hydrographic Office of the U. S. Navy from 1904 until 1934.

CONTRIBUTORS: Cooperating observers of the Hydrographic Office

FORMAT OF PRESENTATION: Mercator projection with monthly charts of currents and winds. The monthly circulation of the surface currents is shown by black arrows with expected velocities printed in tenths of a knot. The wind character is shown by wind roses.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The atlas provides a monthly observation of the surface current regime as affected by the monsoons within Southeast Asia. The general character of the flow is more easily observed in this presentation than in the Atlas of Surface Currents Indian Ocean.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: METEOROLOGICAL ATLAS OF THE INTERNATIONAL INDIAN OCEAN EXPEDITION VOL. I THE SURFACE CLIMATE OF 1963 & 1964

AUTHOR: U.S. National Science Foundation and India Meteorological Department

PUBLISHER: U. S. Government Printing Office

DATE: September 1972

REGION OF COVERAGE: Indian Ocean

SOURCE OF DATA: Ship observations made during 1963 and 1964.

CONTRIBUTORS: U. S. National Science Foundation; India Meteorological Department; Office of Oceanography UNESCO; WMO; U. S. NASA, University of Hawaii, Australia, France, Japan, Netherlands, U. S. Navy.

FORMAT OF PRESENTATION: Mercator projection with 1:40 million scale used as background for analyses. SST's and Air Temperature minus SST analyses done monthly throughout 1963 and 1964 on the same charts for evaluation. SST isotherms in orange are analyzed at 2°C contour intervals using solid lines in areas of plentiful data and dashed lines in areas of sparse data. Long-short broken lines used for 1°C isotherm interval in areas of weak gradients. Air Temperature minus SST isopleths are represented by 1°C isopleth intervals using solid blue lines (dashed in areas of sparse data). Average air temperature and SST to 0.1°C printed one above the other for each 5° lat-long square. Heat exchange at the sea surface in cal $cm^{-2}day^{-1}$ plotted for each month of the two year period. Net radiation gain shown by orange isopleths with 100 cal $cm^{-2}day^{-1}$ contour intervals. Equivalent heat loss (latent plus sensible heat) shown at the same contour interval with blue isopleths. Net radiation gain, heat loss through evaporation, and sensible heat loss values printed for each 5° lat-long square.

QUANTITY OF DATA: 194,000 ship observations.

SUBJECTIVE EVALUATION: The atlas is meteorologically oriented, but the oceanographic information is useful as a comparison tool. The SST analyses show broad scale smoothing of temperatures for the Indian Ocean, with no great detail. When compared to the Oceanographic Atlas for the Indian Ocean from the International Indian Ocean Expedition the two SST analyses clash. The Oceanographic Atlas has much more detail in the monthly analyses than found here in this historical two-year series. The Air Temperature minus SST analyses do provide useful information, especially for air-sea exchange computations and evaluations of oceanic influence on lower layers of the atmosphere. The heat exchange presentation for the net heat gain and loss at the sea surface adds a unique ingredient to meteorological and oceanographical knowledge.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: OCEANOGRAPHIC ATLAS OF THE INTERNATIONAL INDIAN OCEAN EXPEDITION

AUTHOR: Klaus Wyrtki, University of Hawaii, Honolulu

PUBLISHER: U. S. Government Printing Office (prepared for National Science Foundation)

DATE: November 1971

REGION OF COVERAGE: Indian Ocean 70°S-30°N lat, 20°E-150°E long

SOURCE OF DATA: Atlas includes all data collected in the Indian Ocean from the mid-1920's to 1966 by many different countries.

CONTRIBUTORS: Some of the major contributors include Australia, France, Germany, India, Indonesia, Japan, Pakistan, Portugal, Republic of South Africa, Union of South Africa, Thailand, USSR, United Kingdom, United States of America, Denmark, Norway, Malagasy Republic, and Sweden.

FORMAT OF PRESENTATION: Most of the oceanographic parameters in the atlas were presented on an equal area map projection by Kansev 1965. Scatter diagrams and vertical profiles were also used to depict other oceanographic properties. Isotherm analysis done monthly with 1°C contour intervals. The presentation is aided by every 5°C isotherm being darkened, red shading of areas over 28°C, blue shading of areas cooler than 20°C, and the number of observations used printed on the chart for each month of the year.

QUANTITY OF DATA: 12,000 ocean stations; 24,800 bathythermographs records; and 70,000 sea surface temperature observations.

SUBJECTIVE EVALUATION: The atlas concerns itself with physical and chemical properties of the ocean including: temperature, salinity, oxygen, phosphate, nitrate, and silicate. The temperature data for the surface is limited to that obtained for 1 year (1963). Smoothing of the isotherms is not totally representative for a long-time hydroclimatic average. The SST analyses could be useful in studies of anomalous conditions as compared to a mean SST condition. Analyses were generally limited to the region north of 40°S.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: U. S. NAVY REPRINT - WIND AND WEATHER CURRENTS, TIDES, AND TIDAL STREAMS IN THE EAST INDIAN ARCHIPELAGO NAVAER 50-1R-39

AUTHOR: J. P. Van der Stok, Director of the Meteorological and Magnetical Observatory

PUBLISHER: Government of Netherland's India

DATE: 1896

REGION OF COVERAGE: East Indian Archipelago 15°S-10°N lat, 90°E-140°E long

SOURCE OF DATA: Data collected from log books of ships during the 77 years from 1814 to 1890.

CONTRIBUTORS: Men of War ships, Ministry of Marine in the Hague, and Observatory at Batavia.

FORMAT OF PRESENTATION: Equatorial cylindrical map presentation. Surface currents shown by black arrows with the length proportional to the percentage of frequency. Two charts depict current analyses for months April - September and October - March.

QUANTITY OF DATA: Over 80,000 observations.

SUBJECTIVE EVALUATION: The atlas is a classical publication on meteorological and oceanographic information collected on board Men of War ships. The analyses for surface currents on a winter-summer seasonal basis have been far surpassed by newer atlases based on much larger collections of data with much more detail.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: MONTHLY CHARTS OF MEAN, MINIMUM, AND MAXIMUM SEA SURFACE TEMPERATURE OF THE NORTH PACIFIC OCEAN SP-123 (Replaces IR. No. 68-2)

AUTHOR: Paul E. LaViolette & Sandra E. Seim, Physical Properties Section, Oceanographic Analysis Div., Marine Sciences Dept.

PUBLISHER: U. S. Naval Oceanographic Office

DATE: 1969

REGION OF COVERAGE: North Pacific 20°S-66°N lat, 117°E - 70°W long

SOURCE OF DATA: Charts based primarily on ship injection temperature data collected over more than 100 years. Data is numerous in all but the equatorial portion of the Pacific and during winter in the Bering Sea and Sea of Okhotsk.

CONTRIBUTORS: U. S. Navy, U. S. Merchant Marine, Japan, Britain, USSR, Netherlands, Germany, and Denmark.

FORMAT OF PRESENTATION: Equatorial cylindrical map projection with isotherm analyses, blue shading to indicate quadrangles containing 10 or more observations, isopleths to indicate the extent of sea ice concentration, and monthly variability charts of sea surface temperature in 62 selected regions of the Pacific Ocean. Monthly charts from January through December depict mean SST, minimum SST, and maximum SST at 2°F isotherm intervals with each 10°F interval isotherm darkened. Appendix A provides a temperature conversion chart from degrees Fahrenheit to degrees Celsius. The isopleths of ice extent show mean extent of sea ice of 5/10 concentration for the mean SST charts, the absolute maximum extent of sea ice for 1/10 or greater concentration for the minimum SST charts, and the absolute minimum extent of sea ice of 1/10 or greater concentration for maximum SST charts. The southeastern portion of Pacific from 170°W to 70°W and from bottom of chart to 10°S shows no analysis in all charts.

SUBJECTIVE EVALUATION: Excellent statistical representation of SST properties over a long period of time. The isotherm interval, shading, darkening of every 10°F isotherm all add to the presentation and ease of obtaining desired information. This larger presentation far surpasses in quality the informal report IR NO. 68-2 published earlier based on the same work.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: MONTHLY MEAN CHARTS SEA SURFACE TEMPERATURE NORTH PACIFIC OCEAN 1949-62 CIRCULAR 258, United States Dept. of the Interior U. S. Fish and Wildlife Service, Bureau of Commercial Fisheries

AUTHOR: L. E. Eber, J. F. T. Saur, & O. E. Sette

PUBLISHER: Bureau of Commercial Fisheries, Ocean Research Laboratory, Stanford, California

DATE: June 1968

REGION OF COVERAGE: North Pacific Ocean 20°S-60°N lat, 110°E-70°W long

SOURCE OF DATA: Marine weather observations including SST's for the period of record, January 1949 through December 1962 contained in the records of the National Weather Records Center, Asheville, North Carolina.

CONTRIBUTORS: National Weather Records Center, Fleet Numerical Weather Facility, and Stanford University Computation Center.

FORMAT OF PRESENTATION: Lambert's Azimuthal Equal-Area projection with isotherm analyses of SST's. Initial data collected in (F°) and converted to (C°) for presentation. The mean SST isotherm analyses have a 1°C contour interval with every fifth isotherm darkened. Sparse data regions are represented by broken isotherm lines, no data by hatched areas. Distribution of data is included on each chart in light gray showing the number of observations for each grid area.

QUANTITY OF DATA: More than 2 million marine weather observations over the 14-year series of data from 5000 observations per month at the start to 15,000 observations per month at the end of the series.

SUBJECTIVE EVALUATION: The atlas provides an excellent historical series of monthly SST's from January 1949 to December 1962. More extensive data collection in area 10°N to 20°S in later years shows up in the monthly series. Regions of non-coverage over the years for each month graphically illustrates the problem in preparing an atlas of mean SST over these regions due to

lack of data. This type of historical series approach adds a useful tool to the scientist using only SST means or annual ranges. A sequence for the Atlantic and Indian Oceans would be a useful complement to this atlas.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: ATLAS OF MONTHLY MEAN SEA SURFACE AND SUBSURFACE TEMPERATURE AND DEPTH OF THE TOP OF THE THERMOCLINE NORTH PACIFIC OCEAN

AUTHOR: Margaret K. Robinson, Scripps Institution of Oceanography & Roger A. Bauer

PUBLISHER: Fleet Numerical Weather Central, Monterey, California

DATE: May 1971

REGION OF COVERAGE: North Pacific Ocean 5°S-73°N lat, 100°E-76°W long

SOURCE OF DATA: Atlas based primarily on BT data collected at Scripps Institution of Oceanography during the past 29 years, XBT data from FNWC, hydrocast files from NODC, data interchanges with foreign institutions, EASTROPAC STD data tapes, and published reports and atlases.

CONTRIBUTORS: U. S. Navy and Coast Guard ships and ships of scientific institutions. Major countries include Canada, Colombia, Ecuador, France, Japan, Mexico, Peru, Thailand, Korea, Germany, and the U.S.S.R. The Inter-American Tropical Tuna Commission also provided information.

FORMAT OF PRESENTATION: Equatorial cylindrical map projection with monthly isotherm and isopleth analyses. The 12 monthly groups of charts, six charts in each group, represent isotherm analyses at the surface, 100, 200, 300, and 400 ft depths. The mean isotherm analyses are done at 2°F contour intervals with every 10°F isotherm darkened. A 6th chart in each group is the mean thermocline depth in feet with an isopleth analysis at 50-ft intervals.

SUBJECTIVE EVALUATION: This atlas presents an interesting new approach to preparation of mean temperatures for the ocean. The primary use of BT data has allowed for the first time subsurface levels to be analyzed at 100 ft increments to 400 ft in addition to SST's. The topography of the top of the

thermocline, defined as that depth at which the temperature is 2°F less than the surface temperature, is also a new atlas feature. A knowledge of the complicated subsurface temperature structure in the layers affected by seasonal heating allows the climatologist to better understand the heat sources in the ocean. This type of atlas, when completed for the world's oceans, will be quite useful.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: ATLAS OF NORTH PACIFIC OCEAN MONTHLY MEAN TEMPERATURES AND MEAN SALINITIES OF THE SURFACE AND SUBSURFACE LAYERS

AUTHOR: Margaret K. Robinson

PUBLISHER: Unpublished

DATE: (possibly 1975-76)

REGION OF COVERAGE: North Pacific Ocean 5°S-73°N lat, 113°E-75°W long

SOURCE OF DATA: Extensive file of BT observations from Scripps Institution of Oceanography and NODC with additional hydrocast, XBT, STD data collected from many institutions and countries.

CONTRIBUTORS: Some of the major contributors were NODC, CALCOFI, Japan, Bureau of Commercial Fisheries, Russia, Germany, Korea, FNWC, XBT's EASTROPAC, Netherlands, Canada, Thailand, Australia, Colombia, Ecuador, French New Caledonia, and Mexico.

FORMAT OF PRESENTATION: A mercator projection background is used for monthly mean sea temperature analyses at the surface, 100, 200, 300, and 400 foot levels with a 0.5°C isotherm contour interval. Each horizontal level also has a companion chart depicting the data distribution of temperatures for that month. In addition each monthly series has a chart depicting the temperature difference between the surface and 400 feet analyzed at 0.5°C contour intervals and a second chart with mean depths to the top of the thermocline using a 50 foot isopleth interval. The top of the thermocline is defined as that depth at which the temperature is 1.1°C less than the surface. The surface mean temperature chart and the temperature difference chart both have mean ice limits of 4/8 concentration indicated by hatching for each month of the year. All five levels and the temperature difference chart have an inserted temperature conversion table from °C to °F. All

charts have a geographical insert for the region from 5°S to 23°N lat, 99°E-122°E long to include the South China Sea and adjacent waters. All charts are color coded for further interpretation. Annual mean temperatures, annual temperature range, and total data distribution for the surface and subsurface horizontal levels presented in same format. Annual cycle temperature curves prepared for selected ocean stations scattered across the Pacific oriented in a latitudinal-longitudinal grid network.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The atlas definitely presents an oceanographic view of the important temperature structure in the oceans for the surface and subsurface. The 0.5°C isotherm interval shows a detailed analysis that becomes awkward only in areas of strong gradients. The subsurface temperature presentation in addition to the normal SST analyses provides a basis for a knowledge of the main surface and subsurface heat sources in the ocean to be gained, especially within the complicated subsurface temperature structure in the layers affected by seasonal heating. The temperature difference charts estimate the strength of the thermocline gradient confined between the top of the thermocline and 400 feet. Overall, this atlas will be an excellent presentation of the temperature properties of the Pacific Ocean when published, and if companion atlases are published for the Indian and Atlantic Oceans they will provide one of the better sets of atlases ever produced.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: FAR EAST CLIMATIC ATLAS

AUTHOR: Technical Services, 20th Weather Squadron, USAF

PUBLISHER: USAF

DATE: 1965

REGION OF COVERAGE: Western North Pacific Ocean 5^{o}N-60^{o}N lat, 90^{o}E-165^{o}E long

SOURCE OF DATA: Data extracted from publications and summaries of the weather services of various countries, the data covering a period up to 83 years.

CONTRIBUTORS: United States, Japan, and other Far Eastern countries.

FORMAT OF PRESENTATION: Equatorial cylindrical map projection with monthly isotherm analyses of mean, maximum, minimum, and 83-year range of SST at a 2^{o}F isotherm contour interval.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The atlas is primarily oriented meteorologically, but the hydroclimatic analyses are very good. It is an operational atlas that lends itself easily to scientific evaluation due to the quality and detail of the analyses over a long period of time.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: MONTHLY MEAN CHARTS SEA SURFACE TEMPERATURE NORTH PACIFIC OCEAN CIRCULAR 134

AUTHOR: J. F. T. Saur and L. E. Eber, Bureau of Commercial Fisheries, Biological Laboratory, Stanford, California

PUBLISHER: United States Fish and Wildlife Service, Washington

DATE: April 1962

REGION OF COVERAGE: North Pacific Ocean 20°S-60°N lat, 110°E-70°W long

SOURCE OF DATA: SST data compiled in punched card deck 116, U. S. Merchant Marine and Other Ship Observations, 1949 from the NWRC.

CONTRIBUTORS: Cooperating ships from the United States of America and foreign countries making marine weather observations.

FORMAT OF PRESENTATION: Lambert's azimuthal equal-area projection used as background for monthly mean SST analyses of 1956 and 1957, and a series of 12 SST difference charts showing 1957 minus 1956 temperature differences on a monthly basis. Isotherm analyses at 1°C contour intervals in red with every fifth isotherm darkened. Analyses hatched in areas of sparse data. Mean temperature to a 0.1°F and the number of observations printed for every 2° square and where data available. Data generally sparse or absent south of 10°N except along well-traveled routes. Temperature conversion tables from °C to °F printed on each monthly SST chart. Issallotherm analyses of SST difference charts at 1°C intervals with red hatching for warming, blue hatching for cooling.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The atlas provides a good historical monthly series of 1956-1957 SST's with SST differences. The atlas has been superceded by a much more complete historical SST presentation in 1968, Circular 258, with the same title, but lacking the SST Difference or SST anomalies for the longer period 1949-1962.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: U. S. NAVY MARINE CLIMATIC ATLAS OF THE WORLD VOL. V NAVAER 50-1C-532

AUTHOR: Naval Weather Service

PUBLISHER: U. S. Government Printing Office

DATE: 1 November 1959

REGION OF COVERAGE: South Pacific Ocean 55°S-32°N lat, 147°E-58°W long

SOURCE OF DATA: 100-year record of weather observations provided by ships from many countries and collected at U. S. Weather Bureau, NWRC.

CONTRIBUTORS: Britain, United States of America, Germany, Netherlands, and many other island and coastal stations representing many countries.

FORMAT OF PRESENTATION: Mercator map projection with monthly isopleth charts of air temperature minus sea surface temperature differences at a 2°F contour interval, on odd numbers. Red isopleths for positive values where air is warmer than sea surface. Blue isopleths for negative values when air is colder than sea surface.

QUANTITY OF DATA: 2,300,000 weather observations for the oceans and seas.

SUBJECTIVE EVALUATION: This is primarily a meteorological climatic atlas with only one reference to sea surface temperature values. The analyses show only broad-scale features with no detail.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: MONTHLY THERMAL CONDITIONS CHARTS FOR THE NORTH PACIFIC OCEAN H. O. Pub. No. 762

AUTHOR: Bathythermograph Section, Scripps Institution of Oceanography

PUBLISHER: U. S. Navy Hydrographic Office

DATE: 1952 (reprinted 1954)

REGION OF COVERAGE: North Pacific Ocean 0°-60°N lat, 115°E-78°W long

SOURCE OF DATA: BT observations taken in the ocean by vessels of the U. S. Navy, U. S. Coast Guard, and civilian research activities.

CONTRIBUTORS: U. S. Navy, U. S. Coast Guard, and civilian research facilities.

FORMAT OF PRESENTATION: Equatorial cylindrical projection used as background for monthly isopleth analyses of average temperature difference ($^{\circ}$F) between the surface and 30-foot depth and for monthly isopleth analyses of average layer depth in feet. The average temperature difference charts are analyzed at 0.1°F contour intervals and have hatching in areas of complicated thermal structure. The layer depth represents the depth to the top of the seasonal or permanent thermocline and is contoured at 50-foot intervals with stippled areas representing areas of frequent shallow layer depths. Months of April and May have additional feature with dashed contour for deep layer depth when shallow layer depth is absent.

QUANTITY OF DATA: 100,000 BT observations.

SUBJECTIVE EVALUATION: The atlas presents a unique approach to observing the thermal structure of the upper layers of the ocean. Although there are no SST evaluations, the chart series will be a valuable asset for a better understanding of the total ocean's hydroclimate.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: CLIMATE - NORTH PACIFIC OCEAN 14ND-FWC-P-26

AUTHOR: U. S. Fleet Weather Central, Pearl Harbor Hawaii

PUBLISHER: Naval Weather Service

DATE: 6 October 1969

REGION OF COVERAGE: North Pacific Ocean 0-70°N lat, 100°E-106°W long

SOURCE OF DATA: Not stated.

CONTRIBUTORS: Not stated.

FORMAT OF PRESENTATION: Equatorial cylindrical map projection with seasonal (February, May, August, November) SST analyses at 2.5°F isotherm contour intervals. Mean extent of ice coverage shown by hatching in northern regions for conditions $\geq$ 5/10 ice limits.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The abbreviated atlas presents climate factors for survival, both meteorological and oceanographic. The atlas would be far more useful to an operational unit working in the North Pacific than to a climatologist trying to evaluate the ocean hydroclimate.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: U. S. NAVY MARINE CLIMATIC ATLAS OF THE WORLD VOL. II NAVAER 50-1C-529

AUTHOR: Naval Aerology Branch of the Office of Chief of Naval Operations

PUBLISHER: U. S. Government Printing Office

DATE: 1 July 1956

REGION OF COVERAGE: North Pacific Ocean 0°-70°N lat, 100°E-106°W long

SOURCE OF DATA: U. S. Weather Bureau, NWRC

CONTRIBUTORS: United States of America, Canada, Japan, Netherlands, United Kingdom, Germany, plus many coastal stations and islands around the North Pacific representing many different countries.

FORMAT OF PRESENTATION: Mercator map projections used as background with seasonal air temperature minus SST difference for January, April, July, and October representing the mid-months of seasons. The isopleth intervals were 2°F on odd numbers.

QUANTITY OF DATA: 2,500,000 ship weather observations for ocean and seas. Ocean station observations: 100,000.

SUBJECTIVE EVALUATION: The atlas is primarily a meteorological climatic presentation with only one hydroclimatic parameter. The broad scale features of the oceanic influence on the lower layer of the atmosphere can be observed.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: ATLAS OF TEMPERATURE, SALINITY AND DENSITY OF WATER IN THE PACIFIC OCEAN

AUTHOR: A. M. Muromtser, State Oceanographic Institute

PUBLISHER: Publishing House of the Academy of Sciences of the USSR, Moscow

DATE: 1963

REGION OF COVERAGE: Pacific Ocean 80°S-70°N lat, 110°E-80°W long

SOURCE OF DATA: Collected data from 1874 to 1961 and stored in the IGY World Data Center B (Moscow).

CONTRIBUTORS: Not stated, except as many countries.

FORMAT OF PRESENTATION: Equatorial cylindrical map projection with isopleth analyses, and vertical profiles of temperature, salinity, and density. The horizontal charts are analyzed at 10 levels from 0m to 500m on a seasonal basis, summer and winter, for each of the three oceanographic parameters. Additional horizontal charts are prepared for depths down to 5000m below the seasonal changes. The SST's isotherm analyses, one each for winter and summer seasons, like all the other sea temperatures at various depths were at 1°C contour intervals.

QUANTITY OF DATA: 30,000 deepwater stations.

SUBJECTIVE EVALUATION: This atlas provides an opportunity for comparison between oceanographic data collected and presented by the USSR and those presented by other countries, yet a direct comparison would be difficult due to the seasonal and depth format. The subsurface temperature information provides a good look at the heat reservoir in the ocean.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: OCEANOGRAPHIC AND METEOROLOGICAL OBSERVATIONS IN THE CHINA SEAS AND IN THE WESTERN PART OF THE NORTH PACIFIC OCEAN NAVAER 50-1R-173 (reprint of Royal Netherlands Meteorological Institute No. 115)

AUTHOR: Royal Netherlands Meteorological Institute (original); Aerology Section U. S. Navy

PUBLISHER: Government Printing Office, The Hague (original) U. S. Government Printing Office

DATE: May 1945 (original 1935)

REGION OF COVERAGE: China Seas and Western part of N. Pacific Ocean 0°-45°N lat, 98°E-145°E long

SOURCE OF DATA: Oceanographic and meteorological observations collected over period from 1910 until 1930.

CONTRIBUTORS: Netherlands, Britain, United States of America, Germany, France, and numerous other countries.

FORMAT OF PRESENTATION: Equatorial cylindrical map projection used as background for monthly analyses of resultant surface currents, current roses, and mean SST's. The resultant surface currents are depicted by black arrows within each 1° square with the length and thickness of the arrows indicating the stability of the general surface circulation. The velocity of the current in nautical miles per day is printed beside the arrow and the number of observations is given in the lower left hand corner of each 1° square. Wind roses drawn within boxed areas of 2°-4° quadrangles with arrows indicating direction and velocity (in nautical miles per day) of current. The number of observations printed in center of rose. The mean SST values for each 1° square are printed to 0.1°C along with the number of observations. Red isotherms show a 1°C contour interval with every fifth isotherm darkened.

QUANTITY OF DATA: 291,324 SST observations
47,747 surface current observations.

SUBJECTIVE EVALUATION: The atlas combines a good selection of hydroclimatic information on the ocean's surface conditions. The extremely well-defined temperature analyses for each month of the year, along with the surface current information, make this atlas a valuable asset to complement other North Pacific Atlases.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: ATLAS OF SURFACE CURRENTS NORTHEASTERN PACIFIC OCEAN H.O. Pub. No. 570

AUTHOR: U. S. Navy Hydrographic Office

PUBLISHER: U. S. Navy Hydrographic Office

DATE: 1947 1st edition (reprinted 1967)

REGION OF COVERAGE: Northeastern Pacific Ocean 0-60°N lat, 160°W-75°W long

SOURCE OF DATA: Information used in preparation of this atlas was compiled from observations during the month for all years prior to 1935.

CONTRIBUTORS: Cooperating observers of the Hydrographic Office

FORMAT OF PRESENTATION: Equatorial cylindrical map projection used to portray monthly isotherm analyses of mean sea surface temperatures at 5°F contour intervals, current roses of prevailing currents, and arrows of resultant currents. The eight-point current roses graphically picture the frequency of direction and the average drifts within the directions for each area outlined by heavy brown lines, approximately a 5° quadrangle. Resultant currents in each 1° quadrangle are depicted by black arrows showing the mean direction and magnitude. The number of observations and the strength of the surface currents are printed above and below each arrow. Interpolation of SST in areas of sparse data was shown by use of broken isotherm contours as compared to the normal solid line for isotherm analysis.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The primary feature of the atlas is surface currents which are well presented for both prevailing and resultant currents. The broad scale temperature field for each month of the year is a secondary feature of the atlas. The 5°F isotherm interval leaves much to be desired.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: ATLAS OF SURFACE CURRENTS NORTHWESTERN PACIFIC OCEAN H.O. Pub. No. 569 (Formerly H. O. Misc. 10,058 A)

AUTHOR: U. S. Navy Oceanographic Office

PUBLISHER: U. S. Navy Oceanographic Office

DATE: 1st edition reprinted 1969

REGION OF COVERAGE: Northwestern Pacific Ocean 0°-60°N lat, 113°E-155°W long

SOURCE OF DATA: Information used in preparation of this atlas was compiled from observations during the month for all years prior to 1935.

CONTRIBUTORS: Cooperating observers of the Oceanographic Office.

FORMAT OF PRESENTATION: Equatorial cylindrical map projection used to portray monthly isotherm analyses of mean sea surface temperatures at 5°F contour intervals, current roses of prevailing currents, and arrows of resultant currents. The eight-point current roses graphically picture the frequency of direction and the average drifts within the directions for each area outlined by heavy brown lines, approximately a 5° quadrangle. Resultant currents in each 1° quadrangle are depicted by black arrows showing mean direction and magnitude. The number of observations and the strength of the surface currents are printed above and below each arrow. Interpolation of SST in areas of sparse data was shown by use of broken isotherm contours as compared to the normal solid line isotherm analysis.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The broad scale temperature field for each month of the year is a secondary feature of the atlas. The 5°F isotherm interval leaves much to be desired. The primary feature of the atlas is surface currents, both prevailing and resultant currents, which are well analyzed for the region.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: ATLAS OF SURFACE CURRENTS SOUTHWESTERN PACIFIC OCEAN H.O. Pub. 568

AUTHOR: U. S. Naval Oceanographic Office

PUBLISHER: U. S. Naval Oceanographic Office

DATE: 1944 (reprinted 1959, 1965, 1968, 1970)

REGION OF COVERAGE: Southwestern Pacific Ocean 60°S-0° lat, 120°E-155°W long

SOURCE OF DATA: Information used in preparation of this atlas was compiled from observations during the month for all years prior to 1935.

CONTRIBUTORS: Cooperating observers of the Hydrographic Office

FORMAT OF PRESENTATION: Equatorial cylindrical projection map used to portray monthly isotherm analyses of mean sea surface temperatures at 5°F contour intervals and black arrows depicting resultant currents at each 1° quadrangle. The black arrows used to position resultant currents show direction and magnitude. The number of observations and force of the surface currents are printed for each 1° quadrangle above and below the current arrows. Broken isotherm contours indicate areas of sparse data and interpolation as compared to the normal solid line isotherm analysis. Little or no data available for analysis below 45°S latitude.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The primary feature of the atlas is surface currents, restricted to resultant currents only. The lack of prevailing current information for this region of the Pacific Ocean hinders a comprehensive study of the surface currents of the whole Pacific Ocean when the remaining atlases in this series have this information. The broad scale temperature field is a secondary feature of the atlas with the 5°F isotherm analysis leaving a lot to be desired.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: CLIMATOLOGICAL AND OCEANOGRAPHIC ATLAS FOR MARINERS VOL. II NORTH PACIFIC OCEAN

AUTHOR: U. S. Weather Bureau (prepared by Office of Climatology) and U. S. Navy Hydrographic Office (prepared by Oceanographic Analysis Division).

PUBLISHER: U. S. Government Printing Office

DATE: 1961

REGION OF COVERAGE: North Pacific Ocean 0°-70°N lat, 100°E-107°W long

SOURCE OF DATA: Climatic charts adapted from U. S. Navy Marine Climatic Atlas of the World, Vol. II. Ocean charts are primarily original compilations based on most recent data and reference sources, with the U. S. World Atlas of the Sea Surface Temperature primary source.

CONTRIBUTORS: U. S. Weather Bureau, U. S. Navy Hydrographic Office, ships from U. S. Navy and Merchant Marine. Also information from Dutch, British, German, Japanese, and Canadian ships. USSR and Japan provided weather observations for island stations.

FORMAT OF PRESENTATION: Equatorial cylindrical map projection used as background for isopleth analyses, wind roses, tables and other forms of presentation for many different meteorological and oceanographic parameters. The SST isotherm analysis charts are provided for representative months (February, May, August, November) at a 2.5°F contour interval, with hatching in northern regions to show the mean ice limits $\geq$ 5/10 ice coverage. Air-Sea Temperature Difference charts are analyzed at 2°F contour intervals on a seasonal basis (December - February - March - May, etc.) for the mid-month of each season. The isopleth analyses are presented with odd numbers, red isopleths for air warmer than sea surface, and blue isopleths for air colder than sea surface. Surface current analyses prepared for winter and

summer seasons use solid black arrows for prevailing current direction and broken black arrows for weak and variable currents. Mean speed range of surface currents to the tenth of a knot are printed randomly on the charts. Four inset maps with surface current analysis are provided for the Philippines, Yellow Sea, and two locations separating the main islands of Japan.

QUANTITY OF DATA: 2.5 million observations collected from weather ships for ocean and sea with 200,000 additional ocean area observations for selected ocean areas. Overall, approximately 3 million observations used, taken primarily along major shipping lanes.

SUBJECTIVE EVALUATION: The emphasis of the atlas is primarily meteorological with a secondary presentation of pertinent oceanographic information for the mariner, not for scientists. The seasonal presentation of hydroclimatic information shows the broad-scale picture for the general observer, but lacks the detail found in a monthly analysis of the same properties. The SST analyses have a rough smoothing of thermal properties with general appearance of isotherms quite irregular. The Air-Sea Temperature Difference provides a generalized picture of the oceanic influence on the atmosphere in addition to a feeling for the average stability or instability of the lower layers of the atmosphere immediately above the sea surface. The seasonal surface current analysis leaves much to be desired, but for the amount of data available is the best that can be done.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: ATLAS OF MONTHLY MEAN SEA SURFACE AND SUBSURFACE TEMPERATURES IN THE GULF OF CALIFORNIA, MEXICO Memoir 5

AUTHOR: Margaret K. Robinson

PUBLISHER: San Diego Society of Natural History Memoirs

DATE: April 16, 1973

REGION OF COVERAGE: Gulf of California & Adjacent Pacific Waters $19^{o}N$-$34^{o}N$ lat, $118^{o}W$-$105^{o}W$

SOURCE OF DATA: Primary source was BT data file at SIO. Also included were reversing thermometer temperatures from CALCOFI Program.

CONTRIBUTIONS: There were many organizations and countries contributing to the data files, with a listing too lengthy to mention.

FORMAT OF PRESENTATION: Equatorial cylindrical projection used as a background for monthly mean temperature analyses at the surface, 100, 200, 300, and 400-foot levels. The mean temperature analyses are done at a $1^{o}F$ isotherm interval with every fifth isotherm darkened. Each monthly series has a sixth chart depicting the mean thermocline depth shown with 50-foot contour intervals. The top of the thermocline is defined as that depth which the temperature is $2^{o}F$ less than the surface temperature. In addition, there are a series of charts depicting the number of observations at 1^{o} squares for each month of the year, and a total for all months.

QUANTITY OF DATA: 35, 804 observations

SUBJECTIVE EVALUATION: The atlas presents a thorough look at mean temperature conditions not only at the surface, but at four subsurface levels. The detail of analyses provides very useful information for studies of heat content within this regional area.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: OCEAN CURRENTS IN THE VICINITY OF THE JAPANESE ISLANDS AND CHINA COAST H.O. Pub. No. 237

AUTHOR: U. S. Navy Hydrographic Office

PUBLISHER: U. S. Navy Hydrographic Office

DATE: 1945 (reprinted 1953)

REGION OF COVERAGE: Vicinity of the Japanese Islands and China Coast 24°N-47°N lat, 116°E-145°E long

SOURCE OF DATA: Observations collected by the Hydrographic Office of the U. S. Navy from 1904 up to 1934.

CONTRIBUTORS: Cooperating observers of the Hydrographic Office.

FORMAT OF PRESENTATION: Mercator projection with monthly charts of currents and winds. The monthly surface current circulation is shown by solid black arrows with expected velocities printed in tenths of a knot. Areas with sparse data have current arrows with dotted shaft. Wind represented by wind roses.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The surface current presentation in this atlas goes beyond the analyses found in the Atlas of Surface Currents - Northwestern Pacific Ocean. The general character of the current direction and flow is more easily seen in this presentation and attempts have been made in areas of insufficient observations to at least put theoretical current directions. More data definitely is needed in this complex oceanographic regime where the dominant Kuroshio Current clashes with the monsoon character of the atmosphere to create confusing and variable currents.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: OCEANIC OBSERVATIONS OF THE PACIFIC 1955 - The NORPAC ATLAS

AUTHOR: NORPAC Committee

PUBLISHER: University of California Press - University of Tokyo Press

DATE: 1960

REGION OF COVERAGE: Pacific Ocean 20°N-60°N lat, 120°E-105°W long

SOURCE OF DATA: Nineteen research vessels representing fourteen institutions from United States of America, Japan, and Canada during July, August, and September 1955.

CONTRIBUTORS: Fourteen research oriented institutions from the United States of America, Japan, and Canada.

FORMAT OF PRESENTATION: Lambert azimuthal equal area projection centered on the equator and 160 degrees west longitude. Subsurface temperatures are analyzed at depths of 10, 50, 100, 200, 400, 600, and 1000 meters using a 2°C contour interval in most cases, but occasionally a finer isotherm interval where needed for the whole northern Pacific and an enlargement area around Japan. Solid red isotherms on even values of °C, dashed red lines used for 0.25° to 1°C isotherm intervals in areas of weak gradient. Mean monthly (July, August, September) SST's in the period 1935 to 1945 and the mean monthly (July, August, September) SST's for 1955 computed to the nearest 0.1°C are printed for each 5° lat-long quadrangle, each printed over the number of observations as per example

10.3	- long term mean	(10.6)	- mean
385	- # of obs	(15)	- 1955 obs

Mean SST's for the periods 11th - 20th of July, August, September 1955 in the western Pacific near Japan have a 1°C isotherm analysis with every fifth isotherm darkened.

Dashed lines represent sparse data regions. In addition, there are surface current charts for July, August, and September 1955 showing average current speed with arrows, the length of arrow indicating frequency and barbs indicating speed in knots.

QUANTITY OF DATA: 1002 hydrographic stations

SUBJECTIVE EVALUATION: The atlas presents a good detailed analysis of sea temperatures, not only for the northern Pacific Ocean, but also a more regional look at the Japanese-Kurshio area. The short period of observation limits the value of the atlas for hydroclimatic purposes, especially since the only hydroclimatic data presented were in printed numbers rather than isotherm analyses. The SST and subsurface temperatures provided do complement a regional atlas with comparable subject matter.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: EASTROPAC ATLAS CIRCULAR 330 VOLUMES 1, 3, 5, 7, &9

AUTHOR: National Marine Fisheries Service, NOAA, U. S. Department of Commerce

PUBLISHER: U. S. Government Printing Office

DATE: September 1971 - February 1975

REGION OF COVERAGE: Eastern Tropical Pacific 25°S-30°N lat, 130°W-70°W long 40°S-10°N lat, 94°W-68°W long

SOURCE OF DATA: Ocean station data collected on 3 survey and 4 monitor cruises between February 1967 and March 1968

CONTRIBUTORS: Inter-American Tropical Tuna Commission, Scripps Institution of Oceanography, National Marine Fisheries Service, U. S. Coast Guard, ESSA, NODC, NSF, U. S. Navy (ONR), Smithsonian Institute, Stanford University, Texas A&M University, Chile, Ecuador, Peru, and Mexico.

FORMAT OF PRESENTATION: Equatorial cylindrical map projection with isotherm analyses of SST and hatching of SST anomalies as compared to 22-year mean. First temperature analyses are for the individual two-month cruise periods at one or both of the two regions based on the Nansen casts only. These analyses show the gross features at 1°C isotherm intervals. The second set of analyses are over variable increments of time (usually half month - August 1-15, 16-31, etc.) The SST are analyzed based on averages for 2° lat-long squares from all available ship observations. Solid line isotherms at 1°C intervals are dashed in regions of sparse data. Positive and negative temperature anomalies are shown by hatching. Printed values of SST averaged for 5° squares are plotted above the mean position symbol of the square with SST minus air temperature difference plotted below the symbol where sufficient data is available.

QUANTITY OF DATA: Approximately 5414 Nansen casts and STD stations.

SUBJECTIVE EVALUATION: The atlas series provides an excellent supply of information for an area of the ocean that has been lacking data for many years. The SST anomalies as compared to the 22-year mean provides the only hydroclimatic product in the atlas series. The additional information within this series will be quite useful when added to the more classical atlases.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: OCEANOGRAPHIC ATLAS OF THE PACIFIC OCEAN

AUTHOR: Richard A. Barkley, Oceanographer, Bureau of Commercial Fisheries Biological Laboratory

PUBLISHER: University of Hawaii Press, Honolulu

DATE: 1968

REGION OF COVERAGE: Pacific Ocean 55°S-65°N lat, 100°E-70°W long

SOURCE OF DATA: Data taken from files of NODC prior to 1965 with additional information from the U. S. Navy Hydrographic Office, all covering a period over 50 years of data.

CONTRIBUTORS: Numerous publications from the following countries: Australia, Canada, Denmark, France, Germany, Great Britain, Japan, Sweden, USSR, and the United States.

FORMAT OF PRESENTATION: Goode's homolosine equal area projection with seasonal (January-March, April-June, etc.) analyses of temperature at 10-meter depth. The isotherm analysis had a 2.5°C contour interval with areas of sparse data represented by dashed lines rather than solid.

QUANTITY OF DATA: 50,000 oceanographic stations with 3,000,000 observations.

SUBJECTIVE EVALUATION: The atlas is definitely oceanographic in nature, but is oriented toward a sigma-T presentation of salinity, oxygen, and depth. The only reference to temperature are the 10-meter depth analyses showing only the broadest of features, lacking required detail for thorough analysis; and the nomogram at the end of the atlas. If one were energetic, temperature could be obtained from the known sigma-T and salinity values found on the charts within the atlas for various levels of depth using the nomogram.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: OCEANOGRAPHIC ATLAS OF THE NORTH ATLANTIC OCEAN SECTION II PHYSICAL PROPERTIES Pub. No. 700

AUTHOR: U. S. Naval Oceanographic Office

PUBLISHER: U. S. Naval Oceanographic Office

DATE: 1967

REGION OF COVERAGE: North Atlantic Ocean 0°-68°N lat, 100°W-40°E long

SOURCE OF DATA: Ship injection temperature reports collected from 1854 and 1958 and stored at the U. S. National Weather Records Center.

CONTRIBUTORS: Major contributors were Germany, Netherlands, Britain, and United States of America.

FORMAT OF PRESENTATION: Mercator projection with monthly isotherm analyses at 2°F contour intervals. The mean SST isotherm analyses cover the entire North Atlantic, including the Gulf of Mexico, Mediterranean, Baltic, and Black Seas. Each monthly chart shows mean limit of ice $\geq$ 5/10 coverage and provides a temperature conversion table for $^{\circ}$F to $^{\circ}$C. Monthly minimum and maximum SST charts represent 95 and 5 percentile values from frequency distribution listing when 5% of extreme data is discarded. Seasonal SST anomalies for February, May, August and November have 2°F isopleth contours, red for positive, black for no change, and blue for negative, for the North Atlantic including the Gulf of Mexico and North Sea. The Baltic, Black and Mediterranean Seas were not analyzed. Subsurface temperature analyses are prepared for 100, 300, 1000 m depths with 2°F isotherm intervals. The 100 m depth analyses are seasonal (Jan-Mar, Apr-Jun, etc.) while the 300 and 1000 m depth analyses have mean temperature averages for the entire year (Jan-Dec). All three sets have ice limits and temperature conversion tables. In addition monthly variability of SST at 9 selected locations and distribution of observations for each month are added to the presentation on temperature at the sea surface.

QUANTITY OF DATA: 10,598,000 ship injection temperature reports.

SUBJECTIVE EVALUATION: The atlas section deals with the physical properties of the ocean including horizontal and vertical presentations of salinity, temperature, and density. Although the temperature analyses are only a segment of the overall atlas, the presentation is good in that it ties in the adjacent seas for continuity. More detailed analyses can and are being produced; until they are available this is a useful atlas for a statistical presentation of SST in the Atlantic Ocean.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: GEOGRAPHIE des ATLANTISCHEN OZEANS

AUTHOR: Gerhard Schott

PUBLISHER: Verlag Von C. Boysen, Hamburg, Germany

DATE: 1944

REGION OF COVERAGE: Atlantic Ocean 90°S-90°N lat, 90°W-30°E long

SOURCE OF DATA: Oceanographic and meteorological observations collected from all major oceanic cruises from 1868 to 1941. Additional information collected from regional studies by various institutions and countries.

CONTRIBUTORS: Some of the major contributing countries were Germany, Norway, Denmark, Italy, Britain, United States of America, Canada, Belgium, Russia, Sweden, and France.

FORMAT OF PRESENTATION: Equatorial cylindrical projection used for geographical information. Lambert's equal area azimuthal projection centered on equator at 30°W long used with isotherm and isopleth analyses for oceanic and meteorological parameters. Scale 1:90,000,000 for the temperature charts, 1:30,000,000 for surface currents. Tables XVII through XX provide annual mean SST, seasonal (February, May, November, May) SST's annual range of SST's, and temperature anomalies of SST. Table XXII depicts surface currents and Table XVII shows a 1°C isotherm analysis of mean annual SST with color shading from low (blue) to high (red) temperatures. Mean seasonal SST's shown in Table XVIII are prepared with the same format. Both of these first two tables have the thermal equator position shown with a dash-dot line. The annual range of SST's in Table XIX have an isopleth analysis at 1°C intervals with color shading. Table XX portrays SST anomalies, red for regions of positive values, blue for negative, again at 1°C contour intervals. The surface currents for the northern winter are depicted by black arrows with the length and width of arrows indicating duration and speed. Speed of currents given by nautical miles per day. The major currents are labeled and dark black lines are used to show areas of

convergence. Sea ice and pack ice limits, as well as regions of upwelling are shown by contrasting green symbols. The subsurface temperature isotherms are again at 1°C contour intervals with color shading.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: A geography text that includes a classical series of tables dealing with climatic and hydroclimatic products. Basically the text covers all phases of the Atlantic Ocean, especially in the fields of oceanography, meteorology, biology, and geology. The twenty-seven tables at the conclusion of the text present many parameters within these subjects. The isotherm analyses of the SST statistical properties at 1°C are excellent for the date that they were prepared and compare well with analyses prepared in more recent years. The only problem involves isotherm packing in strong gradient regions, making it difficult to evaluate. The surface current presentation is well done, especially with the additional convergences, ice limits, upwellings, etc. shown. The subsurface temperature depths show heat content, but the spacing at 400 meters and 1000 meters leaves a lot of depths not represented.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: SERIAL ATLAS OF THE MARINE ENVIRONMENT Folio 16 Mean Monthly Sea Surface Temperatures and Zonal Anomalies of the Tropical Atlantic

AUTHOR: Paul A. Mazeika, U. S. Bureau of Commercial Fisheries

PUBLISHER: American Geographical Society

DATE: 1968

REGION OF COVERAGE: Tropical Atlantic 20°S-20°N lat, 60°W-20°E long

SOURCE OF DATA: Observations collected at NWRC from merchant and naval vessels over 100 years. Additional information from various sources.

CONTRIBUTORS: U. S. Navy and Merchant Marine, ships from Britain, Netherlands, Germany, and Japan.

FORMAT OF PRESENTATION: Miller cylindrical map projection with monthly SST charts at 1°C isotherm intervals (0.5°C intervals where necessary), and mean monthly zonal temperature anomaly charts at 0.5° to 1°C isotherm intervals with red shading in areas of negative anomalies for easy comparison. Additional information on SST anomaly charts shown by dotted and dashed lines. Boundary type thermal gradient indicated by the uniformity test shown by dotted lines. Inferred thermal boundary shown by dashed line.

QUANTITY OF DATA: 2.5 million total observations with 2.25 million from NWRC.

SUBJECTIVE EVALUATION: The atlas provides detailed analyses for an area that has been generally glossed over in the publication of atlases. The existing representations of the SST distribution in the tropical Atlantic are either in degrees Fahrenheit or limited to seasonal months or restricted areas. The zonal anomalies provide supplemental information, describing visually the intensity of the normal heat exchanges of various processes of a dynamic and climatic nature such as currents, upwelling and excessive evaporation.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: SERIAL ATLAS OF THE MARINE ENVIRONMENT Folio 2 North Atlantic Temperatures at a Depth of 200 Meters

AUTHOR: Elizabeth H. Schroeder, Woods Hole Oceanographic Institution

PUBLISHER: American Geographical Society

DATE: 1963

REGION OF COVERAGE: North Atlantic Ocean 0°-90°N lat, 140°W-70°E long

SOURCE OF DATA: BT data collected by Woods Hole Oceanographic Institution from publications, cruises, and various organizations and countries.

CONTRIBUTORS: WHOI, National Oceanographic Data Center, and the Naval Research Establishment at Halifax, Nova Scotia, Canada.

FORMAT OF PRESENTATION: Oblique stereographic conformal projection, centered at 54°N 38°W showing the average temperature, the range of observed temperatures, temperature anomalies, seasonal distribution of data, all at the depth of 200 meters. Shown in tabular form are the average, maximum, and minimum temperatures, number of observations included in the average, and the seasons represented for each unit area. The first 5 charts show temperatures at 1°C isotherm contours with every fifth °C contour darkened for five overlapping areas covering the entire North Atlantic. The sixth chart shows temperature analysis of entire North Atlantic at 5°C contour intervals. Range of observed temperatures depicted by isopleths at 2°, 5°, and 10°C with color shading to distinguish range. Temperature anomalies analyzed at 2°C intervals on even numbers, with blue shading for negative anomalies ≤ 2°C, and red shading for positive anomalies ≥ 2°C. Seasonal distribution of data shown at 1° squares by shading scale. All charts are color shaded.

QUANTITY OF DATA: 96,000 BT observations.

SUBJECTIVE EVALUATION: The atlas has an interesting presentation of subsurface temperature that would be a useful supplement to the traditional SST atlases. The fine detail analyses of five subsections of the North Atlantic permits a good evaluation of subsurface temperature distribution.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: CLIMATOLOGICAL AND OCEANOGRAPHIC ATLAS FOR MARINERS VOL. I NORTH ATLANTIC OCEAN

AUTHOR: U. S. Weather Bureau (prepared by Office of Climatology) and U. S. Navy Hydrographic Office (Prepared by Division of Oceanography)

PUBLISHER: U. S. Government Printing Office

DATE: August 1959

REGION OF COVERAGE: North Atlantic Ocean 0^{o}-70^{o}N lat, 110^{o}E-0^{o} long, 0^{o}-73^{o}N lat, 0^{o}-45^{o}W long

SOURCE OF DATA: Most of the climatological charts adapted from the U. S. Navy Marine Climatic Atlas of the World, Vol. I. The SST data essentially the same as used for H. O. Pub. No. 225 with some additional sources published since 1944.

CONTRIBUTORS: U. S. Weather Bureau, NWRC, U. S. Navy and Merchant Marine ships primary source, plus additional information collected by ships from Britain, Canada, France, Netherlands, Germany, and Norway. Other data supplied by Denmark, Portugal, Sweden, and USAF.

FORMAT OF PRESENTATION: Equatorial cylindrical map projection used as background for isopleth analyses, wind roses, bar graphs, direction frequency bars, tables, and other forms of presentation for many different meteorological and oceanographic parameters. Most analyses extend into the Mediterranean, Baltic, Black, and White Seas, and sometimes into Hudson Bay. Air-Sea Temperature Difference charts are analyzed at 2^{o}F contour intervals on a seasonal basis centered on the mid-month of each season (January, April, July, October). These isopleth analyses are presented at odd number values, red isopleths for air colder than sea surface and blue isopleths for air warmer than sea surface. The SST isotherm analysis charts are provided for representative months (February, May, August, November) at a 2.5^{o}F contour interval. Surface current analyses prepared by the

month with solid black arrows indicating persistence in current direction 25% of the time or more. Dashed arrows and shading used to indicate persistence in current direction less than 25% of the time and variable speed. Mean speed of surface currents to 0.1 knot printed extensively across the charts. All three types of charts, Air-Sea Temperature Difference, SST, and surface currents have hatching in northern regions to show the mean ice limits = 5/10 ice coverage. Spring tidal current charts with same format prepared for Chesapeake Bay. Strait of Dover and Strait of Gibraltar charts also prepared.

QUANTITY OF DATA: 7,000,000 observations for surface isopleths, 650 observations for selected regions.

SUBJECTIVE EVALUATION: The atlas is primarily meteorologically oriented with oceanographic information prepared for the mariner and not the scientist. The seasonal analyses for SST and Air-Sea Temperature Difference provide a limited view of the ocean temperature field and the influence it has on the atmosphere. The SST analyses have a much smoother presentation of thermal properties than the companion atlas for the Pacific Ocean, probably due to the fact that this atlas has more than twice the amount of data for a smaller surface area. The Air-Sea Temperature Difference provides a generalized picture of the oceanic influence on the atmosphere in addition to a feeling for the average stability or instability of the lower layers of the atmosphere immediately above the sea surface. The surface current analyses done on a monthly basis provides a great deal of information, which complements the ordinary Atlas of Surface Currents presented in a different format.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: ENROUTE WEATHER GUIDE

AUTHOR: Naval Weather Service Environmental Detachment

PUBLISHER: Fleet Intelligence Center Atlantic, U. S. Navy

DATE: 1 January 1973

REGION OF COVERAGE: North Atlantic Ocean 45°N-74°N lat, 50°W-50°E long

SOURCE OF DATA: Not stated.

CONTRIBUTORS: Not stated.

FORMAT OF PRESENTATION: Polar azimuthal projection with monthly current and mean SST analyses. Currents are shown by solid arrows indicating persistence in direction 25% of the time or more, and by dashed arrows for less than 25% of the time. SST are analyzed with a 2°F contour interval for the open ocean areas and the inland seas (North Sea, Baltic Sea, White Sea, etc.).

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The Weather Guide presents an excellent hydroclimatic product for operational use within a more climatic-oriented publication. The only problem observed was the mixture of so many arrows, isotherms, grid-lines, continental outlines, etc., all in black ink. Contrasting color presentation would be helpful.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: U. S. NAVY MARINE CLIMATIC ATLAS OF THE WORLD VOL. I NORTH ATLANTIC OCEAN NAVAER 50-1C-528

AUTHOR: Naval Aerology Branch of the Office of Chief of Naval Operations

PUBLISHER: U. S. Government Printing Office

DATE: November 1, 1955

REGION OF COVERAGE: North Atlantic Ocean 0-73°N lat, 0°-45°E long 0°-70°N lat, 110°W-0° long

SOURCE OF DATA: Weather and Marine Observations taken by ships and stations from Netherlands, United States of America, Canada, United Kingdom, France, Norway. Radiosonde data from additional countries.

CONTRIBUTORS: U. S. Weather Bureau, NWRC data files on above.

FORMAT OF PRESENTATION: Mercator map projection with isopleth analyses of seasonal (December-February, etc.) mean air temperature minus mean SST. Isopleth interval at 2°F on odd numerals. Red isopleths for air warmer than sea surface, blue isopleths for air colder than sea surface.

QUANTITY OF DATA: 7,000,000 observations available for surface isopleths.

SUBJECTIVE EVALUATION: This is primarily a climatic atlas of atmospheric parameters with only one series of charts relevant to hydroclimate. The Air-Sea Temperature Difference Charts provide an indication of the oceanic influence on the stability or instability of the air immediately above the sea surface.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: U. S. NAVY CLIMATIC ATLAS OF THE WORLD VOL. IV SOUTH ATLANTIC OCEAN NAVAER 50-1C-531

AUTHOR: Naval Weather Service

PUBLISHER: U. S. Government Printing Office

DATE: 1 September 1958

REGION OF COVERAGE: South Atlantic Ocean 60°S-23°N lat, 110°W-45°E long

SOURCE OF DATA: U. S. Weather Bureau, NWRC storage file of weather observations provided by ships from many countries over 100 year period.

CONTRIBUTORS: Germany, Netherlands, United Kingdom, United States of America and upper air stations and island stations of many countries.

FORMAT OF PRESENTATION: Mercator map projections, with monthly isopleth analyses of mean air temperatures minus mean SST at 2°F contour intervals on odd numerals. Red isopleths for positive values where air is warmer than sea surface. Blue isopleths for negative values when air is colder than sea surface. Areas of sparse data have dotted isopleths.

QUANTITY OF DATA: 4,088,000 weather observations for oceans and seas.

SUBJECTIVE EVALUATION: This is primarily a climatic atlas of atmospheric parameters with only one reference to sea surface temperature values. The analyses show only broad scale features with no detail.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: OCEANOGRAPHIC ATLAS OF THE NORTH ATLANTIC OCEAN SECTION I TIDES AND CURRENTS Pub. No. 700

AUTHOR: U. S. Naval Oceanographic Office

PUBLISHER: U. S. Naval Oceanographic Office

DATE: 1965

REGION OF COVERAGE: North Atlantic Ocean 0°-68°N lat, 100°W-40°E long

SOURCE OF DATA: Tabular data, ship logs, sailing directions, coast pilots, navigation charts, and publications from many different sources.

CONTRIBUTORS: WHOI, U. S. Weather Bureau, U. S. Navy Hydrographic Office, U. S. Coast and Geodetic Survey, various universities in the United States of America, and other countries including Britain, Germany, France, and Norway.

FORMAT OF PRESENTATION: Equatorial cylindrical map projection used as background for surface current analyses for the whole North Atlantic and numerous bays, inlets, and seas. Prevailing surface currents shown seasonally, winter (January-March) and summer (July-September), by colored arrows, colors varying with steadiness of current. Mean current speed shown on plastic overlays with red isopleth analyses at 0.2 knot intervals. Current roses for every 5° quadrangle shown for winter and summer seasons of the North Atlantic, Mediterranean and Black Seas have separate analyses with prevailing surface currents shown by colored arrows for January through December on one chart, plastic overlay of mean current speed, and separate chart of current roses at approximately every 2° quadrangle. Additional surface current charts with varying information: Yucatan Channel - surface and subsurface currents; Gulf of Mexico - current roses for winter and summer; Straits of Florida - surface and subsurface currents; Gulf Stream - observed current speeds, meanders of the Gulf Stream, seasonal

variation of speed; Belle Isle and Cabot Strait - surface currents; Chesapeake Bay - tidal currents; Skaggerak, Kattegat, the Sound, and Belts - surface currents; Baltic Sea, Gulf of Bothnia, and Gulf of Finland - surface currents; British Isles and North Sea - tidal currents (direction and speed); Strait of Gibraltar - currents; Bosphorus and Dardanelles - surface currents.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The atlas represents an extensive evaluation of tides and currents over the North Atlantic Ocean and boundary gulfs, seas, and bays. By far this is the best overall current atlas for the North Atlantic, even though more detailed (monthly and by 1° quadrangles) information can be obtained from other atlases.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: ATLAS OF SURFACE CURRENTS NORTH ATLANTIC OCEAN H.O. Pub. No. 571 (Formerly H.O. Misc. 10688)

AUTHOR: U. S. Hydrographic Office

PUBLISHER: U. S. Hydrographic Office

DATE: 1st edition reprinted 1947

REGION OF COVERAGE: North Atlantic Ocean 0°-60°N lat, 82°W-10°E long

SOURCE OF DATA: Information used in preparation of this atlas was compiled from observations during a given month for all years prior to 1935.

CONTRIBUTORS: Cooperating observers of the Hydrographic Office.

FORMAT OF PRESENTATION: Equatorial cylindrical map projection used to portray monthly isotherm analyses of mean sea surface temperatures at 5°F contour intervals, current roses of prevailing currents, and arrows of resultant currents. Eight-point current roses graphically picture the frequency of direction and the average drifts within the directions for each area outlined by heavy brown lines, approximately a 5° quadrangle. Resultant currents in each 1° quadrangle are depicted by black arrows showing mean direction and magnitude. The number of observations and the strength of the surface currents are printed above and below each arrow. Interpolation was used in areas of sparse data shown by broken isotherm contours as compared to the normal solid line isotherm analysis.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The primary feature of the atlas is surface currents. Prevailing and resultant currents are analyzed with great detail. The broad scale temperature field is a secondary feature of the atlas with the 5°F isotherm analysis leaving much to be desired.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: ATLAS OF PILOT CHARTS CENTRAL AMERICAN WATERS AND SOUTH ATLANTIC OCEAN Pub. No. 106 (Formerly H.O. Pub. No. 576)

AUTHOR: U. S. Naval Oceanographic Office

PUBLISHER: U. S. Naval Oceanographic Office

DATE: 2nd edition 1955 (corrected reprint 1963)

REGION OF COVERAGE: Central American Waters and South Atlantic Ocean 1^{o}N-31^{o}N lat, 100^{o}W-52^{o}W long

SOURCE OF DATA: Data furnished by the U. S. Naval Oceanographic Office and by the U. S. Weather Bureau

CONTRIBUTORS: U. S. Naval Oceanographic Office and U. S. Weather Bureau listed as primary contributors.

FORMAT OF PRESENTATION: Equatorial cylindrical map projection used with prevailing surface current directions indicated by green arrows and printed numerals for approximate speed 0.1 knot. Steadiness of the current indicated by the character of the arrow shaft. Wind roses and air temperatures also shown. Monthly analyses for Central American Waters and seasonal (December-February, etc.) analyses for South Atlantic Ocean.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The atlas is prepared for operational use rather than scientific examination. The general character of the surface current circulation pattern is visible, but no detailed statistical evaluation is evident or extractable.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: ATLAS OF PILOT CHARTS NORTHERN NORTH ATLANTIC OCEAN H. O. Pub. No. 108

AUTHOR: U. S. Navy Hydrographic Office

PUBLISHER: U. S. Navy Hydrographic Office

DATE: 1st edition 1962 (reprinted 1969)

REGION OF COVERAGE: Northern North Atlantic Ocean 55°N-84°N lat, 80°W-55°E long

SOURCE OF DATA: Data furnished by the U. S. Navy Hydrographic Office and U. S. Weather Bureau.

CONTRIBUTORS: Cooperating observers of the U. S. Navy Hydrographic Office and U. S. Weather Bureau.

FORMAT OF PRESENTATION: Equatorial cylindrical map projection with prevailing direction of surface currents indicated by solid green arrows (dashed arrows for approximation) and average speed of the currents shown by numerals to 0. 1 knot on a seasonal basis (January-March, April-June, etc.). Stream drift charts of the world's ocean currents with printed current names prepared for January and July. Red lines indicate warm streams as blue indicate cold streams, 70°S-84°N lat, 65°E-105° long.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The atlas provides not only a generalized seasonal view of surface current characteristics of the North Atlantic, but also a generalized view of the world's circulation of surface currents. There is a definite lack of detail as can be found in the other atlases on surface currents.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: THE ENGLISH CHANNEL PART I OCEANOGRAPHY VOL. IV No. 2

AUTHOR: Oceanographic Section, Directorate of Weather, Headquarters Army Air Forces

PUBLISHER: U. S. Government Printing Office

DATE: November 1942

REGION OF COVERAGE: English Channel 48°N-54°N, $6^{\circ}30'$W-9°E Eg. Cy. Proj. 48°N-61°N, 7°W-8°E Azi. Proj.

SOURCE OF DATA: Not Stated.

CONTRIBUTORS: Not Stated.

FORMAT OF PRESENTATION: Equatorial Cylindrical Projection map used for surface currents. Principal currents in the English Channel are tidal whereas gradient currents are found in the North Sea. Surface currents depicted by arrows with barbs to indicate velocity. Charts series for surface currents are at one hour intervals, six hours before, at, and six hours after the transit of the moon at Greenwich. Azimuthal equal area projection used for SST with the central point at 55°N lat, 1°E long. Monthly mean SST charts have a variable isotherm contour interval from 0.25°C at the Channel Mouth to every 0.1°C within the North Sea. One additional chart of the mean annual SST has the same format.

QUANTITY OF DATA: Not Stated.

SUBJECTIVE EVALUATION: The regional study is of value to complement major ocean hydroclimatic materials. The detail of the SST analyses is excellent, much better than found in a major ocean analysis.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: MONTHLY MEAN SEA SURFACE AND SUBSURFACE TEMPERATURE AND DEPTH OF THE TOP OF THE THERMOCLINE · MEDITERRANEAN, BLACK, AND RED SEAS
Tech Note No 73-3

AUTHOR: Margaret K. Robinson, Scripps Institution of Oceanography

PUBLISHER: Fleet Numerical Weather Central, Monterey, California

DATE: August 1973

REGION OF COVERAGE: Mediterranean, Black, and Red Seas
12°N-48°N lat, 10°W-45°E long

SOURCE OF DATA: Primary sources were BT observations on file at WHOI for the period 1941-1966. Red Sea BT data for period 1948-1966 from Scripps Institution of Oceanography. Other sources were NODC and NAVOCEANO files.

CONTRIBUTORS: Some of the major contributing countries were the United States, United Kingdom, Germany, Netherlands, Denmark, France, Italy, Yugoslavia, Russia, and Turkey.

FORMAT OF PRESENTATION: Equatorial cylindrical map projection with monthly isotherm and isopleth analyses. The mean temperature charts analyzed at 1°F isotherm intervals are arranged in 12 monthly groups, each containing 6 charts at the surface, 100, 200, 300, 400, and 492(150m) feet with every fifth isotherm in $^{\circ}$F darkened. A seventh chart for each month shows the depth of the top of the thermocline, which is defined as that depth at which the temperature is 2°F less than the surface temperature. The contour intervals for the mean thermocline depths are 50 feet in the Red Sea, and 10 feet in the Mediterranean and Black Seas.

QUANTITY OF DATA: 36,461 BT and reversing thermometer observations.

SUBJECTIVE EVALUATION: The author of this atlas provides a bulk of knowledge on the complicated subsurface temperature structure in the layers affected by seasonal heating in addition to the traditional SST. This provides an abundance of information

for the meteorologist or climatologist with which to better evaluate the heat sources within these regional seas. The placement of an additional depth and increasing the contour interval to every $1^{o}F$ shows improvement over the first atlas for the Pacific by this author in 1971.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: Monatskarten der Oberflächentemperatur für die Nord und Ostsee und die angrenzenden Gewässer Nr. 2336

AUTHOR: Gunther Bohnecke and Gunter Dietrich

PUBLISHER: Deutsches Hydrographisches Institut, Hamburg, West Germany.

DATE: 1951

REGION OF COVERAGE: North & Baltic Seas & Adjacent Areas 47° N - 70° N lat, 10°W-30°E long

SOURCE OF DATA: Atlas was prepared from observations taken by ships of opportunity, research vessels, light ships, coastal stations, and predetermined fixed stations between 1906 and 1938.

CONTRIBUTORS: Denmark, Britain, Germany, Finland, and Sweden are the primary contributors.

FORMAT OF PRESENTATION: Lambert's conformal Kegel-projection with monthly SST isotherm analyses at 0.5°C contour intervals, solid lines for whole values, broken lines for half values. Hatching is used to indicate ice limits from October through May.

QUANTITY OF DATA: 3 million observations.

SUBJECTIVE EVALUATION: The surface temperature field has been presented with fine detail due to the large quantity of data and the technique of analysis. It will be difficult to improve on the quality of this product for many years.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: Monatskarten der Temperatur der Nordsee, dargestellt für verschiedene Tiefenhorizonte

AUTHOR: G. Tomczak and E. Goedecke

PUBLISHER: Deutsches Hydrographisches Institut, Hamburg, West Germany

DATE: 1962

REGION OF COVERAGE: North Sea 50^{o}N-62^{o}N lat, 5^{o}W-12^{o}E long

SOURCE OF DATA: Maps based on mean values of 1.5^{o} squares derived from observations (Bulletin Hydrographique) made during the period from 1902-1954.

CONTRIBUTORS: Britain, Scotland, Germany, and Denmark are listed as the main contributors.

FORMAT OF PRESENTATION: Equatorial cylindrical map projection with monthly isotherm analyses at depths of 7.5, 20, 30, 40, 60, 80, and 100 m as well as the depth immediately above the sea bottom. The isotherm intervals vary between 0.5^{o} and 1^{o} C with solid lines for whole values, dashed lines for half values.

QUANTITY OF DATA: 122,151 observations

SUBJECTIVE EVALUATION: Although there is no SST isotherm analyses presented in this atlas, the difference between the surface temperature and the temperature at 7.5 m is insignificant during most of the year, so that this atlas would be useful for regional studies of surface conditions. The subsurface temperature information provides a look at the ocean heat content near the surface. The detail of the temperature analyses is difficult to surpass. The isotherm interval variance between 0.5^{o} and 1^{o} C can be attributed to a dependence on the gradient in the region of coverage and the available data size.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: ATLAS OF MONTHLY MEAN SEA SURFACE AND SUBSURFACE TEMPERATURE AND DEPTH OF THE TOP OF THE THERMOCLINE

AUTHOR: Margaret K. Robinson, Scripps Institution of Oceanography

PUBLISHER: National Technical Information Service, U. S. Dept. of Commerce

DATE: March 1973

REGION OF COVERAGE: Gulf of Mexico and Caribbean Sea
10°N-35°N lat, 60°W-100°W long

SOURCE OF DATA: Based on BT data supplemented by available reversing thermometer data taken from 1942-1968.

CONTRIBUTORS: WHOI provided major part of BT data, Texas A&M University the rest. Data was collected from many institutions and countries for repository at these two locations, including U. S. Navy, U. S. Coast Guard, U. S. Coast and Geodetic Survey, Naval Oceanographic Office, Bureau of Commercial Fisheries, Columbia University, Duke University, University of Miami, University of Rhode Island, Germany, Great Britain, Italy, WHOI, and Texas A&M University.

FORMAT OF PRESENTATION: Mercator Projection with monthly isopleth analyses. The mean monthly sea temperatures were analyzed for the sea surface and five subsurface levels at 100, 200, 300, 400, and 492 feet. These 72 horizontal mean temperature charts were arranged in 12 monthly groups, each containing 6 charts with a 7th chart for depth of the top of the thermocline, defined as that depth at which the temperature is 1.1°C (2°F) less than the surface temperature. The temperature analyses are accomplished at .5°C contour intervals between isotherms. The thermocline contours are at 15m (50 ft). In addition charts are provided of the distribution and numbers of observations at each level for each month and mean annual cycle curves for selected 1° quadrangles.

QUANTITY OF DATA: 51,510 BT and reversing thermometer temperature observations for Gulf of Mexico and Caribbean Sea areas. 59,900 observations for portions of the Atlantic and Pacific.

SUBJECTIVE EVALUATION. For a regional area presentation of SST and the heat content of the near subsurface depths the isotherm analyses were quite detailed. In fact, the isotherm packing in some areas was too dense for accurate evaluation. This new approach to SST and subsurface presentation started by Margaret Robinson would be best done at a 1°C isotherm interval or on a larger scale map projection.

TITLE: THREE-DIMENSIONAL DIGITAL OCEAN CLIMATOLOGY FOR THE WESTERN NORTH ATLANTIC

AUTHOR: S. W. Selfridge, W. C. Woodworth, K. G. Richards

PUBLISHER: Mellonics Systems Development Division of Litton Industries, Monterey, California.

DATE: February 1968

REGION OF COVERAGE: Western North Atlantic Ocean 25°N-50°N lat, 80°W-50°W long

SOURCE OF DATA: Original bathythermograph (BT) data collected between 1940 and 1961.

CONTRIBUTORS: U. S. Naval Oceanographic Office, Scripps Institution of Oceanography, and Woods Hole Oceanographic Institute.

FORMAT OF PRESENTATION: Polar azimuthal projection (standard JNWP grid rotated clockwise - westward 25°) with monthly isotherm analyses at 1°C contour intervals for mean temperatures at the surface, 200, and 400 feet. In addition, the publication has monthly isopleths of mean MLD contoured at 50 foot intervals.

QUANTITY OF DATA: 300,000 BT observations.

SUBJECTIVE EVALUATION: The publication presents an extremely good analysis of SST that agrees reasonably well with the Oceanographic Atlas of the North Atlantic Ocean, Section II, Physical Properties, which was based primarily on ship injection temperatures for the SST analyses and all available BT data for subsurface analyses. This publication should be used as a supplement to the major atlas, though, since it covers only a small portion of the Atlantic and the fact that analyses are not in full agreement.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: SERIAL ATLAS OF THE MARINE ENVIRONMENT Folio 7
Surface Circulation on the Continental Shelf Off Eastern North America between Newfoundland and Florida

AUTHOR: Dean F. Bumpus (WHOI) and Louis M. Lauzier (Fisheries Research Board of Canada)

PUBLISHER: American Geographical Society

DATE: 1965

REGION OF COVERAGE: Eastern North America - Newfoundland to Florida 27^{O}N-51^{O}N lat, 81^{O}W-54^{O}W long

SOURCE OF DATA: Available drift bottle data collected between 1948 and 1962 inclusive by WHOI and 15 other governmental and private research organizations.

CONTRIBUTORS: WHOI, Bureau of Commercial Fisheries, Bureau of Sport Fisheries and Wildlife, Canadian Department of Transport Lightships, Canadian National Railways, Canadian Pacific Railways, Naval Research Establishment, U. S. Weather Bureau, Northumberland Ferries, USAF, U. S. Coast Guard International Ice Patrol Unit, U. S. Coast and Geodetic Survey, U. S. Coast Guard Lightships, Institute of Marine Science.

FORMAT OF PRESENTATION: Oblique stereographic conformal projection centered at 54^{O}N 38^{O}W. Monthly charts with inferred direction of surface currents indicated by black arrows and the speed by the character of the shaft of the arrows with legend of different speeds. Color shading used to indicate the percentage of recovery of drift bottles along the east coast of North America.

QUANTITY OF DATA: 16,668 drift bottle data.

SUBJECTIVE EVALUATION: The atlas provides an excellent supplement to the Atlas of Surface Currents - North Atlantic Ocean. The monthly and seasonal charts at 30 minute quadrangles give a much more detailed picture of the eastern North American coast surface current characters than found in the atlas which they supplement.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: SERIAL ATLAS OF THE MARINE ENVIRONMENT Folio 21 Average Monthly Sea-Water Temperatures Nova Scotia to Long Island 1940-1959

AUTHOR: John B. Colton, Jr. & Ruth R. Stoddard

PUBLISHER: American Geographical Society

DATE: 1972

REGION OF COVERAGE: Nova Scotia to Long Island 39^{o}N-46^{o}N lat, 72^{o}W-64^{o}W long

SOURCE OF DATA: WHOI BT data files

CONTRIBUTORS: WHOI, Canadian Naval Research Establishment, Fisheries Research Board of Canada, U. S. Coast Guard, U. S. Coast and Geodetic Survey, and U. S. Bureau of Commercial Fisheries.

FORMAT OF PRESENTATION: Polar conic projection, nominal scale 1:6,000,000 with monthly isotherm analyses of temperature at 1^{o}C contour intervals on horizontal surfaces from the surface, 10, 20, 30, 40, 50, 75, and 100m levels.

QUANTITY OF DATA: 35,000 ocean stations.

SUBJECTIVE EVALUATION: The atlas contains an excellent detailed study of SST and subsurface temperature structure for a regional area rather than an entire ocean basin. This information could complement a larger Atlantic ocean atlas. The subsurface information provides a good detailed observation of the heat content in these regions.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: ENVIRONMENTAL ATLAS OF THE TONGUE OF THE OCEAN

AUTHOR: Oceanographic Analysis Division, Marine Sciences Department, U. S. Naval Oceanographic Office

PUBLISHER: U. S. Naval Oceanographic Office

DATE: 1967

REGION OF COVERAGE: Tongue of the Ocean, Bahamas 23°N-25.3°N lat, 76.5°W-78.2°W long

SOURCE OF DATA: NAVOCEANO survey of area since 1961, plus other data amassed by other research activities, weather stations, and oceanographic laboratories. Mean SST from oceanographic station data, bucket temperatures, temperature sensor data, and to a lesser extent injection temperatures.

CONTRIBUTORS: Reference list of 70 contributors representing the U. S. Navy, WHOI, various universities, governmental agencies, and other research oriented organizations.

FORMAT OF PRESENTATION: Equatorial cylindrical projection with 1°C isotherm analyses accomplished for monthly mean SST.

QUANTITY OF DATA: Not stated.

SUBJECTIVE EVALUATION: The atlas provides supplemental information to the Atlantic Ocean Atlases for a small regional area, analyzed with fine detail.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: SERIAL ATLAS OF THE MARINE ENVIRONMENT Folio 1 Sea Surface Temperature Regime in the Western North Atlantic 1953-1954

AUTHOR: Robert L. Pyle

PUBLISHER: American Geographical Society

DATE: 1962

REGION OF COVERAGE: Western North Atlantic 23°N-49°N lat, 84°W-59°W long

SOURCE OF DATA: U. S. Weather Bureau, NWRC, coastal tide stations and stationary lightships along the east United States coast. Additional data supplied by research vessels in the area during 1953 and 1954.

CONTRIBUTORS: U. S. Weather Bureau, NWRC, tide stations, lightships, and research vessels.

FORMAT OF PRESENTATION: Oblique stereographic conformal projection for North Atlantic centered at 54°N 38°W. SST analyzed at 2.5°C contour intervals for each month of the years 1953 and 1954, side by side, for comparison with observations averaged at 30' minute squares. 1954 minus 1953 difference in SST analyzed at 1°C isallotherm intervals with color shading to show warmer or cooler years. Spring warming to 7° and 15°C shown by isopleths for the 1st day of March through June for both 1953 and 1954. Autumn cooling to 15° and 7°C shown for last day of August through December (February for 7°C, 1953). Winter and summer range of SST shown by color shading at 2.5°C intervals up to 12.5°C and greater for each year. Winter minimum SST and summer maximum SST analyzed at 2.5°C isotherm intervals for each year. Annual range of SST shown by color shading at 2.5°C intervals from 5°C up to 17.5°C, then a large jump to 25°C.

QUANTITY OF DATA: Approximately 50,000 observations per year for 1953 and 1954.

SUBJECTIVE EVALUATION: The atlas provides a thorough examination of SST statistical properties for a two-year period. Although it is not a hydroclimatic product over a long period of time, the atlas has merit in the comparison of two years side by side to show the anomalies of SST.

REVIEW OF HYDROCLIMATIC PRODUCTS

USEFUL TO METEOROLOGISTS

TITLE: SERIAL ATLAS OF THE MARINE ENVIRONMENT Folio 15 Monthly Sea Temperature Structure from the Florida Keys to Cape Cod

AUTHOR: Lionel A. Walford and Robert I. Wickland U. S. Bureau of Sport Fisheries and Wildlife

PUBLISHER: American Geographical Society

DATE: 1968

REGION OF COVERAGE: Florida Keys to Cape Cod

SOURCE OF DATA: Observations made over past 50 years, 1914-64, mostly 1940-64 by research vessels of governmental and private institutions as well as by lightships, weather ships and shore stations. Data obtained from publications, Navy Oceanographic Office standard Hydrographic station data, and BT's up to 1963 at NODC. Also BT's from WHOI.

CONTRIBUTORS: U. S. Navy Oceanographic Office, NODC, and WHOI.

FORMAT OF PRESENTATION: Isometric block diagrams for temperature profiles, colored coded for ease of visualization in 3 dimensions. Monthly SST isotherm analyses on planimetric map. Monthly maps and diagrams of SST's and temperature structure profiles with depth at 2.5°C contour intervals from the surface to the bottom on the shelf and 275 m depth off the shelf.

QUANTITY OF DATA: 24,456 observations used by selective sampling.

SUBJECTIVE EVALUATION: The serial atlas brings out a new approach to viewing surface and subsurface temperature characteristics. The colorful portrayal of SST's and subsurface temperatures illustrates the warm water presence in the Gulf Stream, with tongues protruding northward especially in the winter season. The temperature analyses at 2.5°C intervals for such a small regional area on a large-scaled map seem rather inadequate for detail.

V. RECOMMENDATIONS

1. Expand the present list of hydroclimatic products (based on the present criteria most useful to meteorologists) to present a more complete selection of this type for the meteorologist. This would necessitate communications with, loans from, or visits with other oceanographic institutions possessing hydroclimatic products.

2. Expand the list of hydroclimatic parameters investigated from those most useful to meteorologists to all of those parameters useful to oceanographers and other scientists. The list of parameters of major importance would start with sea and swell, waves, salinity, secchi disk depths, BT-vertical profiles, sound velocity, density, oxygen, and nutients. Other parameters could be added for the biologist, geologist, and other scientific disciplines interested in hydroclimate.

3. Investigate the hydroclimatic products on computer tape: their sources, format, quantity, availability, cost, and usefulness.

4. Develop a comprehensive hydroclimatic atlas useful to meteorologists. An oversized serial atlas of each major ocean is preferable to a one-volume atlas of the world oceans. This type of atlas would allow the best detailed analysis possible with available data at the time of preparation to be presented without extreme packing of isopleths or other features of presentation. The presentation would be best accomplished on a mercator projection for ease of comparison with other

products and extraction of information. The preferred time-scale of analyses and the hydroclimatic parameters of interest would include: monthly mean, minimum, and maximum SST and subsurface temperature at 100, 200, 300, 400, and 492-foot horizontal levels; monthly SST anomalies; monthly sea-surface heat exchanges; monthly depths to the top of the thermocline; monthly air temperature minus SST differences; monthly surface currents; seasonal (winter-summer) analyses and annual ranges of the above parameters. The parameters should be analyzed under the following guidelines: all temperature parameters at $1^{\circ}C$ isopleth intervals; surface heat exchanges at 50-unit contour intervals; depth of the top of the thermocline at 50-foot intervals, unless data allows more definitive analyses; and surface currents at 1° squares, shown by arrows for direction, and with either accompanying values of mean and range of current strength printed for each 1° square, or separate isopleth analyses of current strength.

APPENDIX A

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