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El-Sayed M. Hassan and Makram A. Gerges

Implications of Climate Change in the ROPME Region: An Overview

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PREFACE

The closely-related issues of greenhouse gas emissions, global warming and climate change have recently come to the top of the international environmental agenda. In particular, concerns over the problems expected to be associated with the potential impacts of climate change have grown over the past decade and captured the attention of the scientific community, the politicians, decision makers, as well as the private and public sectors. These problems may prove to be among the major environmental problems facing the marine environment and adjacent coastal areas in the near future. Therefore, and in line with UNEP Governing Council decision 14/20 on "Global Climate Change", the Oceans and Coastal Areas Programme Activity Centre (OCA/PAC) of the United Nations Environment Programme (UNEP) launched and supported a number of activities designed to assess the potential impact of climate change and to assist the Governments concerned in identification and implementation of suitable response measures which may mitigate the negative consequences of the impact.

Since 1987 to date, Task Teams on Implications of Climate Change were established for eleven regions covered by the UNEP Regional Seas programme (Mediterranean, Wider Caribbean, South Pacific, East Asian Seas, South Asian Seas, South-East Pacific, Eastern Africa, West and Central Africa, the Kuwait Action Plan Region, the Red Sea and Gulf of Aden and the Black Sea. UNEP also established two Global Task Teams on the Expected Impacts of Climate Change on Coral Reefs and Mangroves in cooperation with the Intergovernmental Oceanographic Commission (IOC) and UNESCO respectively. Some of the Regional Task Teams enjoy the support of the Intergovernmental Oceanographic Commission (IOC) of UNESCO and other relevant international, regional and non-governmental organizations.

The initial objective of the Task Teams was to prepare regional overviews and site-specific case studies on the possible impact of predicted climate change on the ecological systems, as well as on the socio-economic activities and structures of their respective regions based on the climate change models/scenarios developed by the Intergovernmental Panel on Climate Change (IPCC) and widely accepted by the international scientific community.

The overviews and case studies were expected to:

- examine the possible effects of the sea-level rise on the coastal ecosystems (deltas, estuaries, wetlands, coastal plains, coral reefs, mangroves, lagoons, etc.);
- examine the possible effects of temperature elevations on the terrestrial and aquatic ecosystems, including the possible effects on economically important species;
- examine the possible effects of climatic, physiographic and ecological changes on the socio-economic structures and activities; and
- determine areas or systems which appear to be most vulnerable to the above effects.

The regional overviews were intended to cover the marine environment and adjacent coastal areas influenced by, or influencing, the marine environment. They are to be presented to intergovernmental meetings convened in the framework of the relevant Regional Seas Action Plans, in order to draw the countries' attention to the problems associated with expected climate change and to prompt their involvement in development of policy options and response measures suitable for their region.

Following the completion of the regional overviews, and based on their findings, site-specific case studies are developed by the Task Teams and are planned to be presented and discussed at national seminars. The results of these case studies and the discussions at the national seminars should provide expert advice to the national authorities concerned in defining specific policy options and suitable response measures.

The Task Team on the Implications of Climate Change in the ROPME Region was established, and met in its first meeting at the Regional Organization for the Protection of the Marine Environment (ROPME) in Kuwait, 20 -22 May 1990, and in its second meeting at UNEP's regional Office for West Asia (ROWA) in Bahrain, 1-4 September 1991. The meetings were attended by experts from the region invited by UNEP in their personal capacities, taking into account the need for expertise relevant to the work of the Task Team and for a balanced geographical representation. It was also attended by representatives of the Intergovernmental Oceanographic Commission (IOC) of UNESCO and the Regional Organization for the Protection of the Marine Environment (ROPME). Each member of the Task Team was assigned a specific subject to address in detail, and the present overview is largely based on the contributions by the individual members of the Task Team.

The Task Team members who contributed to the present overview are: Prof. El-Sayed M. Hassan (Coordinator), Dr. Mohammed Abo-Auf, Dr. Sulaiman Almatar, Dr. Saad Al-Numairy, Dr. Dhafer A. Alumran, Dr. Mohammed B. Amin, Mr. Mohammed A. Borhan, Dr. Paul N. Munton, Mr. Walter Vreeland, Dr. Badria Al-Awadi (ROPME), Dr. Amin H. Meshal (IOC/UNESCO), and Dr. Makram A. Gerges (UNEP). The following members also participated in the work of the Task Team during the two meetings in Kuwait and Bahrain: Dr. Mohamoud Y. Abdulraheem, Dr. Mokhles Abou-Seida, Dr. Bahgat B. Habashi, Dr. Hassan Mohammadi, Dr. Fouad Kanbour (UNEP-ROWA) and Ms. Mariam Alkhalifa (ROPME).

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EXECUTIVE SUMMARY

The ROPME Sea Area can be divided into three distinct areas, each with its own characteristic response to climate change. These areas are: SA-I, the northern part of the Arabian Sea bounded to the north by the south coast of the Sultanate of Oman, the mouth of the Gulf of Oman and the southern coast of the Islamic Republic of Iran; SA-II, the Gulf of Oman, an arm of the Indian ocean open to it by a wide deep mouth, and connected to SA-III by the narrow and shallow Strait of Hormuz; and SA-III named in the literature as the Persian Gulf or the Arabian Gulf.

SA-I is the prime representative worldwide of the monsoonal weather system, which produces strong summertime upwelling which results in rich fisheries that disappear in the winter. SA-II shows transition between the monsoonal system and the desert belt climate of SA-III. The prominent feature of SA-III is its shallowness which results in important consequences: a) the annual range of water temperature is the greatest for any water body freely connected to the world ocean. This restricts the ecosystems that can survive such a range and stresses members of these systems, b) it also enhances the effect of sea level rise on the tidal pattern. More than anywhere else on the globe, this will manifest itself in SA-III.

The area, being the greatest oil producing area in the world, experienced a boom which started in the early seventies and continues to varying degrees in different ROPME Member States. Industry is expanding, population is increasingly urbanised in great coastal cities, influx of expatriates is continuing, infrastructures and services are being established and they grow rapidly. The environment and the existing ecosystems are stressed. The newness of the development offers the opportunity of including measures for protection against anticipated likely climate changes, but this opportunity is not fully utilised. This is partly due to the uncertainties about the magnitude of the changes and partly due to the long time scale in which these changes are expected to occur. It is clear from the information available however that certain coastal areas are more vulnerable than others. Foremost among these is the City of Kuwait.

SA-III exhibits two characteristics worth noting for their relevance to the sea level rise: because the region is the major oil and gas extraction area in the world, resulting land subsidence can produce an apparent sea level rise of the same order of magnitude as that postulated from expected climate change. Thus, observed sea level rise could be at twice the rate of the global one. Also because of the shallowness of the area, the change of tidal pattern resulting from the change of depth will be more dramatic and observable than anywhere else in the world.

For the specific interest of the ROPME Member States and as a general contribution in the international effort of studying and facing the challenge of climate change it is recommended that:

(a) A high quality dense tide recording network be established and connected to a land subsidence recording network.

(b) A regional central data collecting and data processing centre be identified within the region and adequately supported.

(c) An active participation in international relevant programs such as TOGA and GOOS by ROPME Member States be maintained.

(d) The Non-Governmental Organizations (NGOs) concerned with environmental issues, with their proverbial tendency for speedy action, should be encouraged to take an active part in environmental matters, particularly where public awareness is involved.

1. INTRODUCTION

1.1 THE GLOBAL SETTING

In spite of the existence of many different climatic types on earth, and in spite of the great year to year variability of the climate elements at any one place, the global means of climatic elements are nearly constant to a remarkable degree, and dramatic effects on earth are associated with small changes in these global means. The earth's mean temperature during the last ice age is estimated to be a mere 4.5°C below today's mean. At that time, however, ice sheets advanced equatorwards for hundreds of kilometres and covered vast areas in Eurasia and the Americas with drastic consequences to the biota on land and in the ocean and a huge drop in the sea level. Smaller variations in the means of climatic elements occur at different times with commensurate results. Prediction of climatic trends is, therefore, an important element in long term planning, but it is fraught with uncertainties due to the inadequacy of data and the complexity of relationships between causes and effects.

Climate results from the interaction between the incoming radiation and the "local" conditions on earth. For the purpose of this work, the incoming radiation will be considered as constant, and changes in the climate will, therefore, result from changes in conditions on earth.

1.2 BASIC INFORMATION

For all practical purposes, solar radiation constitutes the sole source of energy responsible for the earth's climate. The sun emits quantitative and qualitative radiation whose spectrum is consistent with a black body whose surface temperature is around 6000°K. A small cone of this radiation with an apex of 35" reaches the outer atmosphere directed towards the earth. This radiation is called the short wave radiation and its spectrum spans wave lengths from the ultra violet radiation (UV) through the visible light to the infrared radiation (IR). In the mean, spacewise and timewise, outgoing radiation from earth has to equal the incoming radiation. Otherwise the difference will produce changes in the earth's temperature or manifest itself in other ways.

Observations indicate that this is not the case. At any particular point of time, however, or at any particular place the balance can be violated resulting in temporary or local changes in temperature, evaporation, local importation or exportation of energy, growth of plants, desertification or other phenomena. Part of the outgoing radiation is reflection of the incoming radiation from clouds and the earth's surface and other elements of the atmosphere. The reflected radiation is of the same wavelength as the incoming radiation but the back radiation has a spectrum that depends on the temperature of the radiating surface. Back radiation from earth is totally in the IR part of the spectrum and is called the long wave radiation. While the atmosphere is almost totally transparent to the solar radiation it is much more opaque to the pure IR back radiation emanating from the earth (The ozone absorbs parts of the UV while water vapour, CO_2 and other gases absorb parts of the IR. These wavelengths occur at the extremities of the solar spectrum, and the central part containing most of the energy passes undiminished as visible light). Thus, a portion of the radiation emitted by the earth's surface gets absorbed in the earth's atmosphere. Absorbed radiation raises the temperature of the absorbing medium and causes it to radiate in all directions, thus, returning to the earth's surface part of what it had already radiated. This process raises the surface temperature of the earth, and thus, increases the back radiation, which is proportional to the fourth power of the absolute temperature of the radiating surface, until the radiation finally leaving the earth (reflected + back radiation) again equals the incoming radiation in the mean. Because the gases that absorb the IR radiation in the atmosphere act in a way similar to the glass walls of a greenhouse, they are popularly called "green house gases" and the radiation returning to the earth's surface as a result of these gases will be called in this overview "the greenhouse radiation". It is estimated that one of the greenhouse gases, water vapour, is responsible for raising the earth's mean temperature by more than 30°C (Gross, 1987). Thus, an earth with an atmosphere sans water vapour, i.e. no oceans on earth either, would have a temperature of 249°K (-24°C) rather than the present mean of 280°K (+7°C). It should be noted that the geographical facts of the earth would not change by changes in the radiation balances. The earth would continue to rotate round its axis which penetrates the surface at the points of the North pole and the South pole, the axis being inclined to the plane of the ecliptic by 23.5° etc., i.e. the polar regions, the tropical regions and the equatorial regions would remain where they are, the seasons of the year will occur in their regular times while the polar climate, the tropical climate and the equatorial climate would change.

1.3 GLOBAL CONSEQUENCES

A rise in the earth's surface temperature unleashes other effects. Water, which covers more than 70% of the earth's surface would evaporate in greater amounts. Water vapour which carries with it a great amount of energy in the form of latent heat of evaporation, releases it to the atmosphere when it condenses as clouds. The released energy is the major contributor to the creation of wind and other weather phenomena such as storms, hurricanes and typhoons. The increased strength of wind results in higher waves (rough seas and erosion) and stronger currents. As winds and ocean currents are also the major transporters of heat from the excessively heated equatorial regions to the deficiently heated higher latitudes, stronger winds and currents will transport more heat from the lower latitudes to the higher latitudes. Thus, the temperature rise due to the greenhouse gases will be more observable in high latitudes. Increased evaporation will result in increased precipitation. If this falls in the "right" places at the "right" times it can be a great boon for agriculture and forestry. If it falls at inappropriate times or places it can create problems causing floods and water erosion.

Some further consequences

A rise in the ocean surface temperature would increase surface water stability and diminish vertical mixing and upwelling phenomena. However, a rise in the ocean surface temperature coupled with increased wind speed would increase evaporation and mixing which increases salinity reducing stability and enhancing vertical mixing. Which factor will dominate? Will the stability increase or will it decrease? It is safe to say that stability will increase in some areas of the ocean and will decrease in others and that in some it will increase at one time and decrease at another. It is felt that in the case of the ROPME Sea Area the balance will tip to enhanced upwelling, i.e. the effect of the wind will be stronger than that of the increased surface heating. The current regimes driven by the wind and thermohaline causes will also be modified feeding back changes that are dimly understood and poorly predictable.

As water temperature rises, water volume will increase in all oceans expanding the water covered portion of the earth's surface and increasing evaporation because of increase in both surface temperature and surface area.

Polar ice caps and mountain glaciers will diminish as the temperature rises or expand as precipitation increases in the form of snow that does not melt because the temperature in these regions is below the melting point of snow.

Ecosystems on land and in the water will extend polewards if their range is now restricted by cold temperature, and will be curtailed from the equatorial side if they cannot tolerate warmer temperatures. The ecosystem composition itself will change as warm temperature tolerant species will be favoured over others. Some of these changes have positive feedbacks, i.e. change induces further change of the same kind e.g. the increase of water evaporation leads to higher concentration of water vapour in the atmosphere leading to further absorption of back radiation leading to an increase of greenhouse radiation leading to higher water surface temperature leading to enhanced water evaporation and so on. Positive feedback phenomena lead potentially to instability. However, enough negative feedback mechanisms exist in the earth's climate system that restore a new equilibrium (at a higher temperature). In the example cited above, increased evaporation would increase the amount and thickness of the earth's cloud cover resulting in increased cloud reflectivity reducing the solar short wave radiation that reaches the earth's surface, thus, reducing the temperature leading to a reduction of evaporation from the surface of the ocean.

1.4 VARIATIONS

The response of the earth's surface to increased radiation is not uniform. Water bodies absorb more radiation than land surfaces and allow it to penetrate to much greater depths. Partly because of the penetration, partly because of the heat capacity of the water, and in high latitudes because of the limit as to how low the temperature of a water body can reach before the surface freezes and isolates the water underneath from further cooling, ocean surface temperatures fluctuate within a much narrower range than the land surface temperatures. Within the water bodies themselves, size, latitudinal location, orientation, depth, proximity of land, discharge of rivers, magnitude and direction of currents, all affect the range of temperature fluctuations. Variations on dry land are more dramatic where elevation and the nature of the land vary to a greater extent and on a finer scale than water bodies. It is difficult enough to take small bodies of water in consideration but infinitely more difficult to consider dry land of the same dimensions.

1.5 GENERAL CIRCULATION MODELS (GCMs) AND REGIONAL MODELS (RMs)

Because fluids (air and water) are major actors in the world climate, and because these fluids travel the world affecting local and regional climates and being affected by them, it is reasonable that global climate would best be modeled as a single model for the whole earth including the motion of air and water. GCMs are numerical models for the earth's weather that apply the laws of physics and the incoming solar radiation to a rotating earth with oceans, land masses and atmosphere containing the present concentration of carbon dioxide or other concentrations for prediction purposes. All this is represented in detail to the extent allowed by the computer used (at present ~5°lat. and ~7°long.) and as our understanding of the physical processes and relationships allows. The ocean and the atmosphere are represented by several layers and the physical processes by approximations of known laws, equations of state, turbulence, etc. GCMs use the state of the art computers and are marvels of ingenuity. Compared to the earth which they represent, they are, however, crude, inaccurate and may even be wrong in detail (see e.g. Palutikof *et. al.*, 1992). Nature is infinitely complex and subtle. The smallest model of the earth that can faithfully reproduce all its details is the earth itself. GCMs are useful in giving a crude indication of what is likely to happen on a global scale if the assumptions and approximations are good. Because of their immense complexity and the resources required to construct them and to run them there are only a few GCMs in existence at any one time. They all predict global warming, but they vary greatly in regional details of the prediction. It is hoped that breakthroughs in human understanding of the laws of nature and the emergence of larger and faster computers may allow better predictions to emerge and reconcile some of the differences among different GCMs' results.

RMs, modelling a portion of the globe only, might be thought of as partially solving GCM's difficulties since they allow a greater resolution. This is not so, as while GCMs do not need lateral boundary conditions because they cover the globe and thus have no lateral boundaries, RMs need lateral boundary conditions. These boundary conditions control the results due to the time scale considered in climatic research. Specifying the boundary conditions for all the time for RMs requires GCMs again. With few exceptions, therefore, different regions in the world take the agreed upon temperature elevation and sea-level rise and consider with available existing knowledge the expected implications or take boundary conditions from one GCM or the other, thus, implicitly accepting the results of that GCM.

1.6 ASSUMED CHANGES

The assumed changes in this overview are those accepted by the Intergovernmental Panel on Climate Change (IPCC), i.e. a temperature increase of between 1.5°C and 4.5°C and a sea-level rise of 0.3 m. by the year 2030 (from 1990) and a rise of 1m. by the year 2100 (IPCC, 1990, IPCC, 1992). Because of the mostly qualitative nature of this overview, the conclusions drawn here would not be crucially affected if the changes are somewhat different from those proposed by IPCC. Recent observations indicate that the change may be less than the postulated figures.

1.7 AN IMPORTANT POINT

Two characteristics of the greenhouse radiation should be emphasized:

(a) The effectiveness of this radiation in raising the skin temperature of the ocean is orders of magnitude greater than the solar radiation. This is because all this radiation lies in the IR which is absorbed in the first few microns of the skin layer of the ocean. In contrast, the solar radiation penetrates a few meters at least. Consequently greenhouse radiation heats a much thinner layer and raises its temperature higher than what would be expected from comparing the ratio of energies contained in these radiations. The greenhouse radiation reaching the earth's surface contains <2% of the energy in the solar radiation in case of a 1.5°C rise and <6.5% in the case of a 4.5°C rise of the surface temperature. Because evaporation from the ocean is sensitive to the skin temperature of the water, the greenhouse radiation by raising the temperature assumes an important role in the process of evaporation. The evaporating water would draw on the great amount of heat stored in the ocean leading to the paradoxical situation that the added greenhouse radiation leads to a warmer skin and a cooler surface layer albeit with increased evaporation. The increased amount of latent heat contained in the water vapour and later released when it condenses as clouds or fog is the prime supplier of energy for storms while the water vapour supplies the rain. This is happening gradually and it is possible that the severe storms experienced recently in Bangladesh, the ferocious hurricanes in the United States and the floods in Pakistan, India and Sri Lanka could be indications of things to come as one result of climate change, particularly as they occurred at a time when the solar radiation reaching the globe was diminished by the dust from the major eruption of Pinatubo, a volcano in the Philippines.

(b) The difference between the response of dry land and the ocean to the greenhouse radiation is much smaller than the difference in their response to the solar radiation. This is another consequence to the depth of penetration of radiation. While the solar radiation penetrates the water to an extent which is orders of magnitude greater than the depth of penetration in dry land, the depth of penetration of the greenhouse radiation is almost the same. This reduces the contrast between land and sea affecting some important weather phenomena.

Note that in the end the radiation emanating from the earth to space does not change, as the radiation reaching the earth does not change. The elevation of the earth's surface temperature would be to overcome the increased opacity of the atmosphere to IR radiation due to the increased concentration of the greenhouse gases.

2. DESCRIPTION OF THE ROPME AREA

2.1 BOUNDARIES

From the ocean side the area is bounded by the following rhumb lines (Figure 1):
From Ras Dharbat Ali Lat. 16° 19'N Long. 53° 03' 30"E
Then to a position in Lat. 16° 00'N Long. 53° 25' E
Then to a position in Lat. 17° 00'N Long. 56° 36' E
Then to a position in Lat. 20° 00'N Long. 61° 25' E
Then to a position in Lat. 25° 04'N Long. 61° 25' E

Then from the continental side, the boundary follows the coastline of the ROPME Member States. These are (in alphabetical order): The State of Bahrain, the Islamic Republic of Iran, the Republic of Iraq, the State of Kuwait, the Sultanate of Oman, the State of Qatar, the Kingdom of Saudi Arabia and the United Arab Emirates. All member States are coastal states and have important coastal zones.

2.2 CHARACTERISTICS OF THE SEA AREA

The sea area can best be looked at as comprising three distinct divisions: Sea Area I (SA-I), lying in the Northwestern Indian Ocean (IO) to the south of the southern coast of Oman and Iran and the mouth of the Gulf of Oman; Sea Area II (SA-II) which is the Gulf of Oman and Sea Area III (SA-III) which is the inner ROPME Sea Area.

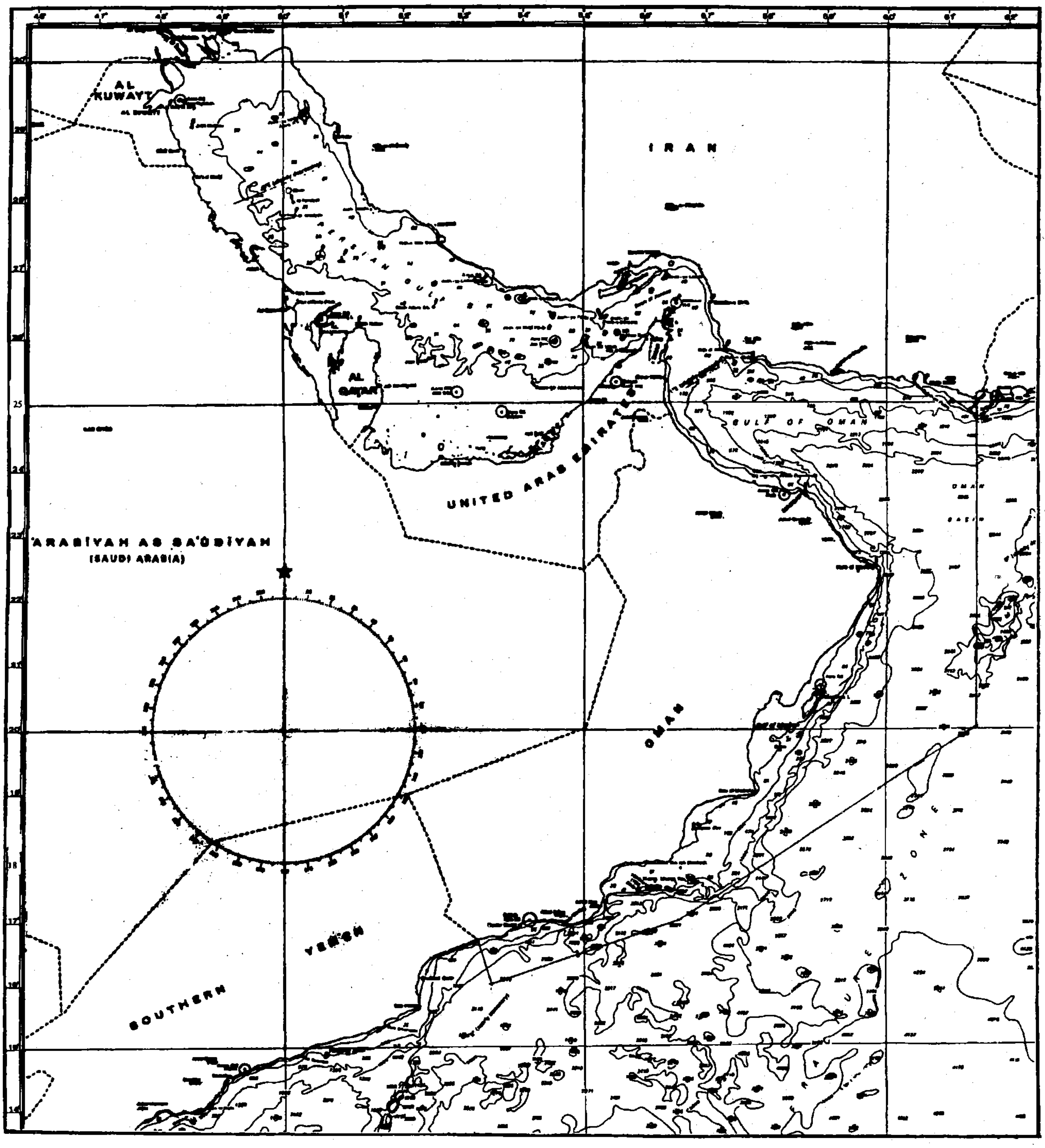


Figure 1: ROPME sea boundaries and surrounding Member States

SA-I: This is the northern part of the Arabian Sea. Its climate is typically monsoonal (Meshal, 1991). During the winter monsoon (November to February) light dry winds blow from the NE. These are associated with low waves (Murty and El-Sabh, 1983), convergence of surface waters to the coast resulting in downwelling and west going current (Hunter, 1983). The summer monsoon (April to September) packs stronger winds from the SW, is rainy and produces strong upwelling. It is not an active region for the development of tropical cyclones, although satellite data appear to suggest that the occurrence of tropical storms might be more frequent than believed earlier (Murty and El-Sabh,1983). The sea bottom is underlaid by an oceanic crust, with a narrow continental shelf which disappears at Ras El-Hadd to reappear again bordering the Iranian coast (Evans, 1985). Surface sediments are from both aeolian transport from the Arabian and the Iranian land masses and fluvial, from intermittent fluvial monsoonal streams and from the Indus River (Evans, 1985, Abu Auf, 1989).

SA-II: (The Gulf of Oman). It is a triangular wide and deep arm of the IO that extends northward and westward for about 400 km. to connect to SA-III through the shallow (maximum depth 100m) and narrow (narrowest width 24 km) Strait of Hormuz. It is affected by the monsoons to varying degrees, according to the strength of the monsoonal system but within SA-II, the effect diminishes as the distance from the IO increases. There is an active exchange of water with SA-III through the Strait of Hormuz with the tide playing a major role in mixing the Gulf of Oman water (originally IO water) with SA-III water. The mixing results in the formation of intermediate water characterized by high salinity, high temperature in summer, and high salinity, low temperature in winter and that flows outwards along the coast of Oman at a depth of 200 - 300 m. SA-II is underlaid by an oceanic crust which undergoes oceanic subduction under the continental crust of the Eurasian plate due to the movement of the Arabian plate at an estimated rate of 5.1 cm/yr. (Evans, 1985). Sediments are of aeolian origin and from the intermittent monsoonal streams from the Arabian and the Iranian sides.

SA-III: This area is also known by other names in literature, viz. the Persian Gulf, the Arabian Gulf and increasingly simply as the Gulf. It is a shallow shelf area (mean depth 38 m). The maximum depth occurs near the Strait of Hormuz which connects SA-III with SA-II. SA-III does not have a sill, and thus, the saline water that forms inside SA-III flows freely to SA-II where it sinks and flows along the coast of Oman as intermediate water. The bottom profile across SA-III is not symmetrical with gentler slopes on the Arabian side and steeper ones on the Iranian side (Purser and Seibold, 1973). Thus, the channel with maximum depth lies on the Iranian side. Bottom sediments result from aeolian transport carried by the dominant northerly winds but also by other winds passing over the Arabian Desert or the Iranian Zagros Mountains and fluvial transport from the Tigris-Euphrates-Karun river system (TEK), and the various ephemeral streams from Zagros and Oman mountains, in addition to sediments of biological origin, both indigenous (e.g. coral reefs) and due to the oceanic influence. It is dotted with islands, mostly topping salt domes (Evans, 1985). The salinity of water in SA-III ranges widely, from 36.5 at the Strait of Hormuz to above 70 in shallow semi- enclosed embayments, e.g. Salwa Bay. In the open part it reaches 42 near Bahrain, Qatar, and the United Arab Emirates. There is an area near the mouth of Shatt Al-Arab and the Iranian and Arabian streams where salinity decreases significantly, the extent depending on the fresh water discharge, but the low salinity water never spreads far from the source. The high salinity results from the excess evaporation estimated at 1.40 m./yr. (Meshal and Hassan, 1986).

Currents in SA-III are complex in detail as they result from the combination of tidal, wind and thermohaline forces. Several models have been built for one driving force or the other and for the total area or for only a part (Hunter, 1983, Le Provost, 1983, Chao *et.al.*, 1992). Direct measurements are spotty both in time and in space but few exist either published (e.g. Hassan and Hassan, 1987) or preserved in the archives of the several concerned national ministries, port authorities and oil companies working in the region. From theoretical considerations currents run in an anticlockwise sense in SA-III. This is consistent with tidal heights measured in ports of the region and does not contradict ships' observations (Hunter, 1983) although the latter include a high noise to signal ratio. Four tidal components -M2, S2, K1, O1- have been analysed by the British Admiralty (Chart No.5081, 1976). The semidiurnal components have two amphidromic points each in the area and the diurnal components one each. The maximum amplitude of these components (Table 1) occur at the Strait of Hormuz and at the head of the area.

Table 1: Maximum amplitudes of the four harmonic tidal components

COMPONENT	M_2	S_2	K_1	O_1
MAXIMUM AMPLITUDE (in metres)	0.8, 0.9	0.25, 0.25	0.5, 0.3	0.3, 0.2
LOCATION 1st figure occurs at head of the area and second at the Strait of Hormuz				

2.3 TEMPERATURE AND SALINITY

Surface temperature in SA-I reflects its monsoonal nature. During the winter monsoon the sea surface temperature (SST) changes from 26°C in the whole area in November to 22°-23°C in February. With the onset of the summer monsoon the temperature rises to around 28°C in May but as upwelling takes hold the temperature in the upwelled areas drops to below 22°C near the coast in August. The low temperature near the coast continues until the upwelling weakens and in November it is again around 26°C in the whole area starting a new cycle.

In SA-II, SST is not affected by the monsoons to the same extent. The effects decrease as one moves from the mouth of the Gulf of Oman where they are strongest until the normal seasonal march of temperature is experienced at Hormuz. Minimum winter SST of around 22°C occurs in February and maximum SST of 32°C occurs in August with water along the Arabian coast being generally warmer than along the Iranian coast.

In SA-III the shallowness of the area accentuates the seasonal differences of SST with temperatures as cold as 13°C and colder occurring at the head of the area in February and nearing 35°C at the height of the long summer. The temperature difference between summer and winter is greatest (>20°C) in the northwestern part and least (<11°C) at Hormuz.

Also, in SA-III water with characteristic seasonal temperature and high salinity forms. Because the area has no sill separating it from the Gulf of Oman and because of the relatively large tidal range (~3m.) at Hormuz, the SA-III water mixed with SA-II water flows to the Gulf of Oman where it can be detected on the Arabian side at a depth of ~ 200-300m. as water of high salinity. It can be detected as water of high salinity and high or low temperature according to the season of formation and the distance from Hormuz. Because of the long summer in SA-III the warm high salinity pulse prevails over the cold high salinity pulse in the intermediate water that reaches the Gulf of Oman.

2.4 HYDROLOGY OF THE ROPME MEMBER STATES

Three sources of fresh water exist in the ROPME region and are utilized. These are rivers, ground water and desalinated water.

Rivers: The major river system that flows through ROPME Member States is the Tigris-Euphrates-Karun river system (TEK). They join together forming Shatt Al-Arab which flows into SA-III near the Iraqi town of Fao, a short distance after the juncture. Together TEK drain a large area in Armenia, Turkey, Syria, Iraq, and Iran. The fresh water carried by the system is continuously and to an ever increasing degree being depleted by the large scale irrigation projects implemented and planned by different countries. Major hydroelectric power projects change the rhythm of the river flow. The final amount that reaches SA-III is estimated as $5x10^{10}$ m^3/yr. (Hassan and Hassan, 1987). Other ephemeral or highly fluctuating rivers and streams occur on the Iranian side. Examples are: Hendian, Mand, Rasul, Kul and Minots. Lesser streams occur in the United Arab Emirates and in Oman draining towards the sea (SA-II and SA-III) or towards the hinterland (Alrubh Alkhali).

Ground water: This falls into two categories: surficial ground water which is fed yearly by the present day precipitation and is nearest to the surface. It is affected by the amount and pattern of the rainfall as well as by the amount and pattern of the water extracted from it. The increasing demand on it for the use in agriculture exposes this layer to salt water penetration from the sea which is seldom very far and thus, to a rise in its salt content as the withdrawal rate exceeds the replenishment rate. The problem appears on the Arabian side of the ROPME Member States and regulations are gradually being put in place in different states in the region to limit the use of surficial ground water so as to stop the rise in its salinity.

Fossil ground water: On the Arabian side this occurs in six layers separated from each other by impermeable ones. Its quality varies according to the layer and the location. It is most valuable in the four desert states of ROPME (Bahrain, Qatar, Saudi Arabia and the United Arab Emirates) and most of all in Saudi Arabia because of its land area and the distances from the sea where fresh water is needed. In Saudi Arabia the size of the proven reservoir is estimated to be 337.5 km^3 while the consumption up to 1420 H(~1999) is estimated to be 3.43 km^3/yr. (Ministry of Planning, Saudi Arabia, 1400 H). At that rate of consumption the fossil water would last for another century.

Desalination: Because of the ready accessibility of the sea and the existence of a cheap energy source in the shape of natural gas, most of the ROPME Member States have turned to desalination to meet the great and increasing demands for fresh water associated with a modern industrialized society. At present the area has the greatest capacity for desalination in the world, and new plants are being built and/or planned from Kuwait in the north to Oman in the south. In Saudi Arabia the amount of desalinated water is projected to increase 19 times in 20 years (from $63x10^6$ m^3/yr in 1400 H. [1980] to $1198x10^6$ m^3/yr in 1420 H [1999]) (Ministry of Planning, Saudi Arabia, 1980). The pattern is the same in Kuwait, Bahrain, Qatar, the United Arab Emirates and Oman. The economics of desalinated water depend on whether it is considered as a by-product to electric generation (another necessary pillar of the emerging industrialized society) in which case it becomes inexpensive or whether the reverse is considered the case. In either case the energy cost is cheap at the present time as natural gas is abundant. In the post gas era difficult questions will have to be faced and planners must be thinking even now about this and a host of other related questions.

2.5 STATES AND POPULATIONS

This section is based on the following works: (Alumran, 1991; Amin, 1991; Borhan, 1991 and Gulf Organization for Industrial Consulting [GOIC], 1989). Because the information is intertwined in this synthesis the references have been clumped together above. When a reference can be identified, it will be.

The eight states surrounding the ROPME Sea Area have greatly varying sizes. Their areas vary by more than three orders of magnitude from less than 1000 km^2 (Bahrain) to more than 2,000,000 km^2 (Saudi Arabia) and the populations by more than two orders of magnitude from less than 400,000 (Qatar) to more than 40,000,000 (Iran). In comparing one state with the other, per capita figures will be used often but in contexts where total country numbers are more appropriate, figures for the whole country are used. The differences should be kept in mind. Some basic statistics appear in Table 2.

Three of the ROPME States have populations in excess of 10 million each while the other five have populations of less than 2 million each. While the majority of population of the bigger states live in the hinterland, four of the five smaller states are totally within the coastal zone.

Within the past quarter of a century, the ROPME States have witnessed three major events that affected their development to a degree that cannot be exaggerated: the rise in the price of oil and two major wars. The first event has increased their income from the export of oil and oil products. For the Arabian ROPME Member States the value of oil exports increased from \$11.2 billion in 1972 to \$63.2 billion in 1974 and peaked at $185.0 billion in 1980 (GOIC,1989) i.e. >16 times in 6 years or a rate of increase of 58% per year. This allowed an unprecedented rate of development, industrialization, trade, and consumption that stressed the environment greatly, and still does. It also made the area a great centre of attraction for an expatriate working population which shows as an abnormal bulge in the population age distribution profile (Table 3 and Figure 2). This also produced social problems which will not be discussed here. The rate of net population growth in all the Arab ROPME Member States exceeds 3% per annum and exceeds 5% per annum in Qatar and the United Arab Emirates. Imported food and beverages in the Arabian ROPME Member States more than doubled in two years from $ .7 billion in 1972 to $ 1.8 billion in 1974 (GOIC, 1989) i.e. an increase in excess of 60% per annum and peaked at $ 9.7 billion in 1984 (GOIC,1989) i.e. >20% per annum for a decade. Similarly the cost of imported machinery and transportation equipment jumped from $1.2 billion in 1972 to $ 3.1 billion in 1974 and peaked to $ 32.8 billion in 1982 (GOIC,1989), again an annual growth of nearly 40% sustained over a decade. The consumption of electric power increased more than five folds from 14 billion KWHs in 1975 to more than 83 billion KWHs in 1984 (GOIC 1989).

Table 2: Some basic statistics for ROPME Member States

States	B.	In.	Iq.	K.	O.	Q.	SA.	UAE.	Total
Area [1] [1000 km^2]	0.7	1648.0	438.4	24.3	272.0	11.4	2400.9	64.8	4860.5
Pop. [2] [1000000]	0.4	50.0	16.7	1.9	1.3	.4	12.0	1.4	84.1
Coastal zone pop. [3]	0.4	5.0	1.3	1.9	0.3	.4	1.1	1.4	11.8
% of pop. in coastal zone [3]	**100**	**10**	**8**	**100**	**20**	**100**	**9**	**100**	**14**

[1] Times Atlas, 1983 [2] GOIC, 1989 [3] Amin, 1991

Table 3: The age pyramid profile in some ROPME Member States [%]

Age Group	B.	Iq.	K.	Q.	UAE
0-9	23	32	27	21	28
10-9	19	24	19	13	14
20-29	25	17	20	23	27
30-39	15	11	18	26	19
40-49	09	07	10	11	08
50-59	05	05	04	04	03
60+	04	05	02	02	01

Although the growth of industrialization and of consumption are still continuing at a rapid rate, it has greatly slowed down as the price of oil plummeted on the world market. Food and beverage imports fell from 9.7 billion in 1984 to $7.0 billion in 1986, and machinery and transportation equipment from $32.8 billion in 1982 to $15.4 billion in 1986 (GOIC, 1989). This is happening while the population growth continues at its high rate and the industrialization potential has not yet been realised.

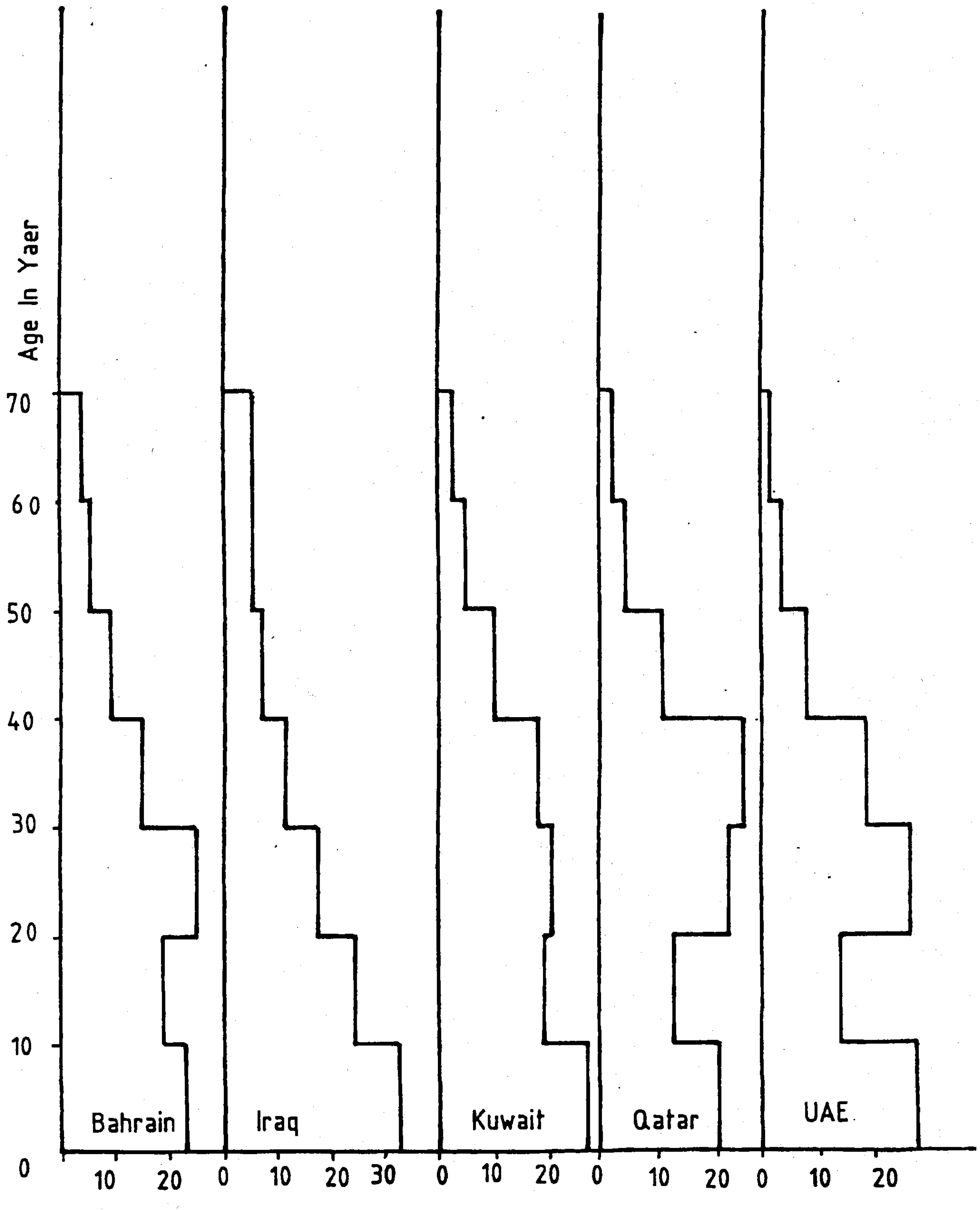


Figure 2: Percentage of population in different age intervals for some ROPME Member States

The effect of the two wars will not be discussed in this overview except to note that one of them, the 1991 war, resulted in a major local temporary increase in the emission of greenhouse gases because of the fires in the Kuwaiti oil wells, but globally this is expected to appear as a minor spike as far as the long-term climate change is concerned.

2.6 IMPORTANCE OF THE COASTAL ZONE

In the ROPME region the coastal zone is important like in no other part of the world. The whole states of Bahrain, Kuwait, Qatar and the United Arab Emirates lie within the coastal zone. Whatever happens in the state affects the coastal zone, e.g. rapid industrialization, rise of consumption, increased demand on ground water, growth of population, rise of tourism, reclamation projects, etc. The other member states utilize the coastal zone preferentially to the hinterland for various practical reasons. Oil, the prime mover in the region, is exported through it, raw material and manufactured goods pass through it on importation and exportation. In the harsh climate of the area, living near the sea offers a great attraction. It is not surprising to find major cities (e.g. Kuwait City, Dhahran, Manama, Doha, Abu Dhabi, Dubai, Sharjah, and Muscat), as well as important oil and industrial complexes (e.g. Kharj, Jubail, Umm Saiid) located there. Although these great human achievements offer outstanding benefits to the member states, they suffer from their vulnerability to climate change and in particular from the sea level rise.

3. IMPLICATIONS OF TEMPERATURE ELEVATION AND SEA-LEVEL RISE ON SELECTED PHYSICAL PARAMETERS IN THE ROPME REGION

3.1 AIR TEMPERATURE ELEVATION

Because life forms exposed to the atmosphere occur on dry land, and only very marginally at sea, what follows is valid for the dry land area of the ROPME region. This region is characterized by two traits: high temperature during the summer time and a great temperature range, both diurnally and seasonally, i.e. between the high daytime temperature and the cool night time temperature or between the high summer time temperature and the low winter time temperature. Both these characteristics put stress on plant and animal life and dictate the composition of the ecosystems that can exist naturally in the area. A most illustrative example is the mangroves and the mangrove ecosystem, (Al-Numairy, 1991; Vreeland, 1991 [a,b]). Mangrove trees themselves are high temperature tolerant and can survive the high temperature of the area, but they cannot survive the cold winter temperature for long periods. This is why they occur (when allowed by other favourable conditions) in the ROPME area from the southernmost part to a point in the north beyond which the winter temperatures becomes too cold for too long (around Tarot Bay, Saudi Arabia). As the winter air temperature rises, the mangroves would expand northwards, subject to other unrelated conditions such as soil suitability and man's interference. The mangrove trees act as the principal host in an important ecosystem. The whole system would have a chance to expand northward with the expansion of the range of the trees, but its composition may undergo changes, as the rise of summer temperature may limit the advance of one component or the other. Thus, not only will there be a change in the range of the mangrove ecosystem but the components of the system itself could be different in different areas of the region. This example can be multiplied many times when considering other ecosystems such as sea grass, mud flats, etc. (Al-Numairy, 1991).

Man will also be affected. He will consume more energy as the temperature rises. The energy increase will be in the domestic use, in agriculture and in industry.

Domestically, air-conditioning represents the greatest demand in electric consumption. The consumption of electricity is rising faster than the rate of industrialization. If the value of exports (excluding oil) is taken as a simple measure of industrialization, then one finds that the industrialization measure has increased ~4.17 folds from 1975 to 1984, in the Arab ROPME Member States while electric consumption has increased ~5.95 times during the same period (GOIC, 1989). This indicates that home consumption, principally air conditioning, is rising faster than industrial consumption. If the climate warms further, more people will be using more air conditioners and for longer periods of time.

At present, greenhouse agriculture is on the increase. Although greenhouses normally protect the plants in cold climate from the chilly weather, their use in the ROPME region is usually to conserve humidity for plants that need it. During the summertime they may need to have the greenhouse air-conditioned for the temperature not to become too hot for the plants.

Industry, which is situated mostly on the coast, uses sea water for cooling purposes. Assuming that the generated heat from the industrial processes raises the temperature of the cooling water by 30°C during the cooling operation, it can be seen that a rise of 1.5°C could add 5% to the amount of pumped water to absorb the same amount of heat and that a rise of 4.5°C would add 15% requiring more pumping equipment and consuming more energy, thus, increasing the cost of production for industry.

3.2 SEA TEMPERATURE CHANGE

Because the characteristics of water at any depth in the ocean are gained mainly when that water was at the surface, perhaps thousands of kilometres from its present location, the change of the climate will be reflected in the oceanic water at all depths with different time delays. The delays depend on the length of time it takes for the particular water type to reach the particular location. In general, the deeper water of SA-I and SA-II comes from further distances than the shallower water and the warming from the climate change would appear first at the surface and gradually extend downwards. The implications of deep water warming will not be discussed in this overview as it is expected that centuries will pass before it is detected. Climate change would, in the absence of other factors, increase the static stability of the surface layers at the beginning. But there will be other factors. If the wind speed increases as generally expected, this may overwhelm the increase in the static stability and the temperature of the whole layer would suffer the normal global increase. Marine ecosystems and fisheries will be affected by the temperature and the circulation pattern changes (Almatar, 1991, Munton, 1991). SA-III, being very shallow, gets all its water from the surface water of the Gulf of Oman. The temperature of its source water will thus, be immediately affected by the global warming. Once inside SA-III, the water temperature will rise more because of the local conditions favouring the rise during the water's residence time, the mean of which is estimated to be three years (Hassan and Hassan, 1987). It is expected, therefore, that the temperature rise in SA-III would be above the world average.

3.3 EVAPORATION

A rise in surface temperature increases the potential for evaporation. This initiates two feedback mechanisms, one positive and one negative. Increased evaporation supplies the atmosphere with increased energy as the latent heat of evaporation is released when the water vapour condenses to water droplets and the latent heat of melting is released if the water droplets further freeze into ice crystals. The released energy partly heats the air and partly supplies it with kinetic energy which moves it as wind. Both the increase in air temperature and the wind enhance evaporation, and hence, the positive feedback. At the same time enhanced evaporation needs a source of heat to supply the latent heat. Water is the most likely source and thus, water temperature decreases inhibiting evaporation, and hence the negative feedback. Although the final temperature rises, the magnitude of the rise is controlled by the negative feedback because of the more fundamental and universally controlling conservation laws. The IPCC scenario of a temperature rise of 1.5°C and 4.5°C is consistent with an increase in radiation reaching the earth's surface of 2% and 6.6% respectively.

3.4 RAINFALL

In the ROPME area rainfall results from a combination of the general weather situation (e.g. monsoons, tropical cyclones and extra-tropical depressions) and the topography of the land. Some of the GCMs predict a shift in the rain belt and an increase of the aridity of the region, even with the increased evaporation. The mesh of the GCMs is, however, still too rough to allow for the effect of the local topographic features and their influence on the rainfall. At present, when the air is sufficiently moist, rain falls when the air rises as it meets the mountain ranges in Iran, Oman or the United Arab Emirates. This type of rain is expected to continue and its amount to increase. Because it occurs in short bursts of intense showers and because its space scale is small, its management to minimize harm and maximize benefits will be difficult and the increase in precipitation would contribute more to erosion than to increasing fresh water supply.

3.5 STORMINESS

Storminess will increase on the global scale because of the increase of energy imparted to the wind by the increased water evaporation from the ocean. This will be the first effect to be felt from the climate change. Because of the dominant importance of the coastal zone storm surges would be among the most devastating phenomena associated with storms. The magnitude of sea-level rise resulting from the climate change in decades could be matched by storms in a matter of hours or days (i.e. the rate of local sea-level rise resulting from storms is three to four orders of magnitude greater than the global rate of sea-level rise expected from climatic reasons). Great attention has, therefore, to be paid to the state of preparedness against such possibilities in vulnerable areas. The worst conditions occur when high water spring tide coincides with a violent storm. Vulnerability of coastal areas will be determined by three factors: Natural storminess of the location, range of the tide and the topography of the land. The first factor affects the southern coast of Oman and Iran as strong winds are associated with the south westerly monsoon blowing during the summer; the second factor affects the area around Hormuz and the area at the head of SA-III as they have the greatest tidal range in the ROPME Sea Area while the third factor affects the Arabian side of SA-III due to the gentleness of its slopes exposing large areas to flooding with a relatively small rise in the sea level. Considering the combinations of these factors it is likely that the most vulnerable area is SA-III and in particular its head including the city of Kuwait.

3.6 PATTERNS IN THE SEA LEVEL

ROPME coastal areas share the effects of the global sea rise with the rest of the world. Protection from the effects of individual events such as storms which have been discussed earlier is more pressing, more difficult and perhaps more expensive than facing the slow and gradual sea-level rise, as the longer time scale in the latter case allows protection measures to be taken at a deliberate and less expensive way.

SA-III, however, requires detailed treatment for two reasons: First, it represents the greatest concentration of oil and gas extraction on earth. Between the years 1971 and 1987 the crude oil production from the Arabian ROPME Member States was 81.83 billion barrels (GOIC, 1989) equivalent to ~13 billion m^3. The extraction continues and the total volume would conservatively reach 20 billion m^3 by the year 2000. This volume, if not replaced would produce a subsidence of 20 cm. in a strip 1000 km. long by 100 km. wide. The rate of this subsidence is of the same order of magnitude as that expected from the sea level rise. The value of subsidence estimated above increases when gas extraction and formation water are added to the oil. If fossil ground water extraction is added, the figure could easily double. Note that in Saudi Arabia alone, the extraction for the same period of fossil ground water exceeded $55*10^9$ m^3 (Ministry of Planning, Saudi Arabia, 1980). Not all of this water extraction would affect the coastal zone but if even 20% does, the subsidence due to fossil ground water extraction would again be of the same order of magnitude as the sea-level rise.

The combination of subsiding coast because of oil and water extraction and rising sea level could make the apparent sea-level rise in the Arabian ROPME Member States at least double the global average.

Secondly, the special tidal response of SA-III. In theory tides in the world ocean are affected by the water depth. In practice the changes produced in the tides by a change in the ocean depth of tens of centimetres where the original mean depth is ~3800m. is negligible. In SA-III with a mean water depth of ~38m only, the effect would be observable and important consequences would result. SA-III has two amphidromic points for each semidiurnal tidal component and one amphidromic point for each diurnal component (Figures 3a and 3b). These and the resulting tidal pattern have been calculated by the British Admiralty for the components K1, O1 and M2 and S2, (British Admiralty, 1976). With the sea-level rise and the apparent deepening of the sea area the amphidromic points would move towards the mouth (Hormuz) raising the tidal range in locations whose distance from the amphidromic point increases and vice versa. Not only would the range change but also the composition of tide at any one place (the ratios S2/M2,

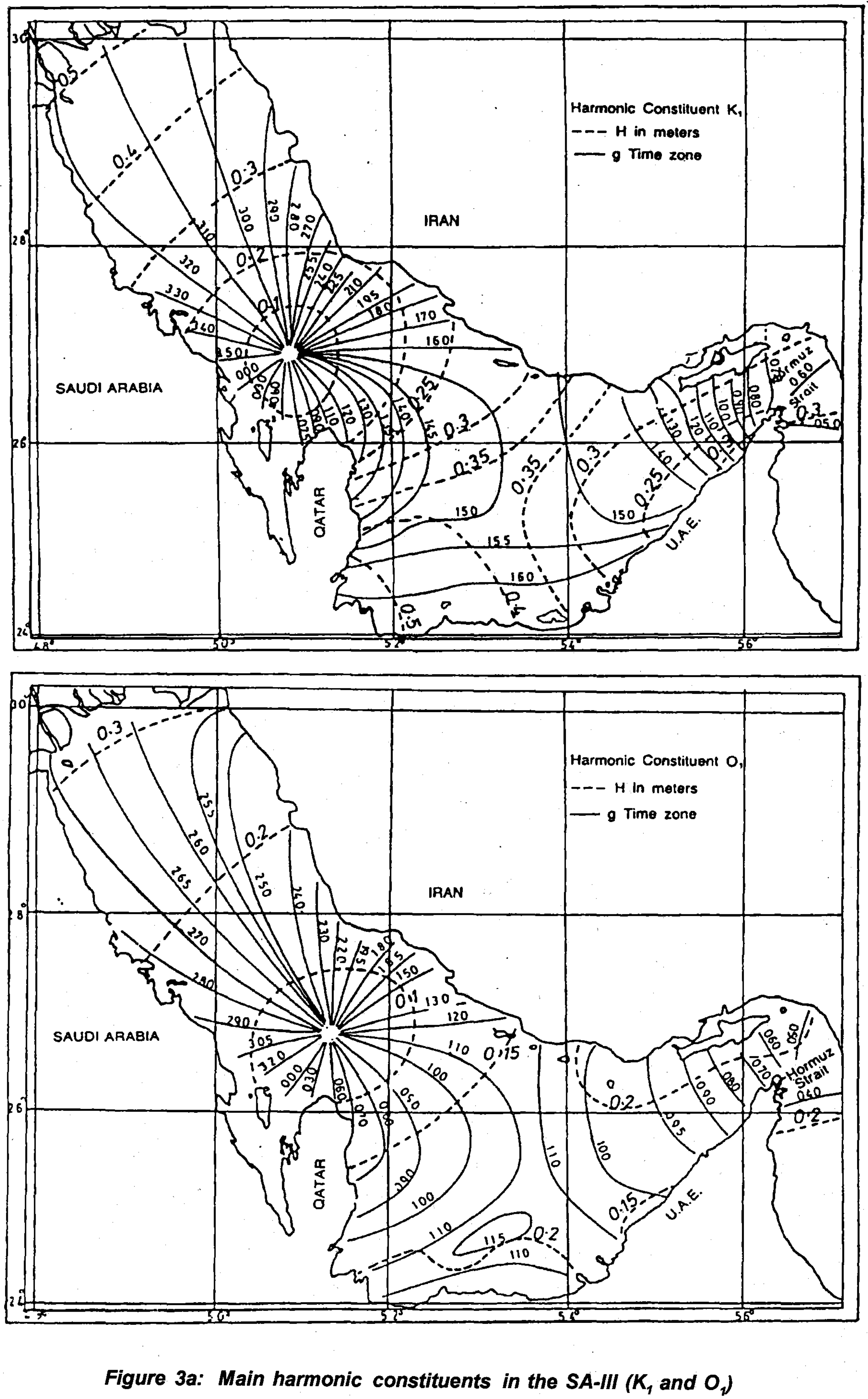
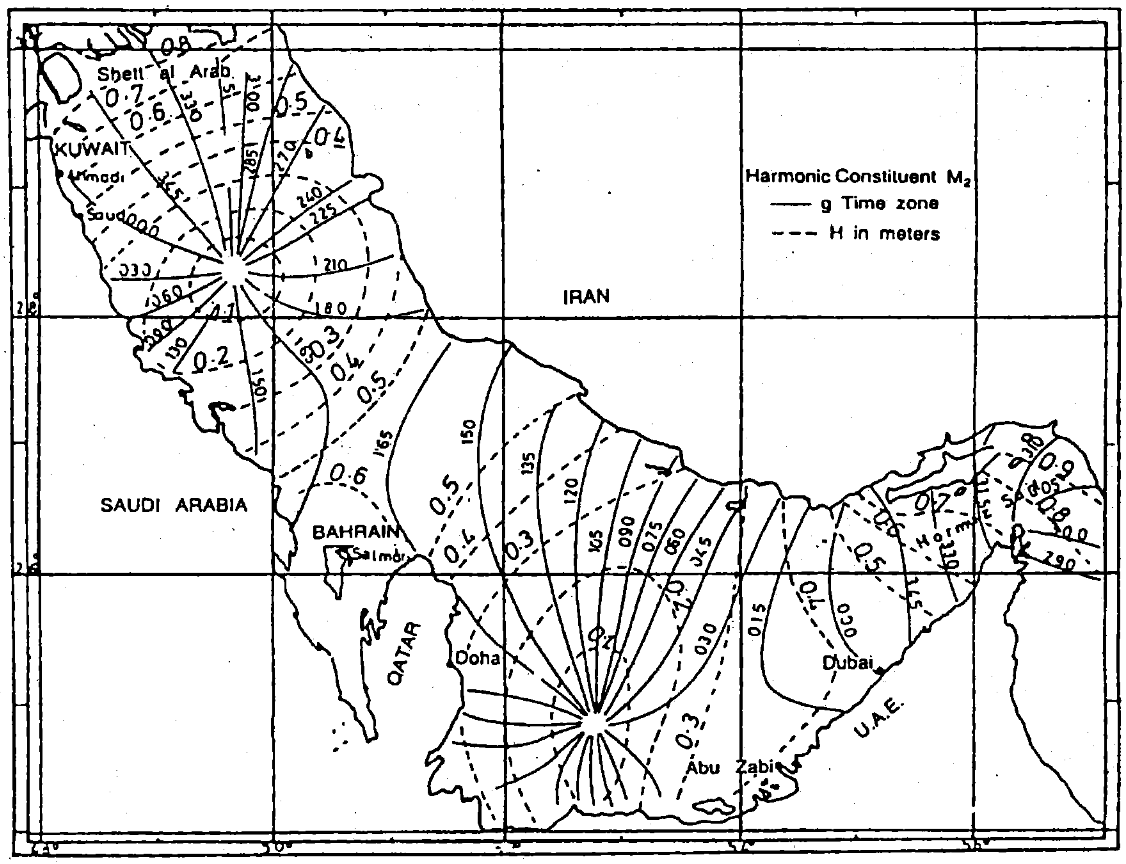


Figure 3a: Main harmonic constituents in the SA-III (K_1 and O_1)



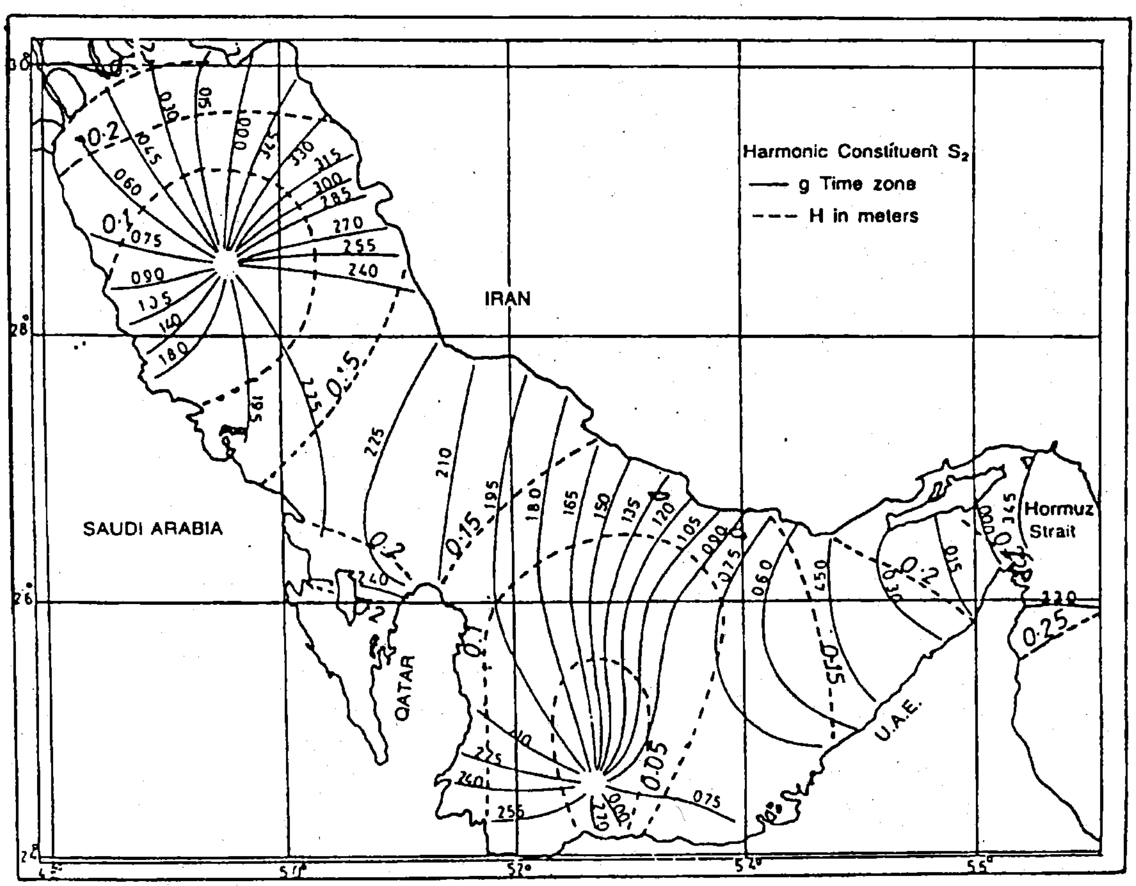


Figure 3b: Main harmonic constituents in the SA-III (M_2 and S_2)

K1/M2, O1/M2) as the positions of the different amphidromic points change with respect to each other. The head of SA-III, again Kuwait City would experience the greatest increase in range while Doha in the middle would experience a change in the tidal composition. Again with the movement of the amphidromic points the amplification of the tidal components will be affected differently, the maximum again being at the head of the area.

3.7 STABILITY OF THE WATER COLUMN

Stability is determined by the vertical distribution of the potential density. As oceanic water acquires its temperature-salinity characteristics mostly when it was at the surface, the vertical density structure below the surface layer in the ROPME Sea Area reflects more or less the latitudinal surface values (SA-III excepted). Although the rise of surface temperature is predicted to be greatest at high latitudes, the effect of the temperature rise on the density will not be greater than the effect of the tropical temperature rise because of the peculiar thermal expansion character of the water. For a few decades, the water column stability would not be greatly affected. However with the slow erosion of the permanent and other deep water thermal structure due to the greater increase of deep water temperatures originating in high latitude at the surface the stability would decrease and the ocean becomes less stratified. This would obviously affect the absorption of atmospheric gases (including CO_2) in the ocean as well as the upwelling phenomena.

3.8 LOW-LYING ISLANDS

The effect of storms (waves and surges) on low-lying islands when added to a sea-level rise can be devastating. The ROPME Sea Area has a wealth of islands that vary in importance and size from a sovereign island state (Bahrain) to small uninhabited rocks. Many of them sit on salt caps such as Halul Island of Qatar and are potential sites for oil and gas extraction. Some others are important ecologically as sites where turtles or other sea and land biota inhabit or visit at one time or another in their lives. Some are important resting or nesting stations for migratory birds in their north south annual migrations. Some of them are important politically and they can be taken as pivotal points in defining the baselines which determine the extent of the territorial waters and the EEZ.

In SA-III most of the area has been demarcated by bilateral or multilateral agreements, but some islands are still contested. Without adequate protection against sea rise the islands face an inevitable decrease in area and eventual disappearance. However, they cannot all be defended against the sea-level rise and a selection has to be made by ROPME Member States collectively and individually about which ones to protect and to what extent. Some may indeed be saved because of unique ecological features in which case international assistance may be a possibility.

3.9 OTHER EFFECTS RESULTING FROM SEA-LEVEL RISE

In common with other low lying coastal zones, ROPME Member States will suffer different degrees of coastal erosion, the more so the longer the coastline. On the Arabian side the erosion would be greater than on the Iranian side due to the difference in slopes and the nature of the bottom.

As the sea rises, inland salt water ponds would form where none existed before. These would be created by high spring tides and by severe storm surges, with potential for future evaporite bed formation.

Salt water will intrude further in rivers and streams. It will further contaminate ground water aided by the increase in ground water withdrawal.

4. MONITORING REQUIREMENTS

Because global sea-level rise and temperature elevation have come to the world attention only relatively recently, monitoring systems specifically tailored to them do not exist. However, advantage can be taken of systems already existing for other purposes. These can be supplemented to fulfil the new needs.

The rise of temperature and sea level have three characteristics: they are global in scale, their signal is weak embedded in strong noise, and their time scale is relatively long. The first characteristic indicates that ROPME Member States would do well to coordinate and indeed pool their efforts with the global efforts and programmes relevant to climate change by actively participating in all stages of these programmes (planning stage, implementation and analysis). At present some of these programmes exist such as Global Ocean Observing System (GOOS) and Global Climate Observing System (GCOS). The coastal module of GOOS includes a UNEP/IOC long-term monitoring system for coastal and near-shore phenomena related to climate change. More programmess will undoubtedly emerge. It is also important for ROPME Member States and for ROPME to play an active role in the present organizations which breed such programmes such as IOC of UNESCO, WMO and UNEP.

4.1 METEOROLOGICAL ELEMENTS

Traditional meteorological networks exist in ROPME Member States but few of them are equipped to measure nontraditional parameters relevant to climate change. ROPME Member States already have a network of meteorological stations integrated with the world network. It is recommended that this network supplement the equipment in their stations so that they can measure parameters relevant to climate change such as measuring CO_2 concentration and those of other greenhouse gases, incoming solar and sky IR radiation and back radiation. Relevant satellite observations such as surface temperature and atmospheric water vapour content should be archived within the area and be made available to investigators. A regional climatology oriented data bank (or alternatively, national data banks) should be created in order to keep the collected data, and carry out the normal and necessary tasks of quality control and data retrieval as needed. Meteorological monitoring is the easiest monitoring to implement due to the existence of the basic observational structure and the communications network.

4.2 OCEANOGRAPHIC ELEMENTS

The sea-level rise needs more elaborate monitoring. The rise cannot be simply measured by tide gauges. These measure the relative change of the sea level with respect to land which might itself be subsiding or uplifting. Tide gauges are, however, necessary. One tidal station in Oman has been designated as one of the networks for the Global Sea Level Observing System (GLOSS). More tidal stations in the area are needed, however, in order to establish the detailed pattern of the tides and the sea-level rise. A number of tide gauges exist already in ports and in oil loading terminals. Their records should be collected centrally, perhaps by ROPME, assessed for quality control purposes and made available to investigators. Because this network was not established for sea-level change purposes, it needs to be supplemented by a few other gauges. ROPME has plans in that regard and it is recommended that they be implemented in the not very far future. To get the absolute sea rise, vertical land movement has also to be known. This can be done by establishing three locations in the area (suggest Iran, Oman and Saudi Arabia) where the vertical movement would be monitored by the combined use of Very Long Base Interferometry techniques and GPS (Carter *et. al.*, 1987, Diamante *et. al.*, 1987 and Bock, 1991). Like the tide gauge programme, this would be a continuing programme subject to periodic reviews.

In order to answer questions about the sea-level rise resulting from changes in the temperature structure of the water column, a moored deep multilevel temperature recording station in the Arabian Sea (south of Oman) should be established in order to determine temperature changes affecting the ocean volume and hence, the sea-level rise. Resulting data should again be kept in the regional data bank.

In addition to the rainfall records of the catchment areas of rivers and streams flowing into the ROPME Sea Area, it is recommended that ROPME Member States regularly report all fresh water that flows into the ROPME Sea Area.

4.3 NUMERICAL MODELLING

All these data will be helpful in constructing models for changes in ROPME Sea Area, predicting possible future events under different scenarios to help decision makers evaluate different options. These models would fall in the category of RMs. As mentioned earlier, RMs derive their boundary conditions from GCMs. It is important, therefore, to establish close connections with GCMs and to feed the data and results that accumulate to the GCMs as needed. The rivers and streams in the area may again have their own sub-models that include the rainfall and the management schemes of fresh water for irrigation, flood control and power generation.

5. DESCRIPTION OF ECOSYSTEMS AND POSSIBLE IMPACTS OF CLIMATE CHANGE

5.1 FISHERIES

The ROPME area has important fisheries. Iran and Oman had a combined landing of more than 119,000 tons of fish in 1980, which rose to more than 316,000 tons in 1989, representing 52% and 65% of the total catch of ROPME Member States in those two years, an average annual increase in excess of 10% (Table 4, extracted from the FAO Fisheries Yearbook, Vol. 68,, 1989).

Table 4: Yearly fish catch of ROPME member states

States	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
B.	5,115	5,747	5,594	4,812	5,599	7,763	8,057	7,842	6,736	9,204
In.	39,981	40,000	87,364	90,264	93,164	96,364	121,771	169,664	188,515	209,450
Iq.	8,400	8,000	7,000	6,000	5,000	5,500	5,000	5,000	5,000	5,000
K.	3,689	3,714	6,628	8,722	9,639	10,118	7,633	7,704	10,796	7,653
O.	79,000	83,650	89,376	108,766	105,000	101,180	96,354	136,240	166,077	107,000
Q.	2,178	2,604	2,331	2,114	3,173	2,484	1,953	2,678	3,086	4,374
SA.	26,425	29,000	33,000	36,000	40,000	43,696	45,517	47,767	46,803	52,190
UAE.	64,400	67,760	69,775	72,716	72,716	72,260	79,321	85,247	89,500	91,160
Total	229,188	240,475	301,048	329,394	334,291	339,365	365,606	462,142	516,513	486,031

(Extracted from FAO yearbook for fisheries, vol. 68, 1989)

Estimates of the biomass of fish in the area vary widely (Almatar, 1991). In his paper Almatar reports that the biomass of demersal fish is 1.3 million tons and of pelagic fish is 0.75 million tons and of the mesopelagic fish in the Gulf of Oman and the Arabian Sea alone as 4 million tons.

Among shellfish, shrimp fisheries is the most important. At its peak more than 12,000 tons per year were caught mostly for export. It underwent the typical history of export industries driven by foreign market demand and not backed by sufficient research or regulations. Starting in the early 60s it produced large catches and high profits followed by rapid expansion of the fleet, resulting in falling profits. Different ROPME Member States have since established an official closed season and there are indications that a slow recovery is taking place.

Most fish are caught by artisanal methods. The labour force has changed mostly to expatriates but the capital remains national. Important exceptions are when concessions are granted to foreign fishing fleets to fish the national waters under national supervision.

In order to realize the fisheries potential of the ROPME Sea Area, it is necessary to have coordinated - if not joint - research, monitoring and control by the ROPME Member States. A useful first step is the free exchange of information concerning fish catch, future plans and regulations and regular meetings to exchange experiences.

Mariculture plays a minor role in the ROPME Sea Area at present, but it is steadily, if not slowly increasing. With repeated scares of polluted sea products, it can only be expected to grow.

Fisheries represents reaping a natural ecosystem. Although most marine animals can move in order to be in preferred habitats their movement is restricted by the movement of other components of the ecosystem of which they are part. Because of this complexity prediction of effects of climatic changes on particular fisheries is, therefore, highly speculative. Changes will, however, occur and fisheries in the ROPME Sea Area need to be monitored and managed, as mentioned before in a coordinated way.

5.2 TURTLES AND DUGONGS

According to Munton (1991), ROPME Sea Area supports five species of turtles four of which nest in the area. They are: the green turtle, the olive riddle turtle, the hawks bill turtle, the loggerhead turtle and the leatherback turtle. The leatherback turtle is not known to nest in the area. The danger to turtles is twofold: the loss of habitat as elements in that habitat change, e.g. the physical parameters, and the nature and distribution of their normal food (note that some turtles are vegetarian, that some feed on small crustaceans and some on jellyfish). The other factor is the loss of their nesting sites. Tagged turtles have returned to within 800m. of where they have originally been recorded, but examples have also been found of females nesting on different islands on different nights. Turtles have survived greater changes of sea level before and are expected to survive this one, too. What they may not survive is the human interference represented by collecting eggs from the turtles' nesting sites. Protection is extended to some of these sites by some ROPME Member States but the problem needs more quantitative studies in order to formulate a balanced response.

Dugongs do not move as widely as turtles do. They are expected to suffer more than the turtles as a consequence of the loss of habitat. They have not been studied sufficiently and an authoritative statement about their response to climatic changes cannot be formulated yet, but it would be prudent to ban their deliberate catching completely until proper policies based on facts and research could be formulated.

5.3 CORAL REEFS

These occur in shallow areas in SA-I and SA-II, and to a great extent in the shallow SA-III. They live under several stresses: the summer high water temperature, the large seasonal temperature range and the high rate of sedimentation. Although no report of coral bleaching was published to the authors' knowledge, this does not mean it did not happen in the area, but that the sparseness of observations and the continuing occurrence of more dramatic events pushed the coral bleaching down the priority scale. Stressful conditions would increase as the water level rises, as the storminess increases bringing additional loads of aeolian sediments from the barren deserts and mountains in the area. If the relative sea rise outpaces the capability of the coral for vertical growth (the maximum being ~8mm/yr), the coral would slowly die as the solar light intensity reaching it decreases. Much work needs to be done to increase knowledge of the coral reefs of the ROPME Sea Area and to estimate their likely response to the new stresses.

5.4 INTER-TIDAL ZONES

According to Al-Numairy (1991), the tidal area contains well defined, distinct and important ecological systems. The nature of the flora and fauna in the different zones depends on two factors: the nature of the bottom (mud, sand, rocks, etc.) and the length of time the bottom is covered by water. Because the tidal range in ROPME Sea Area exceeds one meter in most areas, and because gentle slopes occur in a great portion of the coastline (especially on the Arabian side in RSA-III), the width of the inter tidal zone generally exceeds one kilometer. In his paper Al-Numairy divides the inter tidal zone underlaid by mud bottom into four sub-zones: the upper inter tidal, the blue-green algal mat, the macrophthalamus and the mangrove; each with its typical plant and animal communities. Two other types of the inter tidal zone bottoms that occur in the ROPME Sea Area are the exposed sandy beaches composed largely of carbonate sand the bulk being of biological origin and the rocky inter- tidal zones. The rocky zones are the least productive, as rocks provide the least protection from the sun's heat when the rocks are uncovered. Thus, fauna there are limited to animals that inhabit crevices, holes and the underside of boulders, or else are mobile forms capable of retreating to shelter when the tide is out.

The intertidal zones are expected to creep inlands as the sea level rises, and in SA-III will also be affected by the change in the pattern of the tide. Although the pace of change is slow, it needs continuing monitoring and research.

5.6 KELP COMMUNITIES

In the upwelling region of the Arabian Sea south of Oman, a community of Ecklonia radiata, a southern hemisphere kelp species found only in these waters in the northern hemisphere, and Sargassopsis zanardinii exist and are highly seasonal. They depend for their survival on the annual seasonal upwelling of cold nutrient rich water generated by the summer monsoon. They support communities of grazers and other animals that seek shelter among the kelp forest (Borhan, 1991). A change in the pattern of upwelling in the area will affect this unique kelp community.

If the increased upwelling predicted earlier proves correct, the kelp community would be expected to survive and flourish. Ecological systems, however are complex and ecological relationships are subtle. In common with other systems, the kelp community needs more research and monitoring.

5.6 KHORS

These are coastal features especially of the mud flats where they form a branching meandering drainage system arising in the upper levels of the halophite zone and emptying into the sea at or near the level of the lowest tides. Al-Numairy (1991) distinguishes five zones in the khors: halophite and sabkha zone, blue-green algal zone, crab zone, carithid zone and sea grass zone.

6. GENERAL ASSESSMENT OF THE EFFECTS OF CLIMATE CHANGE ON ECOSYSTEMS

Ecosystems are how they are, where they are, when they are as a result of the interplay of the environmental factors, the life support systems, the food availability and the waste removal. These represent a hierarchy with the environmental factors at the base. As the water temperature and salinity change, as the stability of the water column changes, as the pattern of tides changes, the water currents will change, the plankton distribution will change and equilibrium within and among different systems will shift. It is a fundamental assumption that when conditions are stable, then in time the standing system represents the optimum (in the mean) of what can exist. Any change in the prevailing conditions will, therefore, shift the equilibrium favouring some species over others. If it is not possible at the present time to predict the physical changes except tentatively, predictions about ecosystems become speculations or at best educated guesses. Even so, intensive research should be directed towards these topics and the ROPME Member States would gain greatly by joining present and future international global research projects carried out by such international organizations as the Scientific Committee for Oceanic Research (SCOR), both to gain knowledge and experience in research being done globally, and to attract international research interest to the unique features and opportunities in the ROPME Sea Area.

7. FUTURE STRATEGIES AND POLICY OPTIONS

Strategies chart the road to achieve goals restrained by guiding principles. It is obvious that the goal of ever increasing standard of living without regard to the other earth's inhabitants or to the earth's environment is an inappropriate and an untenable goal. This goal could only be pursued by an ever decreasing number at the expense of ruining the environment and of depriving many of the basic necessities. The basic strategy should, therefore, be to conserve and the goal would be to attain, as far as practicable, equitable distributions of the gifts of nature without discrimination. That means that ROPME Member States as well as other sovereign nations should pursue a policy of moderation and show a kind regard to the earth and other beings on the planet. Consumption should be curbed and new products should be tested for their total effects (present and future, local and global and on humans and other inhabitants of earth). This is likely to require reduction in the per capita consumption and the usage of the most environment friendly methods in agriculture and industry. An obvious example in ROPME Member States would be to move towards greater utilization of solar energy. There is hardly any region on the globe which is more favoured in that regard.

The problem of climate change, being a global problem, will not stop by the change of attitude of mere eight ROPME Member States. Some protection measures will have to be taken. In the first place, all future major projects should be planned with the changing climate in mind. A simple precaution is to build high enough above the sea level (including high tide plus storm surges) to minimize the risk of water inundation for the life time of the project. The economical and cultural value of existing structures have to be weighed against the cost of defending them against climate change.

ROPME Member States should participate actively in the global programmes of research trying to understand and (perhaps in the distant future) control the earth's climate and in the organizations that breed such programmes (connected most of the time to the UN).

In many cases the ordinary people are more sensitive than their governments to the environmental issues and non-governmental organizations (NGOs) play an increasingly important role in promoting public awareness of environmental issues. ROPME Member States should encourage the formation of non-governmental organizations concerned with environmental issues.

8. CONCLUSIONS

Although the global temperature elevation and the sea level rise are not a certainty, it is most probable that they are occurring. Although the rise would not be the same everywhere on earth, and indeed some places may, for a period of time, experience the reverse of the mean trend, it is prudent to take precautions to protect against the mean rise. The ROPME Sea Area again has special features that distinguish it from all other areas. Intensive and extensive research is indicated both nationally regionally and internationally. ROPME Member States are urged to join and cooperate with the international programs concerned with climate change in addition to the research on local climatological issues. NGOs interested in environmental issues should be encouraged to increase the public awareness of environmental problems and to push the heavily inertial governmental machinery to act intelligently, decisively and expeditiously.

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10. ABBREVIATIONS USED IN THE TEXT

EEZ	-	The exclusive economic zone.
FAO	-	Food and Agriculture Organization of the United Nations.
GCM	-	General circulation model.
GCOS	-	Global climate observational system.
GOIC	-	Gulf organization for industrial consultancy.
GOOS	-	Global ocean observational system.
GPS	-	Global positioning system.
IO	-	The Indian Ocean.
IOC	-	The Intergovernmental Oceanographic Commission
IPCC	-	The Intergovernmental Panel On Climate Change.
IR	-	Infrared.
KAP	-	Kuwait action plan.
NGO	-	Non-governmental organization.
ROPME	-	The Regional Organization for the Protection of the Marine Environment.
SA-I	-	Sea area I. (The northern Arabian Sea).
SA-II	-	Sea area II. (The Gulf of Oman).
SA-III	-	Sea area III. (The northwestern part of ROPME Sea Area).
SST	-	Sea surface temperature.
TEK	-	The Tigris Euphrates Karun river system.
UNEP	-	The United Nations Environment Program.
UNESCO	-	The United Nations Educational, Scientific and Cultural Organization
UV	-	Ultraviolet.
VLBI	-	Very long base interferometry.
WMO	-	World Meteorological Organization.

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