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Climate Change Impacts on the Mediterranean Coastal Zones

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NOTA DI LAVORO 27.2001

APRIL 2001

CLIM – Climate Change, Modelling and Policy

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INTRODUCTION

Climate change is widely recognised as a serious threat to the world's environment. In 1995, the Intergovernmental Panel on Climate Change [IPCC, 1996a][1] concluded that: "*the balance of evidence suggests that there is a discernible human influence on climate change*" and asserted that climate is expected to continue to change in the future. More recently Tett *et al*. [1999] argued that the increase of the superficial temperature of the earth-atmosphere system is nearly entirely correlated with anthropic pressures on the climate system. The fact that these changes are likely to occur at a faster rate than any that have occurred during mankind's recorded history, is also generally agreed upon.

The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as "*a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods*". In this paper we employ this definition, and will refer to climate change as those variations in climate which are associated with the enhanced greenhouse effect, the latter effect being caused by human induced variations in the atmospheric concentration and distribution of greenhouse gases and aerosols.

The main objective of this paper is to highlight the potential impacts of changes in climatic conditions and in related variables, which could affect coastal areas, as well as to identify potential response measures which could reduce the vulnerability of coastal systems and enhance their adaptability. Attention will be focused on the Mediterranean basin which is in the climate change context, a zone of great interest and of recent concern at the world scale by some features:

- strong ocean-atmosphere-land interactions;
- contrast between the small size of the sea and its significant role in the global climate system;
- possibility to use it at a scaled down model for the monitoring of environmental and climate evolution;
- critical environmental conditions of some areas and high human pressure;
- strong geographical, socio-economic and climatic contrasts.

Although understanding of climatic processes and the capacity of climatic models to simulate them are improving rapidly, uncertainty remains a common denominator of present scenarios, prevision and assessment of future climate evolution and impacts [ECLAT-2, 1999]. In addition, mainly due to the coarse resolution of global climate models, uncertainty tends to increase when narrowing down to the regional scale. The quantification of climate change impacts is therefore a complex task, in particular socio-economic implications are difficult to forecast, because of the complex inter-relation between environmental and socio-economic parameters. The result of these constraints is that many studies have focused on particular areas of specific vulnerability (like the Nile delta) rather than considering the vulnerability of the whole Mediterranean basin in the light of the climate change and sea level rise impacts. This paper is therefore an attempt to draw a general picture of the likely impacts of climate change on coastal zones of the Mediterranean.

The paper is structured as follows. The fist section provides an introduction to the climate change issue, the past trends and the projections of future climate at the global scale. The second section presents the main features of the Mediterranean basin and some relevant regional projections of future climatic variables. The third section focuses on the main likely impacts on the Mediterranean coasts. Different coastal systems - such as islands, deltas, estuaries, coastal wetlands and coastal

[1] pp. 4-5

cities – and different climate change impacts – such as inundation, increased flooding, salinisation, salt water intrusion, desertification, and increased erosion - are addressed in this section. Finally the last section brings some conclusions and identify some strategies of adaptations and directions for future research aimed at improving our ability to predict and assess the local impacts of climate change in the region.

I / CLIMATE CHANGE AND THE GLOBAL WARMING: OVERVIEW

1.1 THE GREENHOUSE EFFECT AND ITS CAUSES

The earth's climate system is controlled by a continuous flow of energy coming from the sun. To balance the incoming solar energy, the Earth exports the same amount of energy to space in the form of longer wavelength radiation (infrared). The gases of the atmosphere which have the ability to absorb and successively emit infrared radiation are known as greenhouse gases. They are capable of trapping part of the thermal radiation emitted by the earth's surface, producing a natural greenhouse effect that keeps the planet warmer (by 33 °C)[2] than it otherwise would be. Clouds also contribute in controlling the Earth's energy balance by absorbing and emitting thermal radiation. Moreover, they have a primary role in reflecting incoming solar radiation. On average these two processes tend to balance each other, even if on a global scale the net effect of clouds on the climate is a small cooling of the surface. Changes in greenhouse gas concentrations influence the energy balance of the Earth. An increase in the concentration of these compounds produces an increase in the capacity of the atmosphere to trap thermal radiation and tends to warm the lower atmosphere and the earth's surface. The IPCC has called this process *the enhanced greenhouse effect*. Since the industrial revolution, human activities have increased continuously the concentration of greenhouse gases in the atmosphere. The magnitude of warming depends on the size of this increase and on the radiative properties of gases. In order to quantify through a simple measure the importance of a climate change mechanism, such as the increase of carbon dioxide concentration in the atmosphere, IPCC [1994] has introduced the concept of *radiative forcing* as: "the perturbation of energy balance (in W/m^2) on the surface-troposphere[3] system, after allowing for the stratosphere[4] to re-adjust to a state of global mean radiative equilibrium". In practice a positive radiative forcing, such as that induced by an increase in greenhouse gas concentration, tends to warm the surface and a negative radiative forcing tends to cool the surface. In the following section, we sum up briefly the evolution of the main greenhouse gas and aerosol in the atmosphere, and the feedback processes which are likely to modify the climate response.

According to IPCC [1996a][5] the concentration of the main greenhouse gas, carbon dioxide, has increased from about 280 ppmv[6] in pre-industrial times to 358 ppmv in 1994 (figure 1). This increase is mainly due to human activities such as fossil fuel combustion, cement production and changes in land use.

The concentrations of methane have also increased since pre-industrial times. The rise from about 700 ppbv to 1720 ppbv is mainly the result of human activities such as agriculture, waste disposal and production and use of fossil fuel. According to the IPCC [1996a][7], anthropogenic activities are

[2] The annual average temperature of the earth's surface is about 15 °C.
[3] The lowest part of the atmosphere from the surface to about 10 km in altitude in mid-latitudes. It is generally defined as the region where temperature generally decrease with height.
[4] The high region of the atmosphere above the troposphere, extending from about 10 km to 50 km.
[5] pp. 14-17
[6] 1 ppmv = 1 part per million by volume.
[7] pp. 17-19

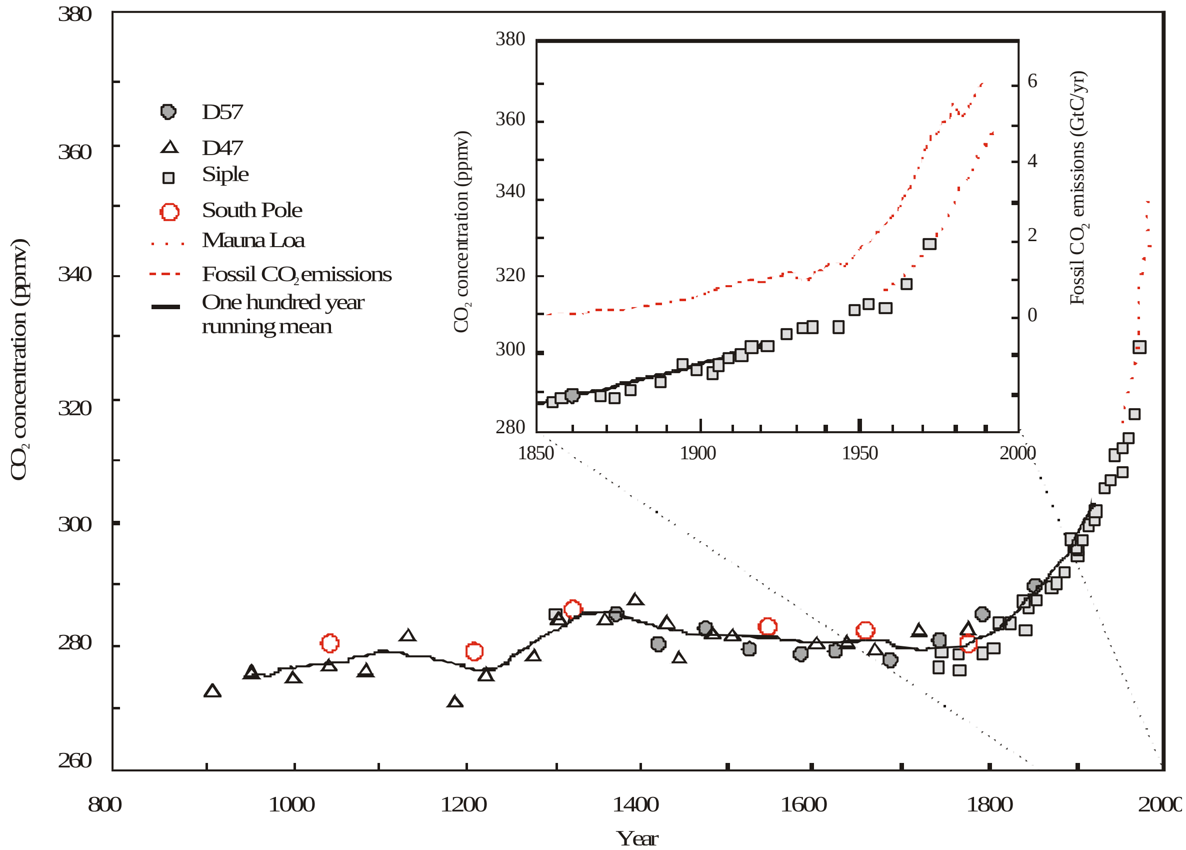
responsible for about 60-80% of current methane emissions. Climate change can have a retroactive effect on methane emissions by indirectly increasing emissions due to greater microbial activities.

Table 1: Greenhouse gases concentration in relation to human activities [*source*: IPCC 1996a][8]

	CO_2	CH_4	N_2O	CFC-11	HCFC-22•	CF_4 §
Pre-industrial concentration	~280 ppmv	~700 ppbv[9]	~275 ppbv	0	0	0
Concentration in 1994	358 ppmv	1720 ppbv	312♦ ppbv	268♦ pptv[10]	110 pptv	72♦ pptv
Rate of concentration change ♠	1.5 ppmv/yr 0.4%/yr	10 ppbv/yr 0.6%/yr	0.8 ppbv/yr 0.25%/yr	0 pptv/yr 0%/yr	5 pptv/yr 5%/yr	1.2 pptv/yr 2%/yr

• a CFC substitute
♣ a per-fluorocarbon
♦ estimated from 1992-1993 data
♠ the growth rates of CO_2, CH_4, and N_2O are averaged over the decade beginning 1984; halocarbon growth rates are based on recent years (1990s).

Figure 1: CO_2 concentration over the past 1000 years from ice core records (D47, D57, Siple and South Pole) and (since 1958) from Mauna Loa, Hawaii, measurement site. All ice cover measurements were made in Antarctica. The smooth curve is based on a hundred year running mean [*source*: IPCC 1996a][11].



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8 pp. 14-17
9 1 ppbv = 1 part per billion by volume
10 1 pptv = 1 part per trillion (million of million) by volume
11 pp. 16-17

Nitrous oxide concentrations have increased since pre-industrial times from 275 ppbv to 312 ppbv. Many sources contribute to the generation of N_2O emissions. The most important souces are natural ones which are probably twice as large as human induced ones. The main anthropogenic sources are represented by agriculture and some industrial processes, for example nitric acid production.

Halocarbons are compounds that contain fluorine, chlorine, bromine and iodine. Emission of many halocarbons is exclusively due to human sources. They have contributed significantly to the enhanced greenhouse effect (according to IPCC [1996a][12], radiative forcing since pre-industrial times is about 0.25 W/m^2) but as a consequence of limitations in their emissions set by the Montreal Protocol (1987) their positive radiative forcing should decline in the future.

Changes in ozone concentration in the atmosphere may influence the greenhouse effect in two different ways. Increase of ozone concentration in the troposphere since pre-industrial time has caused positive radiative forcing contributing to the enhanced greenhouse effect. Some studies suggest that tropospheric ozone may have doubled in the Northern hemisphere (while no evidence about change in ozone concentration is available for the Southern hemisphere) [IPCC, 1996a][13]. On the contrary, stratospheric ozone layer depletion due to the indirect effect of chlorine and bromine halocarbons is associated with negative radiative forcing. The concentration of stratospheric ozone has decreased since 1970s and as a consequence of the Montreal Protocol, it is expected that ozone will return to its natural level before the middle of the 21st century [Brown *et al.*, 1996].

An increase in natural and anthropogenic aerosol concentration in the lower atmosphere is an other factor which can influence the global and regional climate system. Aerosols are small particles and droplets which are originated by natural and anthropic sources. An increase in the concentration of these particles tends to produce negative radiative forcing and to cool the atmosphere through two different processes [Charlson *et al.* 1998]. Aerosols can directly reflect the incoming solar radiation and change cloud properties and their reflectivity, inducing an indirect cooling effect. These particles can also act as nuclei on which cloud droplets condense and can therefore affect the number and size of droplets in the cloud. Some aerosols (for example carbon and soot produced by fossil fuels) can cause heating of the atmosphere through the direct absorption of solar radiation. Large amounts of natural aerosols are generated by volcanic activity. These aerosols can have a temporary cooling effect on the earth's surface and the lower atmosphere. The cooling effects generally do not last more than few years as it was observed after big volcanic eruptions such as the Pinatubo in 1991.

Anthropogenic sulphate aerosols are the most well known and studied aerosols generated by human activities and are principally produced by fossil fuel combustion – which emits sulphur dioxide into the atmosphere - as well as by minor sources such as biomass burning. They are mainly composed of sulphuric acid. It is recognised that these aerosols tend to have a cooling effect that can partially neutralise or mask the positive radiative forcing induced by the increase in greenhouse gases[14] concentration. In general, aerosols have a shorter lifetime (days to weeks) than the majority of greenhouse gases (centuries). This is mainly due to the fact that they undergo rapid chemical and physical transformation in the atmosphere and are removed by precipitation. This means that the effect of aerosols is expected to become less consistent as time passes and that the cooling effect of these particles would end in a very short time if all aerosol emissions were stopped. At the contrary

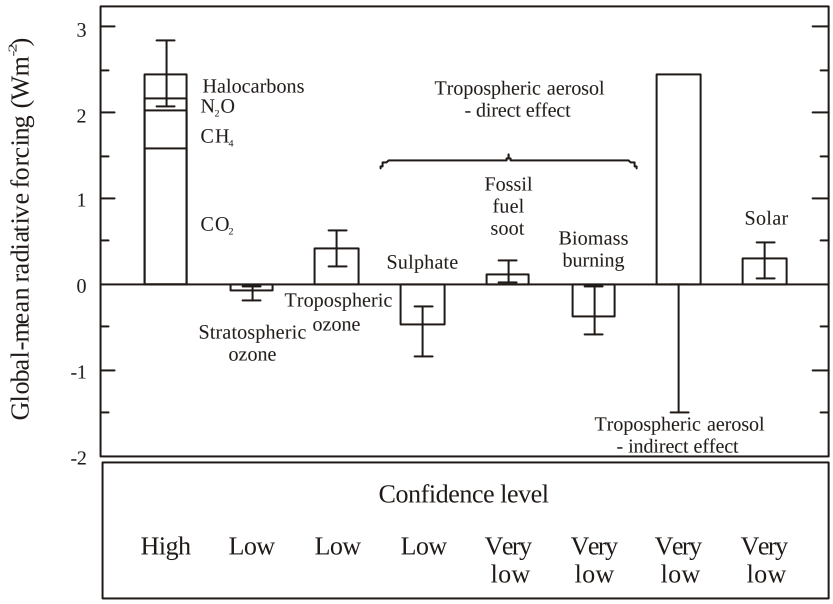
[12] p. 19
[13] pp. 19-20
[14] Sulphate aerosols are also major contributors to acid rain, which produces negative effects on crops, materials and ecosystems.

the warming effect due to greenhouse gases would continue for a period of time from decades to centuries even after the stabilisation of greenhouse gas concentrations in the atmosphere.

Aerosols are not homogeneously distributed in the lower troposphere and tend to concentrate in the proximity of natural - especially desert - and anthropogenic sources - for instance the industrial areas of the boreal hemisphere[15]. The high regional variability of aerosols distribution and the incomplete understanding of aerosol indirect effect, make the estimation of their role in the greenhouse effect complex and uncertain.

In order to quantify the contribution of the described factors to global warning, the IPCC [1996a][16] has estimated the globally averaged radiative forcing due to changes in concentrations of greenhouse gases and aerosols from pre-industrial times to 1992, due also to natural changes in solar output from 1850 to 1992 (figure 2).

Figure 2: Estimates of the globally and annually averaged anthropogenic radiative forcing (in W/m2) due to changes in concentrations of greenhouse gases and aerosols from pre-industrial times to 1992 and to natural changes in solar output from 1850 to 1992. The height of the rectangular bars indicates a mid-range estimate of the forcing, whilst the error bars show an estimate of the uncertainty range. The 'confidence level' indicates the IPCC's subjective confidence that the actual forcing lies within the error bars [*source*: IPCC 1996a][17].



The differences in the geographical distribution of greenhouse gases, aerosols and ozone can lead to significant variations in the distribution of their radiative forcing and in their contribution to climate change. For this reason, the negative radiative forcing due to aerosols can only partially and regionally counterbalance the positive radiative forcing induced by greenhouse gases.

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[15] More than two thirds of gases containing sulphur are emitted by anthropogenic sources, mainly in the form of sulphur dioxide. 90% of them are generated by human activities located in the boreal hemisphere. Boreal human emissions exceed natural ones by a factor of five. On the contrary, in the austral hemisphere human sulphur-gases emissions are one third of natural ones.

[16] p. 21

[17] p. 117

Moreover, important feedback processes are liable to modify the responses of climate to changes in radiative forcing and make the exploration of climate changes more complex. In particular, these feedbacks could affect the global surface temperature either in a positive or in a negative way i.e. amplifying or reducing the surface warming. Climate feedbacks mainly concern water vapour, cloudiness, ocean circulation, ice, snow albedo and land/atmosphere interactions:

- Global warming can increase the atmospheric capacity to store water in the form of vapour. This effect would imply a positive feedback as water vapour is a powerful greenhouse compound which would lead to a further enhancement of the greenhouse effect;

- Cloudiness is related both to a positive and to a negative feedback. Clouds are able to reflect solar radiation – causing a cooling effect – and to absorb and re-emit long wave radiation – causing a warming of the surface. Their behaviour depends on different cloud characteristics such as height, thickness and radiative properties. The range of ‘climate sensitivity’ variables depends largely on this uncertainty;

- Oceans have a crucial role in controlling the climate. They have an enormous heat and carbon storing capacity and transport large amounts of heat from the tropical areas to the poles through the great oceanic currents. Ocean thermal inertia is likely to cause a delay in global warming and to contribute in its non-uniform distribution. That is to say that the ocean mean surface temperature, and consequently the mean sea level, will continue to increase for many centuries even after the greenhouse gases stabilise. The global thermohaline circulation (also called the ‘conveyor belt’) is responsible for a large portion of the heat transport from the tropics to higher latitudes. The Gulf Stream in the Atlantic Ocean is an important component of this global circulation and transports warmer waters northward, thereby contributing to western Europe's relatively mild climate for its latitude. Global warming is likely to produce a weakening of the global oceanic thermohaline circulation leading to a local negative temperature feedback and to a likely decrease of sea surface temperatures in the northern North Atlantic. The global oceanic thermohaline circulation is generated by the sinking of water in the Norwegian Sea and is driven by two opposite forces, acting in the North Atlantic. Haline forcing, due to the salt gradient, is responsible for the cold deep current which transfers water from the North Atlantic to the Indian and Pacific Ocean. On the contrary, thermal forcing, due to the temperature gradient, is responsible for a north poleward surface current, i.e. the global flow of upper warm ocean water from the tropical Pacific Ocean to the Atlantic Ocean, through the Indonesian Archipelago and the Indian Ocean [IPCC, 1996b][18]. At present, thermal forcing dominates. Increase in the strength of haline forcing, caused by an increase of the salt gradient associated with increased precipitation, runoff and ice melt, could produce a weakening of the conveyor belt. This would produce changes in Europe climate conditions.

- The high albedo[19] which characterises ice and snow cover, can have a feedback effect in regard to future climate change. Warming will increase the melting rate of snow cover, ice caps, glaciers, large ice sheets, sea ice and the retreat of the ice and snow occupied surfaces. This will lead to a reduction of global albedo and of the reflecting capacity of the Earth. Global warming will consequently be enhanced.

- Variations of land surface characteristics (due for example to deforestation), such as changes in soil moisture, roughness, and vegetation cover, may lead to the alteration of the climate properties on a local and regional scale. These changes can affect the water and energy

[18] p. 271
[19] The capacity of a surface to reflect solar radiation

exchange capacity between land surface and atmosphere, leading to the modifications in precipitation, water vapour, cloudiness and albedo.

1.2 THE PAST AS A KEY TO THE FUTURE

Projections concerning future changes in climatic variables and related parameters, for example sea level, must take into account analysis of the present situation and the assessment of the past observed trends. The comparison between recent and past conditions allows us to understand whether, and in what measure, climate change has occurred. In this regard, it is important to note that systematic global temperature records, as well as complete data sets concerning other climatic variables (including land-based air temperature and sea surface temperatures) are available only since 1860. Hypotheses about earlier climate characteristics can be derived from the combination of historical documents, instrumental records and environmental indicators and by using models and detective systems which permit the estimation of past climate conditions. Environmental indicators are indirect climate indicators and include the study of tree rings, coral reefs, marine and lake sediments and ice cores. The reconstruction of past climatic conditions through these natural archives can also be used as a check of projections from climatic models. Significant progresses have been made in attempting to reconstruct temperatures and climate changes during past centuries and in particular over the 10 000 years [e.g. Jones *et al*. 1998, White *et al*. 1998, Antonielli *et al.*1999]. Nevertheless considerable efforts and explorations are still required to have a comprehensive overview of past climatic variations.

1.2.1 Past trends of climatic variables

Large and rapid climatic changes characterised the last glacial period (20,000 - 100,000 years ago) and the transition to the current interglacial period (i.e. the Holocene, covering the last 10,000 years). During the Holocene, it is likely that global mean temperature did not vary by more than 1°C/100 yr [IPCC, 1996a][20]. Nevertheless, its last decades seem to have been the warmest since at least 1400, and the 20th century is likely to have been one of the warmest centuries in the last thousand years.

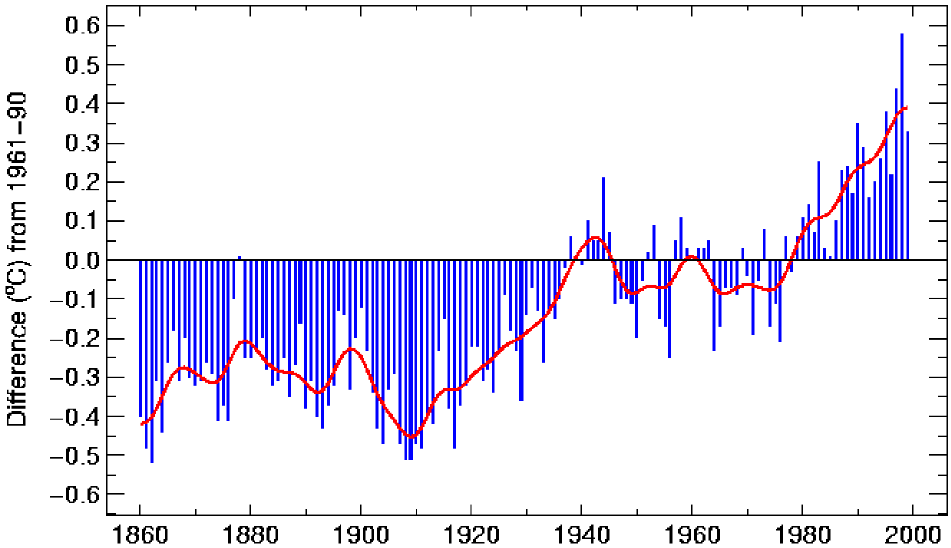
Presently, the mean global surface temperature of the air is about 15 °C, with the exception of the temperature of Antarctica. It has been estimated an increase in the global average temperature of about 0.3 to 0.6 °C since the late 19th century (figure 3) and in a lesser extent about 0.2 to 0.3 °C over the last 40 years [IPCC, 1996a][21]. The greatest warming occurred in the period 1910-1940 and since the mid-1970s. The most recent years, and in particular 1997 and 1998 have turned out to be the warmest of the whole series of measures since 1856 [Jones *et al* 1999]. Temperatures of 0.57°C above the 1961-1990 mean temperature have been recorded for 1998 and have been correlated to the 1997-1998 El Niño /Southern Oscillation event. It has been suggested that 1998 could represent a breaking point of the complete series of measures which would be a sign of acceleration of the rate of the global temperature increase [Karl *et al.* 2000]. The global mean surface temperature in 1999 was substantially lower (due to the cool El Niño phase in the tropical Pacific) than that recorded in 1998 but it is still one of the highest 10 on record [DETR, 1999].

Most of the studies agreed on the fact that warming has occurred both over the continents and the sea with similar trends [Parker *et al.* 1994]. Warming has not been geographically uniform. For instance, the greatest recent increase in temperature has been measured over the continents between 40 °N and 70 °N, while other regions, such as the North Atlantic Ocean and in particular the portion of it located to the north of 30 °N, have been subjected to a decrease in temperature. Many indirect

[20] pp. 26-30
[21] p. 26

warming indicators such as borehole temperature, retreat of snow cover and glaciers and sub-surface ocean temperature, are in agreement with the observed global warming. Short-term changes produced by local events can affect long term temperature trends. In recent years, for example, negative temperature variations were caused by the Pinatubo eruption. In particular in 1992 a decrease of about 0.5 °C in the surface temperature was measured, followed by the reappearance of warmer temperatures in 1994 after the natural removal of the volcanic aerosols.

Figure 3: Combined global land and marine surface temperature record from 1956 to 1999, relative to 1961-1990. The solid curve represents smoothing of the annual mean values shown by the bars to suppress inter-annual variability [*source:* Jones *et al*, 1999].



As far as precipitation is concerned, a small positive global trend (1%) has been recorded over the land areas during the 20th century. The geographic distribution of these variations appears to be more heterogeneous than that concerning temperature. In particular precipitation has increased in the higher latitudes of the Northern Hemisphere, especially during the cold season [IPCC, 1996a][22]. In general, precipitation over land areas increased on average in the period 1900-1960, while since 1980 it has begun to decrease. Rainfall has also increased over the central equatorial Pacific Ocean in recent decades. On the other hand, a decrease in rainfall has occurred in tropical and subtropical areas since 1960, in accordance with the increase of temperatures.

Evaporation has probably increased over the tropical oceans, and a major amount of water vapour has been observed in the tropics since 1973 [IPCC, 1992]. This parameter has probably decreased over many regions of the former Soviet Union and North America since 1951. Cloudiness seems to have also increased over the oceans since the 50s and between the 50s and the 70s in many land areas in which the daily temperature range has diminished.

The snow cover over the Northern Hemisphere has diminished since 1988, resulting in a 10% decrease with respect to the average of the period 1974-1994. The deficit of snow has been more evident during the spring time, but in recent years a low expansion of the snow cover has been observed also during summer and autumn. Similar trends over the North America and Asia have also been suggested [Groisman *et al.* 1994]. Decrease in the snow cover is regarded closely linked to the increase in temperature.

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[22] pp. 137-139

The natural variability is an intrinsic characteristic of the climatic system. The understanding of the driven complex mechanisms of climate variability is not complete. In particular it is difficult to detect whether past changes lie outside the level of natural variability. Furthermore indicators of climate change bring clear evidence of regional changes in extreme events and in climate variability. For example, the persistence of the El Niño -Southern Oscillation (ENSO) events has consistently increased since the mid-70s, and particularly since 1989. The importance of the El Niño-ENSO events relies on the fact that they can have seriously negative effects in many part of the world, contributing in causing droughts and floods.

1.2.2 Past trends in sea level

The rise in sea level is generally considered as one of the more significant consequence of global warming. Studies suggested that over the past two millennia the global sea level variation did not exceed few tens of centimetres [IPCC, 1996a][23]. Over the last 100 years the IPCC has estimated that global mean sea level has risen by about 10-25 cm, with a best estimate of 18 cm. Numerous studies (table 2) agree on a mean sea level rise rate between 1 and 3 cm/year. However it has been considered that over the last century if the average rise has been greater than that of the last thousand years there is as yet no evidence of a consistent increase in the rate of sea level rise during this century [IPCC, 1996a][24].

Over the last century, variations in global sea level have typically been estimated through analysis of tide gauge measurements. Tide gauge records provide important information about long term changes in global mean sea level. A comprehensive review of the estimated rates of sea level rise from these measurements has been carried out by Gornitz [1994]. Most of the estimates considering the last 100 years range between 1 and 3 mm/yr (table 2). Recent estimates of global mean sea level rise from tide gauge measurements range from 1.7 to 2.4 mm/yr [Douglas, 1997].

Table 2: Sea level rise values for the 20th century reported by various researchers and deduced from the analysis of tide gauge records.

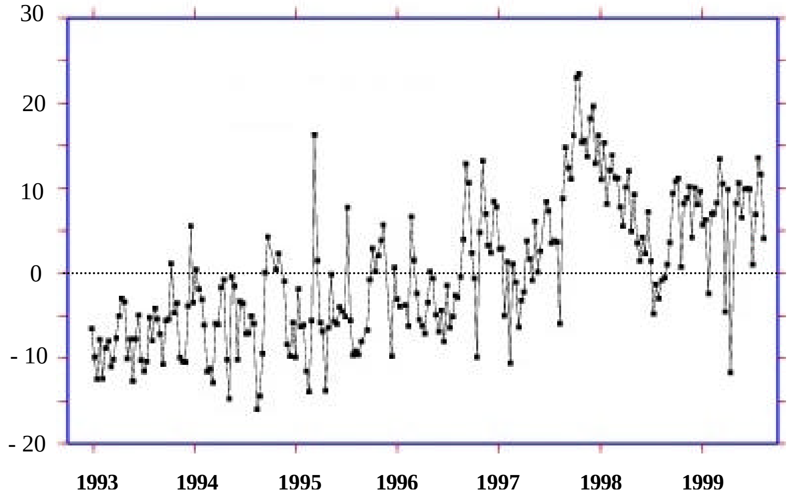
Source	**Region**	**Data used (years)**	**SLR (mm/yr)**
Gornitz and Lebedeff (1987)	Global	1880-1982	1,2 ± 0,3
Trupin and Waht (1990)	Global	1900-1979	1,7 ± 0,1
Douglas (1991)	Global	1880-1980	1,8 ± 0,1
Peltier and Tushingham (1991)	Global	1920-1970	2,4 ± 0,9
Shennan and Woodworth (1992)	North Occidental Europe	_	1,0 ± 0,15
Gornitz (1995b)	Eastern USA	_	1,5
Unal and Ghil (1995)	_	1807-1988	1.62± 0.38
Douglas (1997)	Global	_	1,8 ± 0,1

In situ observations provided by tide gauges, constitute a very important historical reference. A large number of tide gauges were installed in the years following the second world war and long

[23] p 336
[24] pp. 363-364

term records are available in various part of the world. Nevertheless their geographical distribution is very heterogeneous and they provide only indications of relative sea level variations in relation to the coast. In addition vertical movements due to land subsidence, post-glacial rebounds and tectonic processes may affect the measures and complicate the determination of global trends [Douglas, 1995]. Alternatively, recent satellite radiar altimetery provide measurements of the absolute level of the sea and a more homogeneous coverage of the changes in oceans level. Since August of 1992 the Topex/Poseidon satellite mission has been measuring sea level on a global basis (figure 4) in order to provide an improved measurement of global sea level changes, especially over shorter periods [Nerem, 1995; Cazenave, *et al*.,1998]. Results confirm a global mean sea level rise of the same order as estimated by long term tides gauges records.

Figure 4: Temporal variations in global mean sea level computed from Topex/Poseidon over the period from December 1992 to August 1999. Each dot is a single 10-day estimate of global mean sea level.



Although the complex processes affecting sea level operate on time scales varying from hours to million of years, factors of main concern are those regarding changes on time scales from ten to one hundred years and are described below:

- The thermal ocean expansion is a phenomenon linked to changes in water density (steric changes) and is dependant on the temperature and the salinity of the water. Ocean expansion over the last 100 years has been estimated to have contributed about 2-7 cm to sea level rise [IPCC, 1996a][25].

- Melting of glaciers, ice caps and ice sheets are likely to increase as a consequence of global warming. There is a great uncertainty regarding the mass balance of the ice sheet on the globe surface and the precise contribution to sea level rise. The thinning of glaciers has been present in many regions of the world since the middle of the 19th century. Negative mass balance has been registered, for example, in the Alps [Haeberli *et al.* 1995] and in south central Alaska, but not in the Canadian Arctic [Fisher *et al.* 1994]. Observed data and recent models estimate that the retreat of ice (glaciers and ice caps) has contributed to sea level rise over the last 100 years by about 2-5 cm. The rate of sea level rise due to glacier volume reduction has been estimated at about 0.35 mm/yr. in the period 1890 – 1990 and 0.6 mm/yr. between 1985 and 1993 [IPCC, 1996a][26]. The contribution of the Greenland and Antarctic ice sheets to sea level rise remains not

[25] pp 366-370
[26] pp. 371-373

clear. The observational evidence is not sufficient to have a complete understanding of their mass balance and their past role in sea level changes. As most of the fresh water is stored in these two huge ice sheets, even a small loss in their volume could have extensive effects on sea level. A warmer climate in the future will probably increase the melting rate at the margins of the Greenland ice sheet. This effect is unlikely to be counterbalanced by an equal increase in the accumulation rate in its internal part. This could result in a positive contribution to the sea level rise. The Antarctic ice sheet will on the contrary probably experience an increase in the accumulation rate and could consequently cause a sea level fall. As Antarctic temperatures are very low, only little surface melting occurs and the ice loss is mainly due to the breaking-off of icebergs.

- Variations in the quantity of terrestrial liquid water stored in ground and on the surface is thought to have a direct effect on sea level changes water, although it is not clear whether it has had a significant role in past sea level rise. Human interventions - such as the building of water retention infrastructures, excessive ground water withdrawal, deforestation, wetland loss and permafrost thawing - and natural processes may influence the hydrological cycle in a considerable but not fully understood manner. Despite of the uncertainty regarding the contribution of these factors to sea level rise and the lack of result homogeneity, many studies suggest that the hydrologic contribution to sea level rise over the past century could have been significant [Gornitz *et al*. 1997, IPCC 1996a[27]]. The IPCC[28]. [1996a] has estimated that the current contribution may range between –0.4mm/yr and +0.75 mm/yr with a mean estimate of 0.1mm/yr and that over the last 100 years the contribution could be about 0.5 cm, with a high uncertainty.

- Coastal processes such as subsidence, accretion and erosion as well as tectonic phenomenon are site specific and may produce important localised effects reinforcing or reversing sea level rise trend. On the global scale their contribution to sea level rise is considered to be insignificant.

1.3 PROJECTIONS OF CLIMATE CHANGE

The exploration of future changes in climatic and related variables are characterised by a high degree of uncertainty. Giving this consideration, the term of *projection* is more appropriate than *prediction* when considering climate change as well as the use of the concept of climate change scenario which "*is intended to be an internally consistent picture of possible future climatic conditions*" [Wigley 1992].

1.3.1 IPCC scenarios for the future

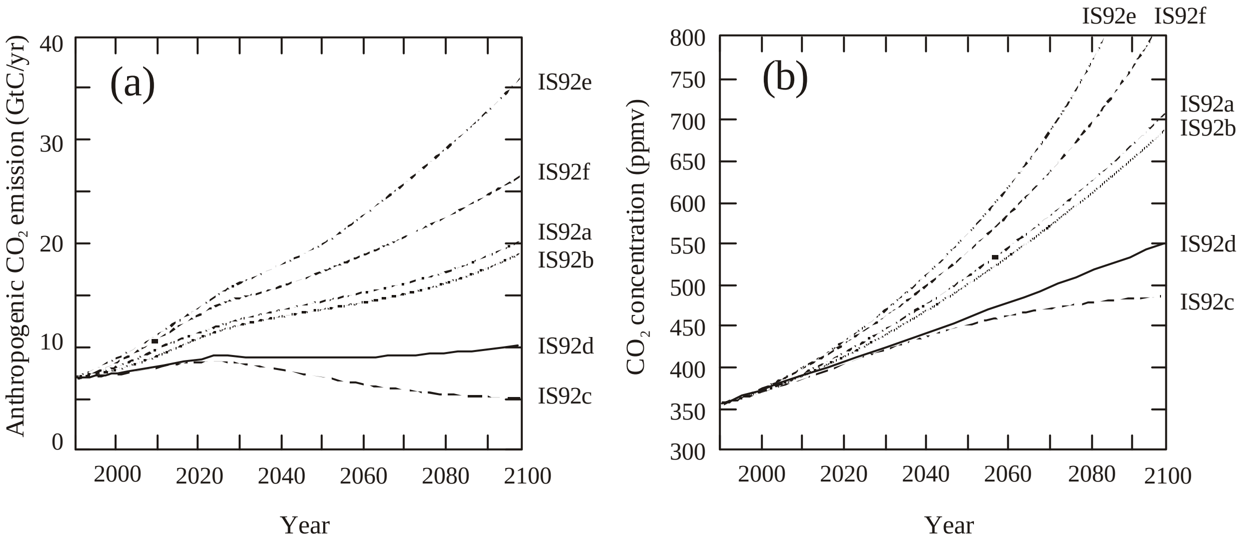
Future greenhouse gas emissions are the result of complex and dynamic processes driven by demographic trends and socio-economic development and technological changes. The evolution of these factors is uncertain, and different assumptions regarding future economic, political and demographic trends, provide different projections and scenarios.

In order to assess variations in the atmospheric composition and to generate projections of climate change for the horizon 2100, the IPCC [1992] has developed six emission scenarios (IS92 a, b, c, d, e and f) (figures 4a and 4b). They provide different projections for the emissions of the main greenhouse gases, the precursors of tropospheric ozone and the sulphate aerosols, as well as for the aerosols generated by biomass burning. These scenarios, and particularly the IS92a known as

[27] p 379
[28] p. 380

“central” scenario[29] have been widely used as a common reference for the analysis of possible climate change impacts and mitigation [IPCC, 2000]. On the basis of the IS92 emission scenarios, IPCC elaborated a set of projections of greenhouse gas concentrations. All these projections consider an increase in the concentrations of greenhouse gases in the period 1990 – 2100 (figures 4a and b) which magnitude varies according to the considered scenario. For example, the percentage increase in CO_2 ranges between 35 and 170%, the increase in CH_4 between 22 and 175% and the increase in N_2O between 26 and 40%. Projections of climate change are realised by means of climate models which allow the mathematical simulation of the interactions between land, ocean and atmosphere. These models are able to reproduce climate variations which have been observed in the past and to generate projections of the future trends and values. Given the uncertainty of future trends, the IPCC advised to consider the full range changes included in IS92 scenarios rather that a unique “central” scenario for the assessment of climate change implications [IPCC, 2000].

Figure 5. a) Total anthropogenic CO2 emissions under the IS92 emission scenarios developed by the IPCC and b) the resulting atmospheric CO2 concentrations [*source*: IPCC 1996a][30].



In 1995 the scenarios have been evaluated and published in the Second Assessment Report (SAR) and in 1996 the IPCC decided to develop a new set of emission scenarios with the aim to account for a wider range of likely future trends (figure 6). The Special Report on Emissions Scenarios (SRES)[31] provides emission profiles as inputs to GCMs and models of regional climate change as well as other information (such as population growth or rates of technological change) required for the assessment of impacts related to climate change. SRES scenarios are based on different natural and socio-economic assumptions grouped into the following four distinct “storyline" families, which are qualitative descriptions of main scenario characteristics and relationships among driving forces (SRES98):

- A1: Rapid economic growth, technological progress, globalisation, and convergence;

[29] IS92a is also known as "non-intervention" scenario, assuming that no new policies are adopted to reduce emissions in response to the threat of climate change.
[30] pp. 285-406
[31] More information on SRES98 can be found in http://sres.ciesin.org

- A2: Regionally oriented economic development resulting in less convergence and more fragmented and slower technological progress and growth than in A1;
- B1: Global co-operative solutions to economic, social, and environmental sustainability, including improved equity;
- B2: Local and regional solutions to economic, social, and environmental sustainability, resulting in more fragmented and slower technological progress and growth than in B1.

Six ‘marker scenarios’ have been developed, covering all scenarios and representing the quantification of the storylines. These ‘marker scenarios’ provide the base for the generation of climate change scenarios. The Data Distribution Centre (DDC)[32] of the IPCC made available the first set of temperature rise and sea level rise projections based on these scenarios and elaborated by means of models used in the Second Assessment Report (SAR) of the IPCC [Wigley 1995; Wigley and Raper 1987; 1992]. The preliminary results, reported on the figures 7, 9 and 11, display general trends of future CO2 concentration, temperature and sea level rise. For instance, the range of CO2 concentration appears to be lower than in the IS92 projections. In addition, a higher increase in global mean temperature (due to the lower estimation of levels of sulphur dioxide emissions than in the previous IS92 projections) and a higher amplitude of global sea level rise are projected with the range of SRES 98 emissions scenarios. Nevertheless, these results should be take with precaution since more precise scenarios will be formally used in the IPCC Third Assessment Report (TAR) which is expected to be completed by mid-2001.

1.3.2 Temperature projections

The IPCC elaborated the mean global temperature projections for the period 1990-2100 (figure 8) based on IS92 emission scenarios, considering three different values for climate sensitivity: a lower value of 1.5 °C, a ‘best estimate’ of 2.5 °C and a higher value of 4.5 °C. Taking into consideration all the IS92 emission scenarios and all the different values of sensitivity, the models project an increase in global mean temperature by the year 2100 in the range of 0.9 and 3.5 °C [IPCC, 1996a][33]. The mid-range emission scenario (IS92a) projects a non-linear increase in anthropogenic CO_2 emission from about 7.5 GtC/yr in 1990 to about 20 GtC/yr in 2100. The best estimate of climate sensitivity and the IS92a scenario produces a temperature increase projection of 2 °C by 2100. All the presented temperature projections consider the effects due to the increase in both the greenhouse gases and the anthropogenic aerosols concentration.

Otherwise, assuming a constant aerosol concentration at 1990 levels and an increasing concentration of greenhouse gases, the increase of the global mean temperature growth by 2100 ranges between 0.8 and 4.5 °C. In this case, the IS92a and the best estimate of climate sensitivity generates a temperature increase projection of 2.4 °C by 2100 [IPCC,1996a][34]. The full set of IS92 scenarios and a climate sensitivity value of 2.5 °C produce temperature projections for the year 2100 ranging between 1.3 and 2.5 °C in the case of changing aerosol concentrations beyond 1990 and between 1.2 and 3.2 °C assuming constant aerosol concentrations beyond 1990. In all cases these scenarios would be consistent with a significant temperature increase. The maximum increase in temperature is likely to affect high northern latitudes during late autumn and winter (causing a reduction of sea ice and snow cover), while the minimum temperature increase will occur around Antarctica and in the northern North Atlantic. A smaller warming will also affect the Arctic in summer. Southern circumpolar ocean and low latitudes will probably be affected by a limited seasonal warming variation. Finally a contraction in the range of diurnal temperature on the land in most seasons and regions of the globe is likely to occur.

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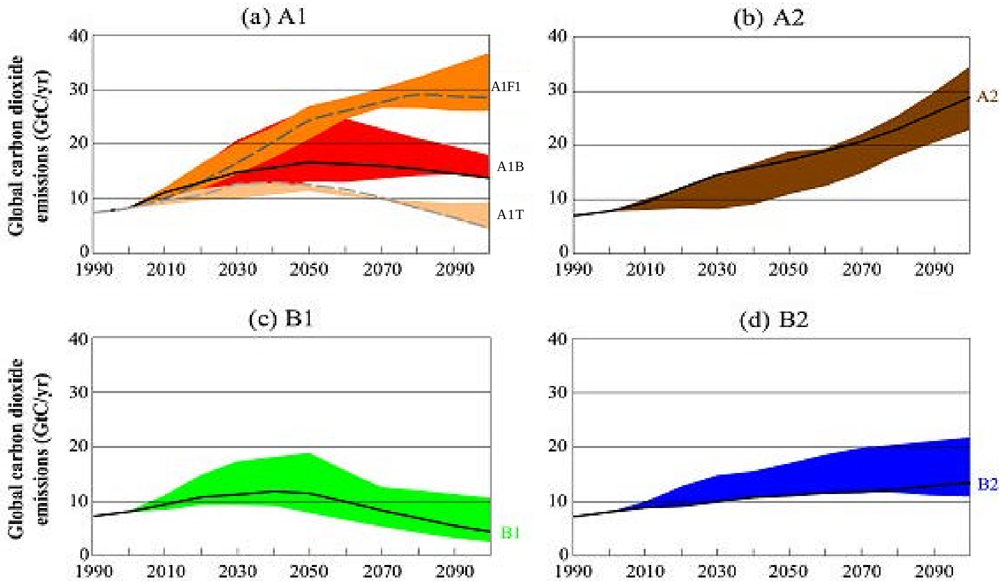
[32] http://ipcc-ddc.cru.uea.ac.uk
[33] p 40
[34] p. 40

Figure 6: Total global annual CO2 emissions from all sources (energy, industry, and land-use change) from 1990 to 2100 (in gigatonnes of carbon (GtC/yr) for the four families and six scenario groups. The 40 SRES scenarios are presented by the four families (A1, A2, B1, and B2) and six scenario groups: the fossil-intensive A1FI (comprising the high-coal and high-oil-and-gas scenarios), the predominantly non-fossil fuel A1T, the balanced A1B in Figure SPM-3a; A2 in Figure SPM-3b; B1 in Figure SPM-3c, and B2 in Figure SPM-3d. Each coloured emission band shows the range of harmonised and non-harmonised scenarios within each group. For each of the six scenario groups an illustrative scenario is provided, including the four illustrative marker scenarios (A1, A2, B1, B2, solid lines) and two illustrative scenarios for A1FI and A1T (dashed lines) [*source*, IPCC, 2000].



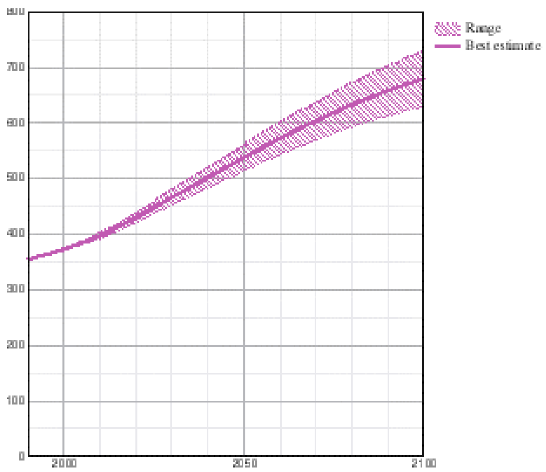
1.3.3 Projections of other variables

All models project an increase in global mean precipitation. Such increase will cause an enhancement of the global hydrological cycle. At the regional scale, projections of future changes in precipitation vary from zone to zone and from model to model. An increase in precipitation is expected in high latitudes, except around the Norwegian Sea, during winter. Global warming is likely to increase the quantity of atmospheric water vapour and to enhance the pole-ward vapour transport to northern high latitudes leading to an increase in precipitation [Manabe *et al.,* 1975]. Most of models project that the increase in precipitation will extend into mid-lattitudes. Pattern of change for other areas vary according to the model which is considered. Many models which exclude the aerosol effect, project general decrease in rainfall over southern Europe and an increase over India and south-east Asia. On the contrary, if the effect of aerosol forcing is taken into consideration, precipitation is projected to increase over southern Europe and to decrease over the Asian monsoon region. This latter effect is due to aerosol cooling, which is likely to reduce the temperature contrast between land and sea and consequently the strength of monsoon occurrence. In general, rainfall variations in the dry subtropics are expected to be small [IPCC, 1996a][35].

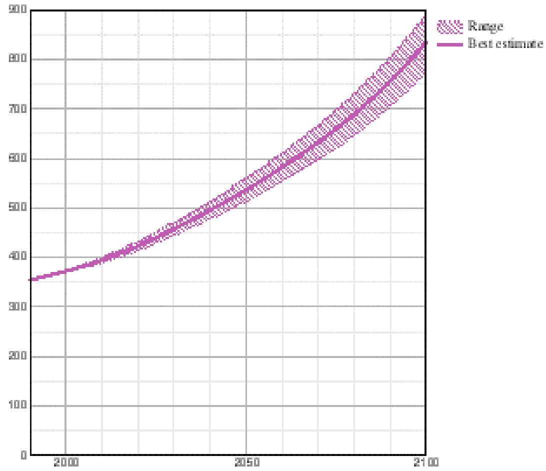
[35] pp. 307-309

Figure 7: Carbon Dioxide concentration in ppmv based on SRES carbon dioxide emissions scenarios.

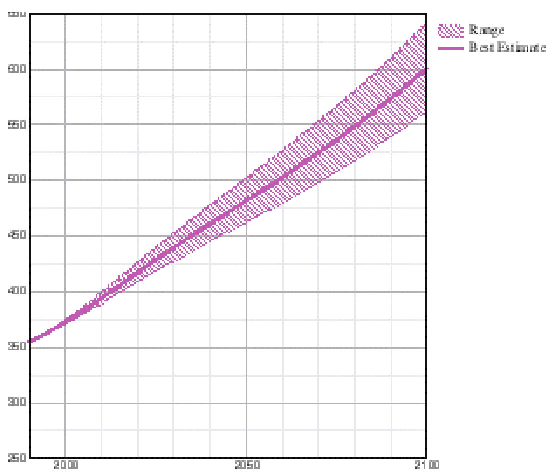
IPCC SRES98A1 emissions scenarios harmonised



IPCC SRES 98 A2 emission scenarios harmonised



IPCC SRES 98 B2 emission scenarios harmonised



IPCC SRES 98 B1 emission scenarios harmonised

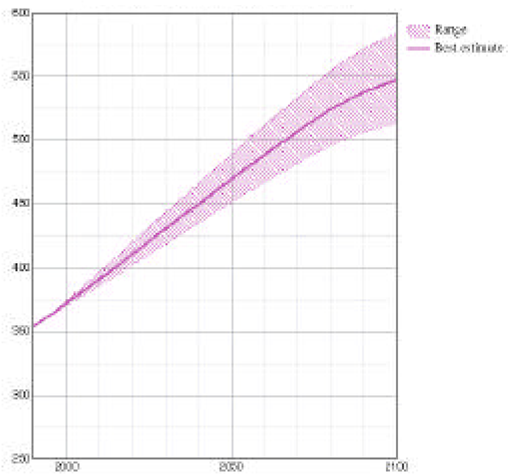
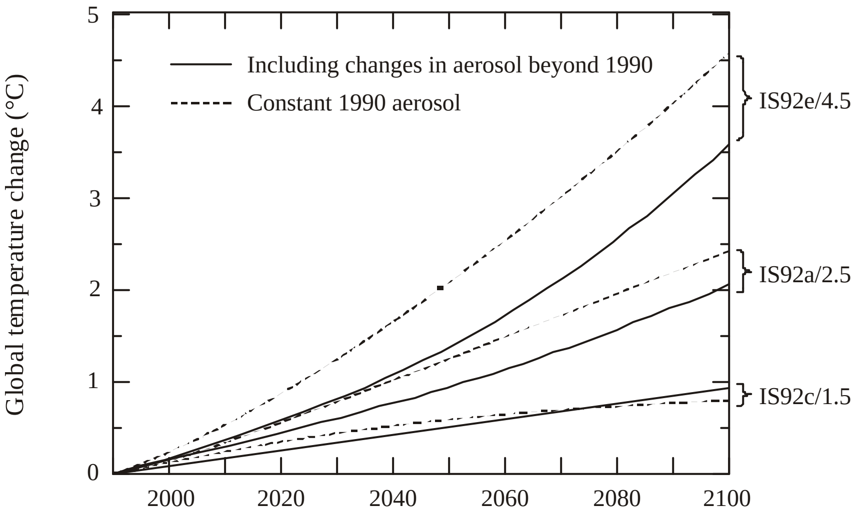


Figure 8. Projected global mean surface temperature change extremes from 1990 to 2100. The highest temperature changes assume a climate sensitivity of 4.5 °C and the IS92e emission scenario; the lowest a climate sensitivity of 1.5 °C and the IS92c emission scenario; the mid-range curve a climate sensitivity of 2.5 °C and the IS92a scenario. The solid curves include the effect of change in aerosol concentrations, while the dashed curves assume that aerosol concentrations remain constant at their 1990 levels [*source*: IPCC 1996a][36].



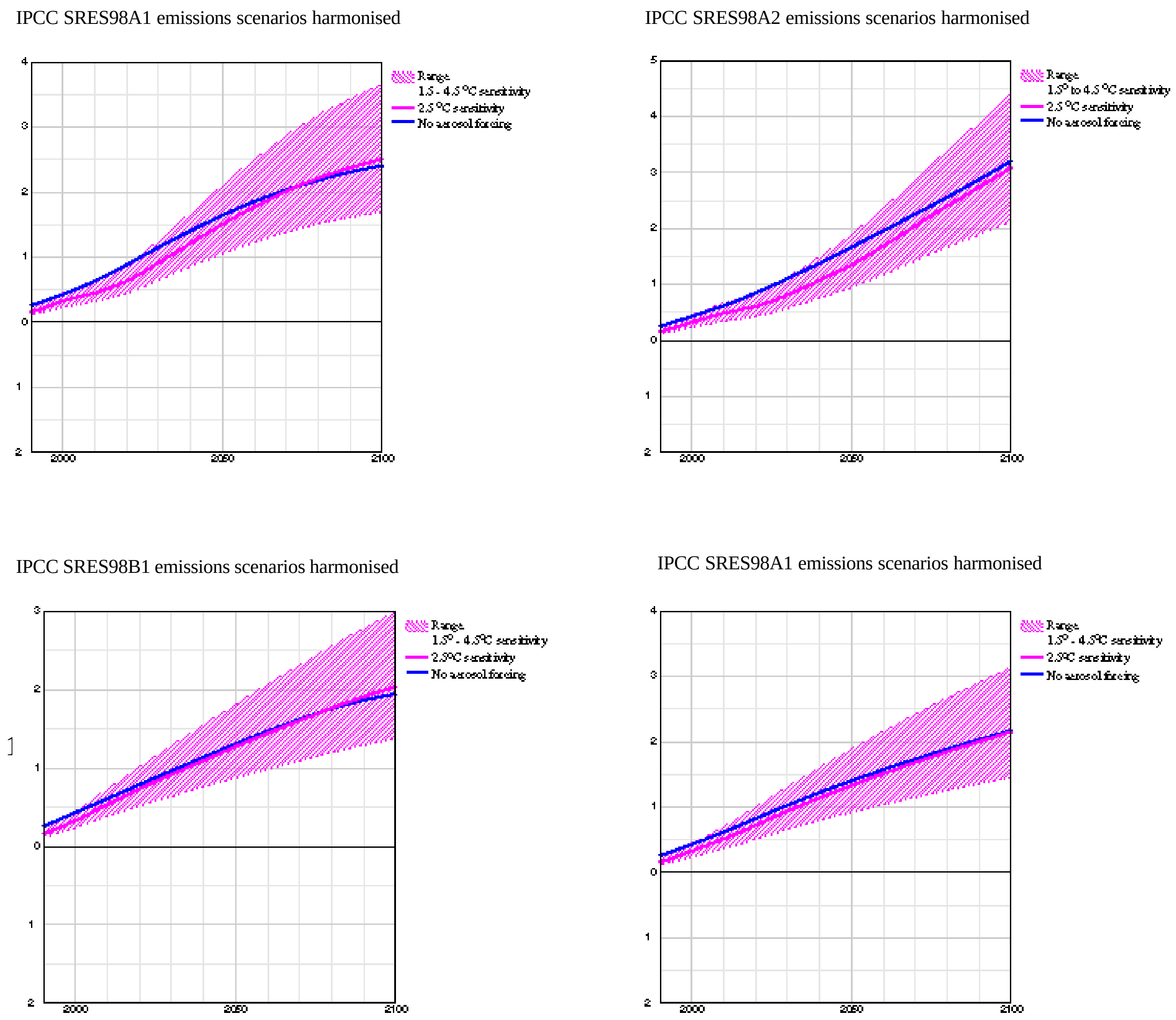
Some general results concerning the effects of climate change on the global ocean circulation emerge from the analysis of various model simulations IPCC [1996a][37]. During winter, surface warming is expected to be more consistent on land than on oceans. Numerical simulations of global ocean circulation have also calculated that small changes in the forces presently controlling the thermohaline circulation at high latitudes could lead to a significant weakening of the 'conveyor belt' which normally transports heat poleward. The projected precipitation increase over higher latitudes can, in fact, diminish surface water salinity and density, leading to a reduction in the sinking of seawater and to a consequent inhibition of the global ocean circulation. In particular, models have predicted that the strength of the ocean circulation in the northern North Atlantic will probably decrease, leading to a reduction of the warming capacity of the ocean around the Northern Atlantic.

1.3.4 Sea level projections

On the basis of the described climate projections and emission scenarios, the IPCC [1996a][38] has estimated the magnitude of future change in sea level for the period 1990-2100 in response to global warming. If all the IS92 scenarios - which include an increase both in the greenhouse gases and aerosol precursors concentration - the range in the estimates of climate sensitivity (1.5-4.5 °C) and the range of values of ice melt parameters (low, mid and high ice parameters) are taken into consideration, the models project a global mean sea level rise in the period 1990-2100 varying between 13 and 94 cm (Figure 10).

[36] p. 40
[37] pp. 39-46
[38] pp. 359-405

Figure 9: Implications of the SRES emission scenarios - Temperature Change (°C) w.r.t 1961-90

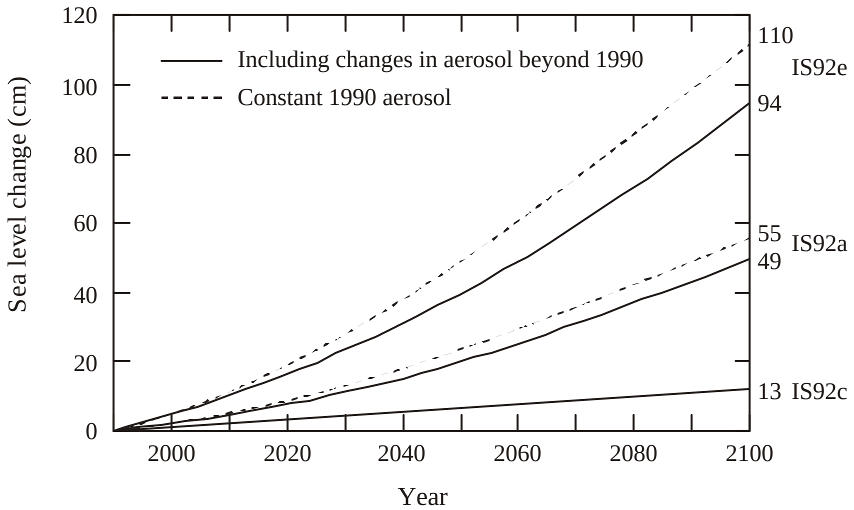


Considering the complete set of emission scenarios, the 'best estimate' value of the climate sensitivity (2.5 °C) and the mid-values of the ice melt parameters, this range is reduced to 38-55 cm (in the case of aerosol concentrations constant at 1990 level this range is 38-66 cm). For the IS92a scenario, which is the mid-range emission scenario, the IPCC provides high, middle and low projections of the sea level rise in regard to the uncertainties of the model, linked to climate sensitivity and ice melt parameters. In this case sea level rise is expected to vary between 20 and 86 cm by the year 2100 (in the case of aerosol concentrations constant at 1990 level this range is 23-96 cm) and 7 and 39 cm for the year 2050. The 'best estimate' for the IS92a scenario is generated if the 'best estimate' value of climate sensitivity and the mid-values of ice melt parameters are taken in account. This best estimate is about 49 cm by the year 2100 (this best estimate is 55 cm if aerosol amounts constant at 1990 levels are taken into consideration) and about 20 cm by the year 2050 [IPCC,1996a][39].

Thermal expansion is expected to be the most important cause of sea level rise. It will be responsible for long term changes as it is capable to affect sea level even beyond the stabilisation of greenhouse gas concentrations. In the models simulation, the great thermal inertia of the ocean-ice-atmosphere system affects the projected sea level rise in such a way that the various adopted scenarios (IS92a-f) produce very little differences in sea level increase for the first half of the next century. Different scenarios generate greater difference in the projected sea level rise in the second part of the considered period (1990-2100). Great uncertainty in sea level rise projection is linked to the role of the polar ice sheets, in particular to their mass balance and to their future response to the global warming. For example, it is likely that warmer polar ocean temperature would cause the melting of part of the Ross and other Antarctic shelves but at the same time warmer polar air temperatures could lead to an increase in annual snowfall [Titus *et al.*, 1995].

Changes in future sea level will not be uniform around the world. The response of regional seas could be substantially different and will depend on local factors. Local climate characteristics, such as some variations in temperature, precipitation, wind and pressure patterns as well as changes in oceanic circulation and water density, will be significant in sea level variations. Other important factors which could influence regional sea level rise are vertical land movements induced both by natural and anthropogenic causes, such as tectonic movements, natural and human induced subsidence, natural uplift, erosion or sediment depletion.

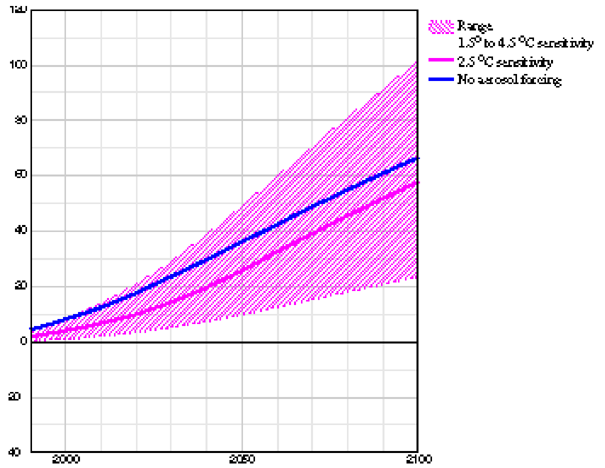
Figure 10: Projected global mean sea level rise extremes from 1990 to 2100. The highest sea level rise curves assume a climate sensitivity of 4.5 °C, high ice melt parameters and the IS92e emission scenario; the lowest a climate sensitivity of 1.5 °C, low ice melt parameters and the IS92c emission scenario; the middle curves a climate sensitivity of 2.5 °C, mid-value ice melt parameters and the IS92a emission scenario. The solid curves include the effects of change in aerosol concentrations, while the dashed curves assume that aerosol concentrations remain constant at their 1990 levels [*source*: IPCC 1996a][40].



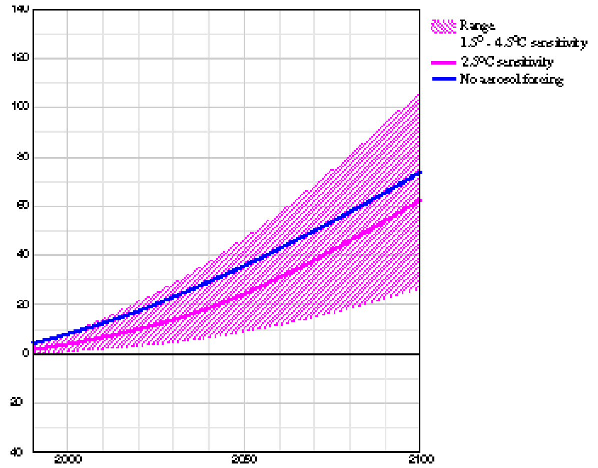
[39] p. 40
[40] p. 385

Figure 11: implications of the preliminary SRES emission scenarios - Sea Level Change (cm) w.r.t 1961-90

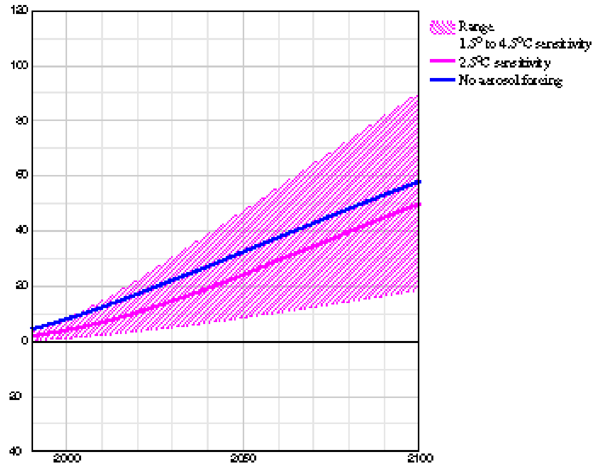
IPCC SRES98A1 emissions scenarios harmonised



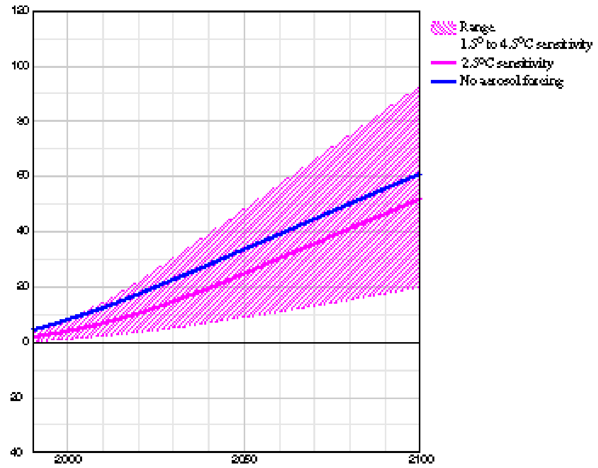
IPCC SRES98A2 emissions scenarios harmonised



IPCC SRES98 B1 emissions scenarios harmonised



IPCC SRES98 B2 emissions scenarios harmonised



II THE MEDITERRANEAN BASIN

2.1 DESCRIPTION

2.1.1 Morphology and hydrology

The Mediterranean Sea is a semi-enclosed sea covering an area of approximately 2.5 million km2, (3800 km wide east-west, and a maximum north-south distance of 900 km). It represents 0.69% of the world ocean surface and 0.27% of the global ocean volume. The Mediterranean Sea is connected to the Atlantic ocean by the Strait of Gibraltar, to the Black sea by the strait of Çanakkale (Dardanelles) and to the Red Sea through the Suez Canal. The mean depth is about 1.5 km and half of the total water volume is characterised by a depth ranging between 2 and 3 km. The Mediterranean is also constituted by zones with limited depth (below 200 m), which occupy 20% of the total surface and 1.5% of the total volume [Grenon and Batisse, 1989]. The length of the Mediterranean coastline is about 46,000 km, of which 18,000 km belong to islands. The Mediterranean basin (figure 12) is characterised by a complex fragmented relief, submitted to strong seismic and volcanic activity. About 54% of the coastline is rocky and 46% is sedimentary. Sedimentary coastlines are subject to the strongest human pressure and are generally more vulnerable to climate change. There are 162 islands exceeding 10 km^2 and another 4,000 smaller islands, which are mainly concentrated in the eastern Mediterranean.

Only a few important rivers flow in the Mediterranean sea (table 4). The four principal ones are respectively: the Nile, the Rhone, the Po and the Ebro. The estimated associated riverine input is about 15,000 m^3/s [UNEP/EEA, 1999b]. 92% of this water input comes from the northern part of the basin shores. Dams and large scale irrigation schemes have decreased the total discharge of some rivers, causing sediment deficit and significant negative consequences. For example, in the delta of the Ebro, erosion has increased as a result of the strong reduction in sediment discharge. Likewise, since the closure of the High Aswan Dam in 1964, discharges of sediments at the mouths of the Nile have been reduced nearly to zero and consequently the shorelines have been affected by an evident erosion [Frihy *et al.*, 1996].

The Mediterranean basin is considered as a “concentration basin” that is to say that evaporation exceeds precipitation. This negative hydrological balance is mainly due to the high rate of evaporation, the poor rainfall during the dry season and the low runoff of the relatively short rivers [Milliman *et al.*, 1992]. As a consequence, the balance is achieved through the marine water of Atlantic Ocean, entering into the Mediterranean basin and the water contribution of the Black sea. The net incoming flow from the Atlantic Ocean is estimated of being about 41,000 m^3/s and the flow from the Black Sea at about 6,000 m^3/s [UNEP, 1989a].

High evaporation and limited input of fresh water and rivers represent the main causes of the relatively high Mediterranean salinity (ranging from 36 to 39 g/l). Mediterranean waters are characterised by warmer temperatures with respect to the Atlantic Ocean and by a complex and variable superficial current system, which transports Atlantic water from the Straits of Gibraltar toward the east, forming numerous whirlpools. Mediterranean sea level is lower than the Atlantic oceanic level, and diminishes progressively from Gibraltar to the Northern Aegean Sea, with maximum differences of about 80 cm [UNEP, 1989a]. Furthermore, the Mediterranean is characterised by a weak tide system, with a very highly oscillation width.

Table 4: Water contribution to the Mediterranean basin from main sources (in km^3/year).

Atlantic Ocean inflow-outflow	1,700
Black Sea inflow-outflow	164
Rivers	
Rhone	54
Po	46
Ebro	17
Neretva	12
Drni	11
Meriç-Evros/Ergene	10
Seyhan	8
Tiber	7
Adige	7
Other minor rivers (including Nile)	50

2.1.2 The climate of the Mediterranean

The Mediterranean climate is subjected to both subtropical and mid latitude weather systems. The basin is generally characterised by a mild climate, with warm or hot dry summers and wetter cooler winters. Climate is influenced by the sea, which tends to reduce daily and seasonal temperature extremes. The Mediterranean climate was defined by Koppen [1936] as a climate characterised by:

- A mean temperature of the coldest month varying between -3 °C and 18 °C;
- A dry summer;
- A rainfall amount in the wetter months which must be at least 3 times greater than that of the driest months;
- A mean temperature of the warmest month greater than 22 °C;
- A mean annual rainfall amount (in mm) that must be greater than 20 times the mean annual temperature (in Celsius degrees).

Microclimate varies from very dry conditions, such as in the Northern Africa countries, to cooler and wetter conditions, such as in some Northern regions of the basin. Rainfall generally decreases from west to east and from north to south and geographic distribution is significantly influenced by the orography. Locally, precipitation may vary between more than 1,500 mm/y to less than 100 mm/y. The Mediterranean climate is dominated by a strong summer-winter rainfall contrast which is also associated with a well-pronounced seasonal cycle in almost all the climate variables. The rainy season generally starts no earlier than September/October and continues until the end of April. The highest rainfall generally occurs in December and the lowest in July. The western region of the Mediterranean is characterised by a more prolonged rainfall season and a less pronounced seasonal cycle. In many regions of the basin, summer rainfall is often zero and in this season water shortage can be a very acute problem [Milliman *et al.*, 1992]. This is particularly true for the southern part of the Mediterranean, where the dry season can even last more than six months.

Potential evapotranspiration shows a north-south gradient [Palutikof *et al.*, 1994]. The greatest spatial variation occurs in summer, when potential evapotranspiration ranges between less than 5 mm/day in the north to more than 8 mm/day in the south. During the other seasons spatial variability is more limited, being slighter in winter (1-3 mm/day). The main Mediterranean winds come from north and west directions. The combination of dry winds and sunny days has a considerable positive effect on surface water evaporation. Extra-tropical storms occur during autumn, winter or spring and can contribute to causing significant waves and surges.

Figure 12: The Mediterranean Basin

2.1.3 Natural features

Many important natural ecosystems are present in the Mediterranean region. The peculiar climate and the relief and soil characteristics make the Mediterranean basin one of the most original bio-geographic regions in the world. The Mediterranean is characterised by distinct features, such as particular ecosystems composition and plants and animal associations.

The Mediterranean vegetation is constituted by a high variety of plants and includes about 25,000 different species, half of which are endemic. Many plant associations can be considered as relicts, since they represent what remains of periods of more favourable ecological or climatic conditions.

Endemic and relict plant species are the most vulnerable to degradation, since once they have been eliminated, their regeneration can be very difficult. The present climatic and ecological conditions, which are different from the original ones, do not represent the optimal and limit the plants' regeneration [Grenon and Batisse, 1989]. Mediterranean vegetation is mostly constituted by plants which have adapted to heat and dryness, developing drought-resistant characteristics. The dominating associations are represented by the "maquis" and "garrigue", which are often the result of degradation processes from the "climax" stage[41]. The most organised level of the Mediterranean plant community is constituted by evergreen forest, in which the prevailing species are holm-oak (*Quercus ilex*) and cork-oak (*Quercus suber*). Proceeding towards lower latitudes, oaks are replaced by trees more resistant to drought conditions, such as thuja. The degradation processes - mainly induced by human factors such as overgrazing, fire, unsustainable management and deforestation – have led to the involution of the evergreen forest into "maquis" and into "garrigue" in many areas of the basin. If the process continues, the "garrigue" can be transformed into steppe and finally into bare soil. The more the degrading process is advanced, the less the soil protection is ensured by the vegetation and the more the process becomes irreversible. Due to the limited capacity of the reduced plant cover to protect the soil Mediterranean soils are widely threatened by erosion processes and by physical and chemical degradation. As far as animal communities are concerned, it is important to stress that many of them are already in a critical situation and some species are at risk of extinction. This is for example the case for some *anatidae* and some mammals, such as bear, lynxes, some antelopes and monk seal as well as large birds of prey.

The Mediterranean sea is characterised by a low biomass and a high diversity. It contains 7% of the known world marine fauna, 18% of the world marine flora. Many species are endemic. There have been recorded a total between 10 000 and 12 000 marine species for the Mediterranean [UNEP/EEA 1999b]. Species are distributed heterogeneously in the sea, and the western part of the Mediterranean sea is richer than the eastern part. The higher biodiversity is concentrated between the surface and the 50 metre depth [Fredj *et al.* 1992], i.e. the zone strongly influenced by the land-sea interactions.

2.1.4 The human factor

The Mediterranean region is a unique frontier dividing two adjacent zones with marked differences in demographic features and levels of development. The considered Mediterranean zone include 22 countries and territories than are generally divided in three geographical sub-regions [Margat J. Vallee D. 1999]:

- **The North**: Spain, France and Monaco, Italy, Malta, Bosnia Herzegovina, Croatia, Slovenia, FR of Yugoslavia, Albania, Greece;
- **The Est**: Turkey, Cyprus, Syria, Lebanon, Israel, Gaza strip;
- **The South**: Egypt, Libya, Tunisia, Algeria, Morocco.

The overall basin is characterised by a large population which tends to concentrate in coastal areas and which is growing rapidly especially in Turkey, Syria and Northern African countries (figure 13). The total resident population of the 22 Mediterranean states is estimated to be currently of 450 million and is expected to reach the threshold of 600 million in 2050. The coastal population is estimated one third of the total population (i.e. 150 million) and could reach 220 million by the year 2025 [Grenon and Batisse, 1989]. This increase will be less consistent in northern countries than in southern ones (where the total population is expected to double by 2025) [e.g Ben Jannet-Allal,

[41] Without human intervention, a vegetal association tends to reach an equilibrium and to conserve a constant species composition. That is the climax. The climax represents a reference point to study the other evolution stages.

1999] (figure 14). In 2025 Northern population is expected to represent only one third of the total population of the basin [UNEP/EEA 1999b].

The most artificial and urbanised coastlines are located in the Northern countries. Mediterranean-European countries have 1500 km of artificial coastlines of which 83% is represented by harbour and port areas [UNEP/EEA, 1999a]. The “Blue Plan” estimated in 1985 that 90% of the urbanised land are on the coastal zone of Spain, France, Greece, Italy and the former states of Yugoslavia [Blue Plan, 1988b]. The urbanisation is expected to increase, and this particularly in southern and eastern parts of the Mediterranean basin [Baric and Gasparovic 1990]. At the horizon 2025, for the whole Mediterranean countries, urban population could represent 275 millions people [Plan Bleu, 2000].

The Mediterranean is the preferred destination of one third of the world’s tourists. Tourism is a typical seasonal economic activity with a peak period in May-September. Annually about 120 million tourists visit the Mediterranean coasts for recreational purposes, lands utilised by tourist facilities amount to more than 2 million m^2 and tourist water consumption to about 569 million m^3 [UNEP, 1989a]. Spain, France, Italy and Greece are the major destinations and accommodate about 80 % of the annual tourist flow [Blue Plan, 1998b]. Tourist pressure on the coasts is expected to increase with the number of tourists which according to some estimates could reach 220-350 million by 2025 [Vallega, 1997; Grenon and Batisse, 1989, UNEP/EEA 1999b].

In addition, Mediterranean coasts represent the physical place where many economic activities, such as industry, agriculture, fisheries, aquaculture, port and maritime transport are located. Coastal zones do not provide a large amount of suitable agricultural land but host agriculture of high quality particularly in deltaic areas. Most of the European countries are characterised by extensive market oriented agriculture with typical Mediterranean crops (such as olive and cereals) and good yields [UNEP/EEA, 1999b] whereas more traditional types of agriculture are represented in the southern and eastern regions of the basin [Bindi and Olesen 1999]. Long-term misuse and overexploitation often threaten agricultural yield. Further constraints are represented by poor soils, dry conditions, land degradation and soil erosion. In the southern regions, where some of these conditions are more acute, heavy irrigation is required. Irrigation is an important factor of pressure on surface and groundwater reserves and is estimated to account for 72% of water consumption in the Mediterranean [Blue Plan, 1988a]. The evolution of agricultural land use is marked by a strong north-south contrast. A decrease of agricultural land and an increase of irrigated agricultural lands characterise the north and west part on the basin while the south and east are marked by an increase of agricultural surfaces [UNEP/EEA, 1999a]. In these regions, driven by a strong demographic pressure, agriculture has expanded into marginal and natural areas, reclaiming land which was previously occupied by fragile ecosystems, such as arid steppes and rangelands.

Mediterranean coastal zones are currently experiencing increased pressures due to rapid urbanisation, development of tourist facilities and industries, and overexploitation of marine resources. The most frequent problems resulting from these pressures include coastal erosion, depletion of aquifers, water shortage, salinisation of freshwater systems, desertification, deforestation, loss of wetland and natural habitat, pollution, human-induced subsidence and forest fire.

Figure 13: Increase of the population in the different Mediterranean countries [*Source* : UNEP/EEA, 1999].

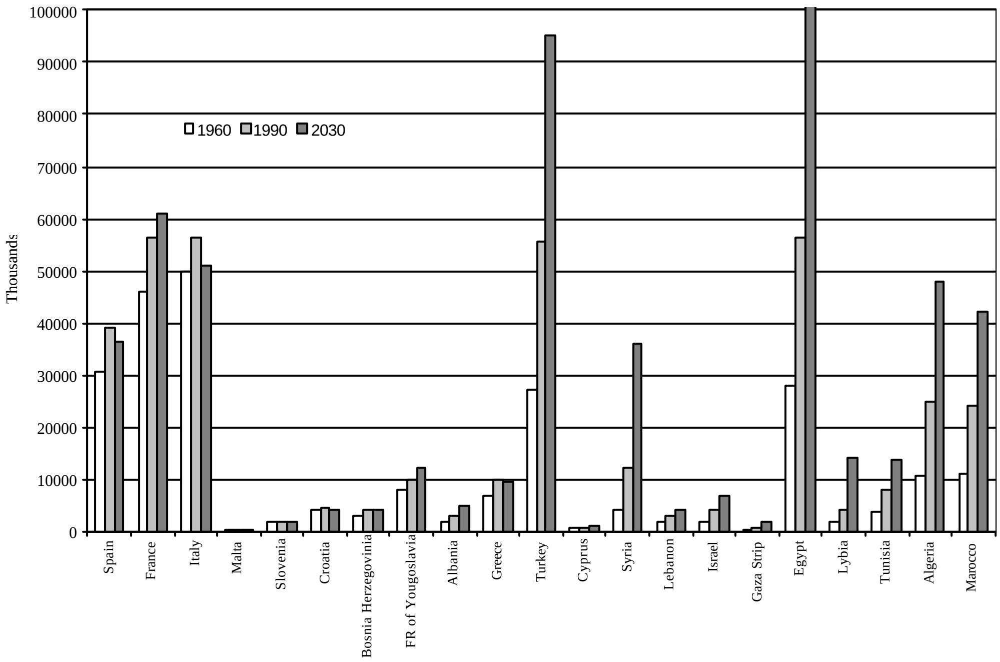
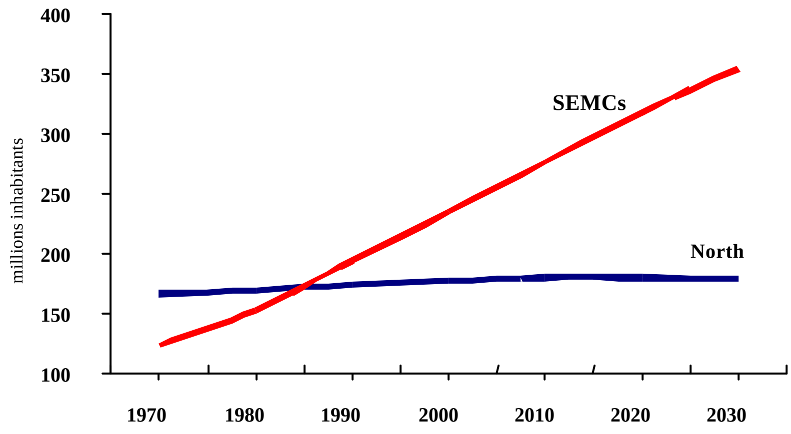


Figure 14: The demography evolution in the Mediterranean countries [*Source* : Allal, 1999]

SEMCs: Southern and eastern Countries



2.2 CLIMATE CHANGE IN THE MEDITERRANEAN BASIN

2.2.1 Past trends of climatic variables and related parameters

The high natural variability of the Mediterranean climate makes difficult the detection of changes in climatic variables and the attribution of their cause. Different studies have attempted to analyse trends of long data series of climatic parameters in the Mediterranean basin, with the aim of assessing whether climate modification is already occurring and whether this modification can be ascribed to human-activities. All parts of Europe seem to have experienced a temperature increase during the last century with some exceptions such as in the case of the eastern Mediterranean where temperature has decreased in the period 1981-1990 [ECSN, 1995]. On the other hand precipitation seem to have decreased in southern Europe. Signals of climate change in terms of surface warming and increase in extreme rainfall events have been recently detected all over the Mediterranean basin [Maracchi *et al.*, 1998]. Piervitali *et al.* [1997] have identified the following variations in the central-western Mediterranean:

- An increase in air pressure at the surface and at the upper levels since 1940 after a period during which this parameter did not change.

- A reduction in cloudiness (by about 1%) and in precipitation (by about 20%) levels during the period 1950-1990. This latter trend agrees with measurements reported by the IPCC [1998[42]] that indicates a reduction in rainfall by as much as 20% over the same area. More recent works [Piervitali *et al.*, 1998; Piervitali *et al.*, 1999] have highlighted that the stronger reduction has occurred in the southern belt[43] of the analysed area (-26%), and that this reduction has been less consistent in the central (-20%) and in the northern (-13%) belts.

- An increase by about 1 °C in surface air temperature during the period 1860-1995 (0.8 °C/ 100 years). This temperature increase is greater than that found at a global scale. Various authors [Jones *et al.*, 1986; Hansen *et al.*, 1987; Vinnikov, 1990] agree on a 0.5 °C/100 years increase of global temperature over the last century. IPCC [1996a][44] has concluded that global surface temperature has increased by about 0.3 to 0.6 °C since the end of the 19th century, and by about 0.2 to 0.3 °C over the last 40 years. The IPCC [1996a][45] has similarly reported that in the central-western Mediterranean the average temperature in the period 1975-1995 was greater than that measured in the period 1955-1975. On the contrary, the comparison of the two average temperatures in the eastern Mediterranean shows a decrease in this parameter.

- Alpine glaciers have retired in altitude by as much as 100-130 meters in the last century [Comitato Nazionale per la lotta contro la desertificazione, 1998]. This trend seems to confirm that climate change has occurred. If Alpine glaciers retirement is attributed to global warming, it is possible to estimate that the temperature has increased by 0.5-0.7 °C in the last century.

- A reduction of strong wind events[46] in the period 1951-1990.

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[42] pp. 156-158

[43] In the studies, the southern belt corresponds to a latitude < 38° N, the central to a latitude included between 38° and 42° N and the northern to a latitude > 42° N.

[44] pp. 141-151

[45] pp. 137-192

[46] In the analysis carried out by Piervitali *et al*. [1997] strong winds are defined as those winds with an intensity greater than 25 knots and a duration greater than 6 hours. In the study, three Mediterranean winds were investigated: the Mistral the Bora, and the Scirocco.

- A reduction of strong cyclogenetic events in the period 1965-1992 and an increase of heat waves in the period 1950-1992. Geeson and Thornes [1996] have also measured an increase in the frequency of heat waves affecting the whole Mediterranean region in the period 1952-1992. Occurrence of other extreme events in the early 90s, such as unusual coldness over the eastern Mediterranean region and extreme drought over much of the Mediterranean, have been linked to the NAO (North Atlantic Oscillation) and partly to the ENSO (El-Niño Southern Oscillation) phenomena [Greenpeace; Hurrell, 1995; Trenberth and Shea, 1997].

Recent trends of sea water temperature and salinity increase have also been reported. In the western Mediterranean basin a significant increase in average deep water temperature and salinity has been observed in the past 30-40 years [Béthoux *et al.* 1990, Béthoux *et al*. 1998]. In particular at a depth of 1000 to 2700 metres the water temperature and salinity have increased by 0.13°C and 0.04 psu[47] respectively (figure 15). Temperature increases twice as high have been recorded as well for the middle water of the Ligurian sea of Nice [Béthoux and Gentili, 1996]. The same temperature and salinity trends have been observed for the Levantine water in the Sicilian channel [Sparnocchia *et al.* 1994]. The causes of such changes, in particular global warming and the reduction of fresh water discharge from Mediterranean rivers are still debated.

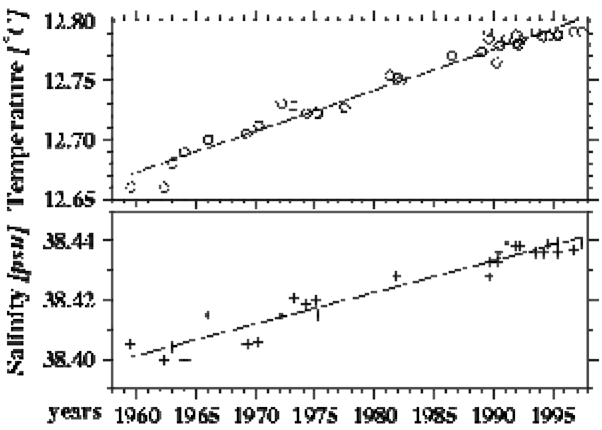
Increase in sea surface temperature may equally have occurred but general trends have not been highlighted. Sea surface temperature records show variations in the last 120 years, but it is difficult to separate seasonal and inter-annual variability from the overall trend of this parameter [Metaxas *et al.*, 1991]. Measures reported by Metaxas *et al*. [1991] for the period 1873-1989 show a minimum around 1910 and a rapid increase until 1940. After this year, the sea surface temperature stabilised until 1960 and decreased until the late 70s (at a global level a continuous increase corresponded to this decrease). A new increase was registered until 1989, when a new maximum (lower than the 1940 one) was reached.

The study of biological indicators can bring useful information for analysing past sea water temperature trends. In particular the analysis of the composition and the distribution of sensitive marine species to temperature changes can give evidence of sea water temperature variations [Sara, 1985]. For instance, recent observations of variations in species richness patterns in the Mediterranean have been attributed to an increase in sea water temperature [Astraldi *et al*, 1995]. Likewise, Francour *et al.* [1994] have observed an increase in the relative abundance of some thermophilic marine flora and fauna species in the north-western Mediterranean waters and have suggested that these changes may be correlated to an increase in sea surface temperature.

Estimates of sea level fluctuations over the past few thousand years are not precise enough to allow the determination of global trends. However, precise specific studies do exist. Holocene (the period covering the last 10 000 years) fluctuations in sea level have been explored through the dating of fossil and coral reefs, and have been successfully interpreted using these paleoclimatic indicators for particular areas [Antonelly *et al.*1999]. Examples of comprehensive studies are those carried out by Bard *et al.*[1996] using Tahiti coral reefs, and Sartoretto *et al.* using submarine coralline alga of the north-western Mediterranean. Mediterranean “substitute reef” indicators have also been recently used (such as Mediterranean gastropods) combined with archaeological data. During the Holocene (figure 16), the most important increase seems to be on the first half part, followed by a significant decrease of sea level rise rate in the late Holocene of about 12-15 cm.

[47] Unity of salinity

Figure 15: Temperature and salinity trends observed in the deep water of the Algero-Provençal basin over the 1959-1997 period. The trends concern the entire deep water from a depth of about 800 m depth [*source:* Béthoux and Gentili, 1996].



Piervitali *et al.* [1997] estimated an average gradual increase of the sea level of about 15 cm over the past 100 years. This estimate is in accordance with the range of 1-2 mm/yr reported by various studies (table 5). Nicholls and Hoozemans [1996] reported the following sea level trends for three sites of the Northwest Mediterranean: 1.1 mm/yr for Trieste (figure 17) [Carbognin L., and Taroni G., 1996], 1.2 mm/yr for Genoa and 1.2 mm/yr for Marseilles. In some specific areas the relative sea level rise has been less consistent (e.g. in the eastern Mediterranean as a consequence of tectonic uplift) or more significant (e.g. in Venice, as a consequence of natural and human-induced subsidence, the average sea level rise rate has been 2.5 mm/y; see figure 17) as results of local natural and human-induced factors. The analysis of satellite data provides a new way to monitor the changes in the mean level of the Mediterranean. Analyses of the altimetric remote sensing data of Topex/Poseidon have shown unexpected seasonal variation of the Mediterranean sea level, with an average summer-winter difference of about 20 cm (figure 18). The signal is related to the steric effect of water surface (phenomenon of concentration and dilatation), to seasonal imbalance of the Gibraltar incoming and outgoing flows and to phenomenon of evaporation/precipitation [Le traon *et al*, 1996].

Figure 16: sea level rise in the Mediterranean region over the past 10 000years [*source*: Pirazzoli, 1991, Antonielli *et al*.1999].

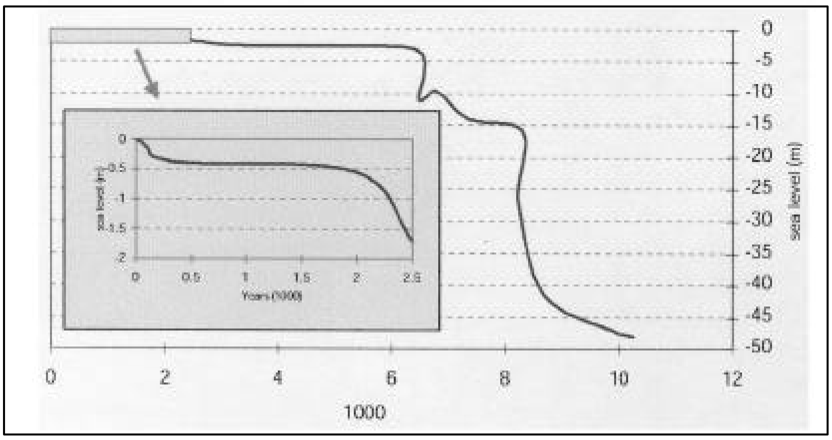


Figure 17: Sea level trend at Venice and Trieste in the period 1896-1996. Sea level refers to the average tide level of 1897 measured at Punta della Salute in Venice [*source*: Carbognin, L., and Taroni G., 1996].

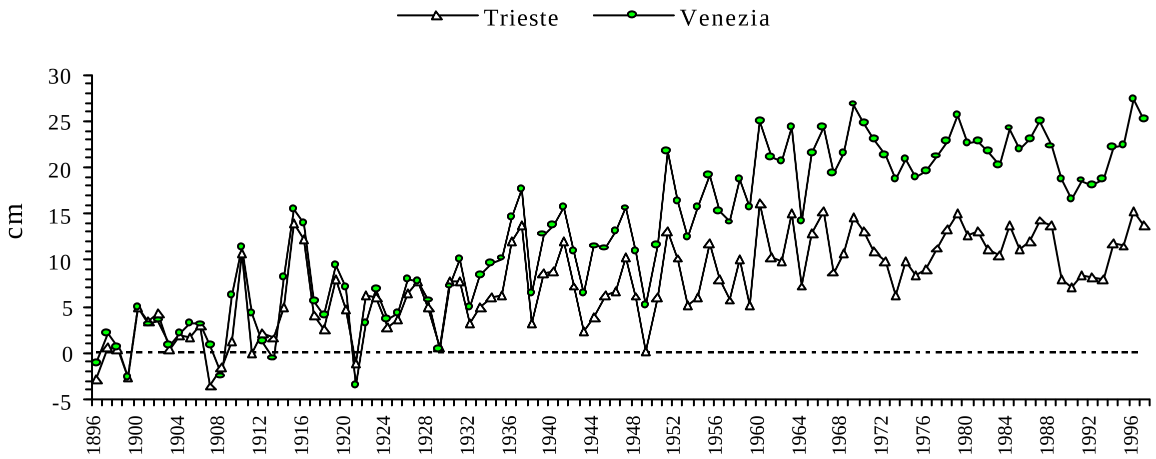
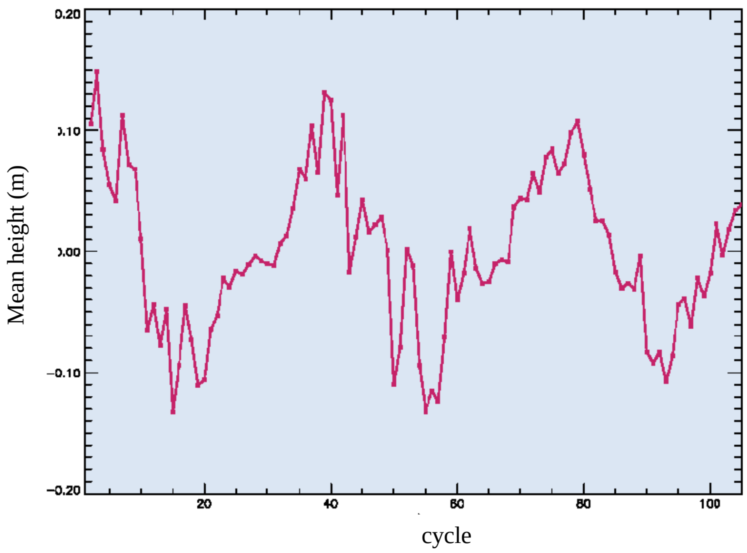


Figure 18 : Mean sea level (in m) in the Mediterranean, October 1992 to August 1995 (Topex/Poseidon cycles 2 to 106) [*source*: Le traon *et al.*, 1996].



Due to high natural variability and the short period of observations, researchers generally highlight the difficulties in identifying clear trends representing climate change at a regional scale. Natural variability can mask the potential influence of global warming on climatic factors. Wigley [1992] has noted that in the period 1947-1986 the whole Mediterranean basin has experienced a decrease in temperature. This has been attributed to the natural variability of the climatic system and to 'anomalies'[48] which are also expected to affect the global warming pattern in the future. Moreover, the influence of human activities (such as urbanisation, deforestation or irrigation) on the local-regional climate system can mask, mitigate and accentuate the effects of global warming. The continuous measurement of significant climate and related variables, in combination with modelling of past trends, assumes a relevant role in detecting the causes of the observed changes and the occurrence of human-induced modification of climatic condition, also at the regional scale.

[48] Defined by Wigley as "*departures from greenhouse effect expectations*"

Table 5: Estimates of regional sea level rise rate for the 20th century reported by different authors.

Source	Region	Sea level rise. (mm/year)
Shennan and Woodworth [1992]	North-western Europe	1.0 ± 0.15
Milliman [1992]	Mediterranean basin	1-2
Piervitali *et al.* [1997]	Central and western Mediterranean	1.5
Nicholls and Hoozemans [1996]	Genoa (1930-1992)	1.2
Zerbini *et al.*, [1996]	Genoa (1884-1988)	1.3
Nicholls and Hoozemans [1996]	Marseilles (1885-1992)	1.2
Zerbini *et al.*, [1996]	Marseilles (1885-1989)	1.1

2.2.2 Future projections for the Mediterranean

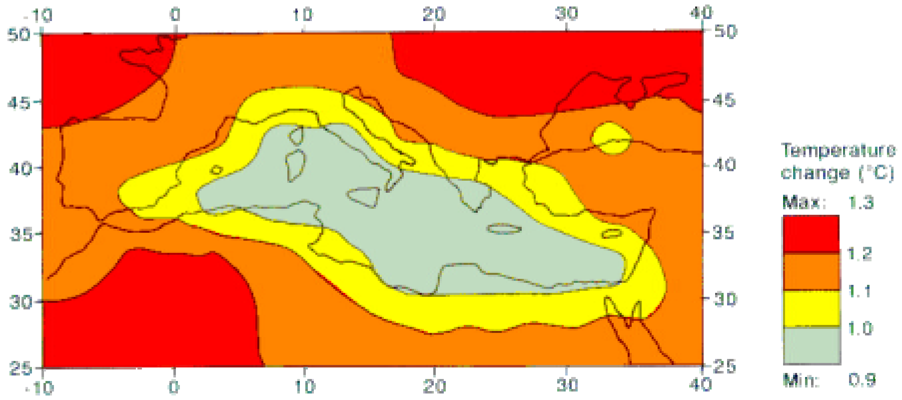
The reliability of projections decreases generally when we move from the global to the regional and further to the local scale. The problem for the Mediterranean lies in the fact that marked regional differences in the rate of change are expected at different locations and that a wide disagreement exists between patterns of change projected by various models. In the following section general trends in the projections of Mediterranean future climate will be identified.

Global Circulation Models (GCMs) have been widely used to examine climate changes and to construct climate scenarios over the Mediterranean basin (figure 18) [Palutikof *et al.*, 1996]. The IPCC [1990, 1992] developed a climate change scenario for Southern Europe and Turkey, using three GCMs and equilibrium-mode experiments[49]. The scenarios projected a warming of 2 °C in winter and 2-3 °C during summer by the year 2030 and suggested a small average increase in precipitation in winter and a decrease in summer (5-15%) as well as a decrease in summer soil moisture of about 15-25%. Rosenzweig *et al.* (1997) have reported for the Mediterranean a change of the same order with a temperature increase of 1.4-2.6 °C by the year 2020. It is important to note that above scenarios have not taken into consideration the cooling effect due to aerosols which can, at least in some regions, partially compensate for the warming effect caused by the increase in greenhouse gases concentrations. Mitchell *et al*. (1995) have suggested that aerosols may reduce warming over the Mediterranean region by 1-2 °C over a period from 1795 to 2030-2050. In the short term aerosols can also partially influence the effects of climate change on precipitation, evapotranspiration and soil moisture. In any case, the role of these particles is still unclear and probably over-estimated, as discussed in the first chapter.

[49] In equilibrium mode experiments, models are run with two different atmospheric CO_2 concentrations. Firstly, pre-industrial CO_2 concentration is used. Successively the model is run with doubled (or sometimes quadrupled) CO_2 concentration. The results generated by the model in the two different modes are compared in order to quantify the perturbation of climatic conditions due to the doubling of the CO_2 concentration. Equilibrium mode experiments do not take time-dependent effects into consideration, such as the effect of the thermal inertia of oceans, which can initially slow down the warming process of the atmosphere, or variation in the radiative forcing of greenhouse gases and aerosols. This means that, among other things, the climate changes predicted by equilibrium mode models will not actually occur by the year when doubling of CO_2 concentration is expected. There will be a delay in the manifestation of the climate changes, whose magnitude depends on various factors, such as properties of ocean heat transport.

Palutikof *et al*. [1992] have developed a regional scenario for the Mediterranean, interpolating and aggregating the results generated by four GCMs[50]. The predicted average increase in temperature spatially varies between 0.9 and 1.3 °C/°C global warming (Figure 18). These projections are expressed as change per 1°C global mean temperature increase in order to avoid the problem of the different sensitivities of the models. According to this scenario the least increase is expected to occur over the Mediterranean sea and the coasts of the Western Italy, Greece and North Africa. Elsewhere, the projected temperature increase exceeds 1 °C/°C global warming. When the Wigley and Raper's [1992] global temperature projections[51] are applied to the scenario previously described, the temperature increase in the Mediterranean basin is estimated to vary between 1.5 and 3.4 °C by the year 2100 over the Mediterranean sea and between 2.2 and 4.9 °C in the north-east region of the basin [Palutikof *et al*. 1996].

Figure 18: Scenarios of changes in average annual temperature (changes are expressed as variation in °C per an unitary global temperature increase) obtained through equilibrium mode GCM experiments [*source*: Palutikof and Wigley, 1995].



Recent results from the Hadley Centre Model indicate that the Mediterranean will experience a probable warming of 2 °C in the next 50 years [Gregory *et al*., 1997]. This increase, according to Piervitali and his collaborators could reach 2-3 °C in the next 100 years over the Mediterranean basin with greatest temperature increase in summer over land regions and particularly on Northwest Africa and Eastern Turkey [Piervitali *et al.* 1997].

Precipitation changes are more difficult to predict than temperature variations and projections are generally considered less reliable [Palutikof *et al*., 1996]. It is generally accepted that precipitation will decrease in the southern Mediterranean region (south of latitude 40-45° N) and will increase in the northern Mediterranean region [Cubasch *et al*., 1996; Barrow *et al*., 1995; Palutikof *et al*., 1996]. Palutikof *et al*. [1992] have projected an increase in winter precipitation of 10% and a decrease in summer precipitation of 10% by the year 2100 over the Mediterranean. Similar patterns (an increase of up to 10% in winter precipitation and a decrease of 5 to 15% in summer precipitation) have been projected by the IPCC [1996a][52] for Southern Europe and Turkey. In

[50] The four GCMs are: GFDL, Geophysical Fluid Dynamic Laboratory [Wetherald et al, 1986]; GISS, Goddard Institute of Space Studies [Hansen *et al*., 1984]; OSU, Oregon State University [Schlesinger *et al*., 1989]; and UKMO, UK Meteorological Office [Wilson *et al*., 1987].
[51] These projections have been calculated taking the ozone-depletion feedback and the aerosols cooling effect into consideration. They foresee, for the IS92a scenario developed by the IPCC [1992], an increase in temperature during the period 1990-2100 ranging between 1.7-3.8 °C.
[52] pp. 289-357

addition Piervitali *et al.* [1997, 1998a; 1998b] have observed that a decrease in precipitation is already occurring in the western-central Mediterranean basin. The authors have projected a further reduction of precipitation in the same area, amounting to –18% (respect to the 1951-1980 reference mean) in 2010 and –24% in 2030. They have also considered that soil moisture reduction could occur when taking into account a simultaneous increase in temperature.

Moisture availability is determined by the balance between precipitation and water loss due to evapotranspiration and runoff. Even where precipitation is expected to increase, moisture availability can decrease if higher temperature and increased runoff produce a negative water balance. Jeftic *et al.* [1996b] have reported that potential evapotranspiration is likely to increase throughout the Mediterranean and consequently, a negative change in the ratio of rainfall to potential evapotranspiration could occur. According to the IPCC [1996a][53] summer moisture availability in Southern Europe and Turkey is expected to decrease by 15 to 25%. The greatest change could occur in spring and autumn in Italian mainland and over Sardinia and Corsica [Palutikof *et al*. 1994]. As a consequence of a reduction in moisture availability, aridity may increase in turn and desertification may affect many areas of southern Mediterranean regions up to Sicily, Calabria and Puglia [Piervitali *et al*., 1997; 1998; 1999].

In addition, authors suggest that the frequency of exceptional events of drought, flood, rainfall, marine storm, tidal surge and eutrophication may increase [Jeftic *et al.* [1996b]. Due to warmer conditions it is also likely that the occurrence of extremely high temperatures will increase. Areas experiencing a decrease in precipitation are likely to be affected by more frequent droughts and longer dry spells. The IPCC [1996a][54] has reported that the doubling of CO_2 concentration could increase the probability of dry spells lasting more than 30 days in summer in southern Europe by a factor varying between two and five, although the mean precipitation would decrease by only 22%.

Statistical downscaling methods and regional climate change scenarios in the Mediterranean

The spatial resolution of global climate models' (GCMs) is relatively coarse (generally 300 km for the current generation) and GCMs' reliability decreases moving from the global, to the regional and the local scale and moving from the annual, to the monthly and the daily scale. GCMs are not able to represent regional and local climate patterns in a precise manner. Therefore analyses of impacts generally require regional climate scenarios and a finer spatial and temporal resolution. Different research groups have been developing methods, such as downscaling which permit the generation of reliable regional and local scenarios. Von Storch et al [1993] defined technique of downscaling as "*sensibly projecting the large scale information on the regional scale*" and used this method to obtain finer resolution scenarios for the Iberian Peninsula. These scenarios can constitute the basis for the assessment of regional and local climate change impacts and for the development of possible solutions, policies and measures for their mitigation. Various downscaling methods have been recently developed (e.g. Wilby, [1998], Goodess and Palutikof [1998]) and are the object of on-going relevant researches. The statistical downscaling method requires the identification of relationships between the observed variables describing large-scale and regional climate which are then applied to large-scale GCM output [Goodess and Palutikof 1998]. Figure 19 reports an example of average temperature change scenario obtained using a statistical downscaling method. The resolution of this scenario is greater than that characterising the scenario presented in figure 18 and therefore the produced pattern is more precise. Recently statistical downscaling procedures were used by the Climatic Research Unit of the University of East Anglia (CRU/UEA) in the EU-funded MEDALUS project (MEDALUS III) in order to construct temperature and precipitation

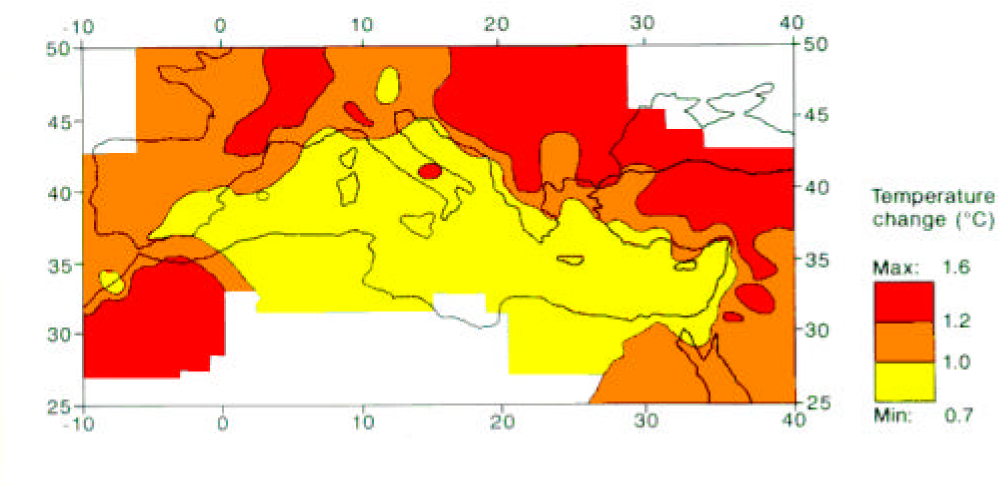
[53] pp. 289-357
[54] p. 336

scenarios for the whole basin. In this purpose, two different approaches have been developed providing with relevant qualitative and quantitative projections [Goodess C., Palutikof J., and Agnew M., 1999].

The fist approach aims at developing scenarios based on Geographical Information System (GIS) in order to map observed seasonal means of temperature and precipitation using spatial information such as height above sea level, distance to the sea and latitude/longitude (e.g Goodess C., Palutikof J., and Agnew M., [1999]). The GIS based technique allows to interpolate spatially climate data from point sources in order to cover the whole Mediterranean region and to produce seasonal scenarios with high resolution (about 1km). Scenarios have been developed for the period 2030-39 and 2090-99 [Palutikof, *et al*., 1999]. The main results are synthesised in the following:

- The average increase of annual surface temperatures for the whole basin is 1.1°C for the 2030-39 scenarios rising to 3.6°C for the 2090-99.
- The greatest warming will affect the Southwest Mediterranean (from the Iberia Peninsula to Northern Africa) with an increase in annual temperature of 3.6-4 °C by 2090-99.
- Annual precipitation changes are likely to be not very significant. A general decrease of 1.6 mm is projected. However substantial seasonal and spatial variations are expected.
- Winter precipitation by 2090-99 is expected to decrease in the Eastern part of the basin (especially Greece and Turkey) and to increase in the western region.
- Spring pattern shows a precipitation increase in most areas expect for the western region (from France to Algeria) and the south-east corner of the basin (Greece and Turkey) for 2090s.
- General drying out will be characteristic of summer and autumn by 2090-99. Drier summer regions would include the Eastern Spain, Eastern Adriatic corner and the heel zone of Italy, with a severe decrease in seasonal precipitation of 12 mm from 1952-89 to 2090-99. The most severe precipitation reduction in autumns is projected to occur in Sardinia and Algeria with a decrease of up to 33 mm per month.

Figure 19: Scenario for the Mediterranean annual temperature change obtained through statistical downscaling based on the interpolation of measures of a network of 248 meteorological stations. Changes are expressed as variation in °C per an unitary global temperature increase [*source*: Palutikof and Wigley, 1996].



In the second approach, sub-grid scale scenarios have been generated by combining the output from four GCMs using the methods describe by Palutikof and Wigley [1996][55]. These scenarios are

[55] More detailed information on downscaling techniques are contained in Palutikof *et al*. [1997], Winkler *et al*., [1997]

expressed as change per 1°C global mean temperature increase. Annual and seasonal sub-grid scenarios of mean temperature and precipitation changes for the Mediterranean have been constructed for the periods 1990-1999, 2030-2039, and 2090-99 [Palutikof, *et al.*, 1999]. The main results are:

- Annual temperatures are expected to increase in all regions of the basin by 2030 and 2099. The greatest increase would occur in summer over land region (former Yugoslavia, northern Africa, and eastern corner of the basin). For the former Yugoslavia the temperature increase will be in the order of 1.6°C per °C global mean temperature (gmt) by 2099. The lower increase would occur in winter.
- Predicted changes in precipitation are less homogeneous and vary between seasons and regions.
- As a general trend, increase in precipitation by 2099 is expected in autumn and winter over north Africa (20-30% for per °C gmt), in summer over Northern Adriatic, Northeast Africa and Turkey and in spring over Spain. Decrease in precipitation could occur in spring over the central Mediterranean (around 20% per °C gmt), in summer over Europe and the central Mediterranean, and autumn over a large part of the basin.

Both approaches project a temperature increase annually and seasonally for all areas. The higher increase is expected in summer over land areas. Regions susceptible to experience higher increase include North Africa, eastern basin (Greece and Turkey) and former Yugoslavia. As regards precipitation, it is more difficult to identify a general trends as precipitation patterns are more variables and shows marked seasonal contrasts. Nevertheless, annual precipitation is expected to decrease slightly in most of the regions.

Narrowing projections down to local scale, specific relevant scenarios have been developed in the Mediterranean Action Plan (MAP site-specific studies, see 3.2.3) by the CRU/UEA. Statistical downscaling procedure has been used for 5 coastal areas. Local scenarios permit only to provide a qualitative indication of changes in climatic variables as a response of an increase of greenhouse gases and aerosols concentrations, by means of sensitivity classes. Sensitivity depends on very local and variable factors. Results of these local scenarios are reported in tables 6 and 7, and are largely heterogeneous, making impossible the identification of local trends.

Table 6: Temperature sensitivity to a change in global mean temperature in five Mediterranean sites [*source*: Palutikof *et al.*, 1996].

	Annual	**Winter**	**Spring**	**Summer**	**Autumn**
Rhodes Greece	<<	<<	<<	>	<<
Kastela Bay Croatia	<	<<	<	<	<
Syrian coast Syria	=	>	<	>	>>
Maltese islands Malta	<	<	<	>	<
Cres-Losinj Croatia	=	<	>	>>	>

<< very low sensitivity
< low sensitivity
= sensitivity approximately equal to global
> high sensitivity
>> very high sensitivity

and Goodess and Palutikof [1998].

Table 7: Probable direction of variation in rainfall variation as a consequence of global warming [*source*: Palutikof *et al*, 1996].

	Annual	***Winter***	***spring***	***Summer***	***Autumn***
Rhodes Greece	N/A	Increase	increase	Increase	Increase
Kastela Bay Croatia	Increase	Increase	increase	Increase	Decrease
Syrian coast Syria	Decrease	Increase	no change	Decrease	Decrease
Maltese islands Malta	no change	Decrease	decrease	N/A	Increase
Cres-Losinj Croatia	no change	Increase	increase	Decrease	Decrease

N/A not available

III IMPACTS OF CLIMATE CHANGE

3.1 VULNERABILITY, SENSITIVITY AND ADAPTABILITY OF NATURAL AND HUMAN SYSTEMS

The quantitative assessment of climate change impacts is generally a complex task. Uncertainty associated with the projections of changes in climate related parameters, on which impacts analysis are based on, represents a major constraint. Other constraints are exerted by (1) the difficulty in modelling the relationship between potential variations in climatic factors and resulting impacts (2) the complexity of the affected systems and (3) the incomplete understanding of ecological processes which come into play. In addition most systems are sensitive to both the rate and the magnitude of climate change. In order to facilitate the quantitative approach to impacts studies, the IPCC has introduced the concepts of vulnerability, sensitivity and adaptability.

Vulnerability can be defined as the *"extent to which climate change may damage or harm a system"*[IPCC 1996b][56]. It is directly related to the system's sensitivity and to its capability to adapt to changed conditions. The most vulnerable systems are those with a great sensitivity to climate change and a low adaptability. Sensitivity is *"the degree to which a system will respond to a change in climatic conditions"*, for example the extent of the variation in the composition, structure and functioning of an ecosystem undergoing a temperature or precipitation change. Adaptability refers to *"the degree to which adjustments are possible in practices, processes or structures of systems to projected or actual changes of climate"*. Adjustments can be spontaneous or planned, reactive or anticipatory, even if planned and anticipatory options are not possible for all systems. Adaptations may reduce negative impacts and in some cases can even enable some systems to take advantage of the new conditions induced by climate changes. Human-induced stresses and non-sustainable management options can greatly influence the vulnerability, sensitivity and adaptability of a system. In addition, the economic and institutional context influences the capacity of the system to adopt suitable responses to climate change. Developing countries are generally very vulnerable to climate change both because of the less favourable economic and institutional situation and because of the many human-induced problems affecting them. Vulnerability assessment must therefore consider the influence of human-induced stresses and the socio-economic context of affected system.

[56] pp. 23-24

3.2 Climate change impacts on coastal zones in the Mediterranean

Coastal zones are commonly the geographical space of transition between land and sea, encompassing shoreline environments as well as adjacent coastal waters. They include many diverse systems such as river deltas, estuaries, tidal wetlands, lagoons, small islands, low-lying coastal plains, sandy beaches, and sedimentary coasts. The limits of coastal zone boundaries are often defined arbitrarily and differ among nations. Coastal zones are inherently dynamic systems, characterised by interacting morphological, ecological and socio-economic processes. Some general features distinguish them from any other systems [IPCC, 1996b][57]:

- A high rate of dynamic changes in the natural environment;
- A high biological productivity and diversity;
- A high rate of human population growth and economic development;
- A high rate of degradation of natural resources;
- Exposure to natural hazards such as cyclones and severe storms;
- The need for management regimes that address both terrestrial and marine issues.

Coastal zones provide natural resources and suitable space for economic activities and human settlements, leading to high concentration rate of population. It is estimated that 50-70% of the global human population currently lives in coastal zones. Climate change is likely to alter coastal zone dynamic by acting on each of its components causing linked and mutually coupled effects [Klein and Nicholls, 1998]. Coastal zones will be especially affected by sea-level rise and changes in temperature and precipitation patterns, as well as by possible variation in the frequency, distribution and intensity of extreme events such as cyclones and storm surges. Climate changes will have a distinct regional character and impacts on different coastal zones will vary from region to region, depending on environmental, social, cultural and economic conditions. Likewise relative sea level changes at regional and local scales may differ from the global mean sea level according to land movements (due to tectonic and volcanic activity, subsidence, sediment depletion and erosion), hydrological processes (such as variation in currents, water density, water exchanges between the Mediterranean and the Atlantic ocean) and climatic factors (such as atmospheric pressure and the wind patterns).

The Mediterranean basin is widely recognised as particularly vulnerable to climate changes [Jeftic *et al.*, 1992; Hoozemans *et al.*, 1993; Nicholls *et al.*, 1996]. Most of current stresses linked to the effects of high human pressures are expected to be exacerbated by climate change. As a general rule, most damaging impacts will be on Mediterranean coastal systems already under stress and where human activities have diminished natural and socio-economic adaptive capacities.

Only a relatively limited number of studies have analysed the vulnerability of the Mediterranean basin in the light of climate change and sea level rise impacts. Consequently, these issues have rarely been considered in coastal planning and management. As highlighted by There is no universally applicable methodologies for the assessment of the impacts of future climate changes and the identification of the vulnerability of a system [Georgas, 1999]. In addition, contrasts in relief, geology, climate and in human activity rates are so marked on the Mediterranean basin that accurate estimates of the impact could be possible only by narrowing down to the very local level. Some coastal systems, such as deltas [Capobianco, 1996a; Corre, 1992; El-Raey *et al.*, 1995; Marino, 1992; Sestini, 1992a, 1992b; Sanchez-Arcilla *et al.*, 1996; Jimenez *et al.*, 1997; Sanchez-Arcilla *et al.*, 1997] have been subjects of particular attention. Notwithstanding this partial limitation, it is possible to analyse the main impacts of climate change on Mediterranean coastal zones on the basis of studies similar to those conducted by UNEP [UNEP, 1989b, Georgas,1999] or

[57] pp. 293

by Nicholls and Hoozemans [1996]. In the present paper biogeophysical and socio-economic impacts will be treated in two different sections.

3.2.1 Biogeophysical impacts

According to Klein and Nicholls [1998] the six more important biogeophysical impacts induced by climate changes on coastal zones are: (1) erosion and sediment deficit, (2) increased flood frequency, (3) inundation of low-lying areas, (4) rising of water tables, (5) saltwater intrusion and (6) consequent biological effects. Due to their significant socio-economic implications, inundation and increased flood frequency will be treated in the socio-economic impacts section, rather than in the biogeophysical impacts one. The enhancement of the desertification process and the related soil degradation is another relevant impact which is already an environmental stress of concern for various Mediterranean regions.

Coastal erosion, sediment deficit and land loss

Coastal erosion is often the result of the combination of natural processes and human intervention. The rise in sea level is likely to increase coastal erosion processes and to affect particularly sandy shorelines. About 20% of the world's coastlines are sandy and according to Bird [1993] about 70% of these coasts have been eroded over the last 100 years. Sedimentary coasts including sandy beaches, dune systems and wetlands represent 46% of the Mediterranean coasts that is the equivalent of around 21,000 km and are highly vulnerable to erosion. The increase of current erosion processes will undoubtedly be the most severe impact of climate change on Mediterranean sandy shores. It has been estimated that around one fifth of the Mediterranean coastal zones are presently affected by coastal erosion [Corine Coastal Erosion Atlas, 1998] and that about 25 % of the Italian Adriatic coast already show erosion trends (figure 20) [UNEP/EEA 1999b]. The shoreline retreat (using the Bruun Rule[58]) according to ACACIA scenarios for Europe could range between 25 m to 110 m in most of European countries by 2080s [ACACIA, 1999].

Mediterranean coastal wetlands are expected to suffer particularly from sea level changes. It has been estimated that a 1 m rise in sea level would harm half of the world's coastal wetlands that have international importance (according to the criteria established by the Ramsar Wetland Convention [1971]). The potential wetland loss in Europe has been assessed by the ACACIA[59] project using the wetland loss model described by Nicholls *et al*. [1999]. According to the most pessimist scenario the wetland loss due to sea level rise for the EU Mediterranean countries could be nearly total by 2080s (figure 21). The high vulnerability of Mediterranean wetlands is due to the low tidal range which determine the potential capacity for wetland vertical accretion and the high human activity rate which reduce the capacity of horizontal migration (inland migration). The limited tidal range of the Mediterranean sea restricts the vertical range of wetlands and their ability to cope with sea level rise by means of vertical accretion [Stevenson *et al.*, 1986]. On the other hand, infrastructures, urbanised areas and protection works such as barriers, bulkheads or levees can represent constraints to inland migration. The ability of wetlands to cope with climate change impacts requires that sedimentation keep pace with these changes and that sea level rise occurs at a rate which allows the system to adapt.

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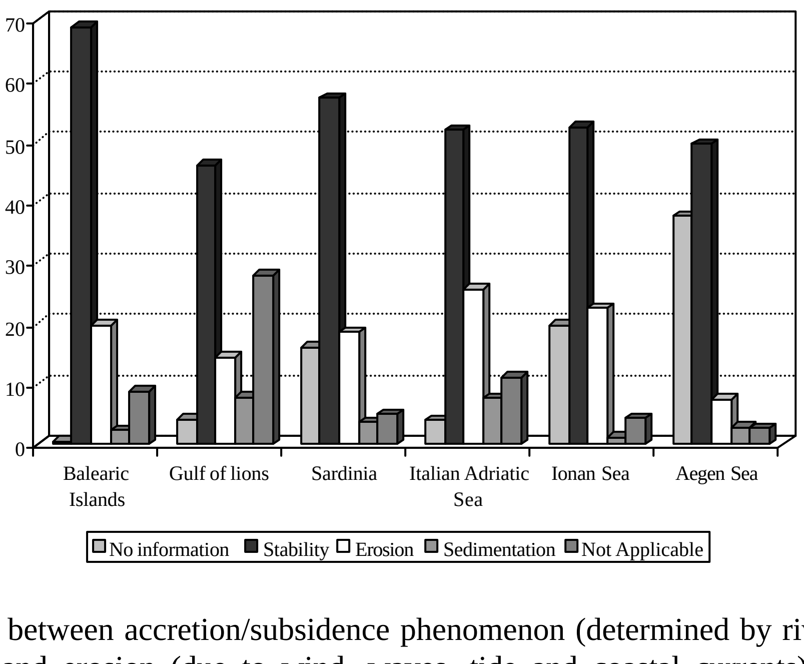
[58] According to the Bruun Rule, the magnitude of shoreline retreat corresponds to 100 times the sea level rise.

[59] ACACIA (A Consortium for the Application of Climate Impact Assessments) is public/private sector program; more information can be found at http://www.cgd.ucar.edu/cas/ACACIA/

Qualitative impacts of sea level rise on the Venice lagoon in Italy have been assessed, anticipating that part of the salt marsh system will suffer a consistent loss in extension [Cecconi, 1996]. Salt marshes located in the central lagoon have already been affected by strong erosion and reduced accretion. Climate change and sea level rise are likely to lead to the complete disappearance of these salt marshes over the next 30-50 years if natural and artificial adaptive responses are not implemented. According to the *Consorzio Venezia Nuova* (CNV) [1997] an increase in sea level could affect the lagoon ecosystem through various impacts:

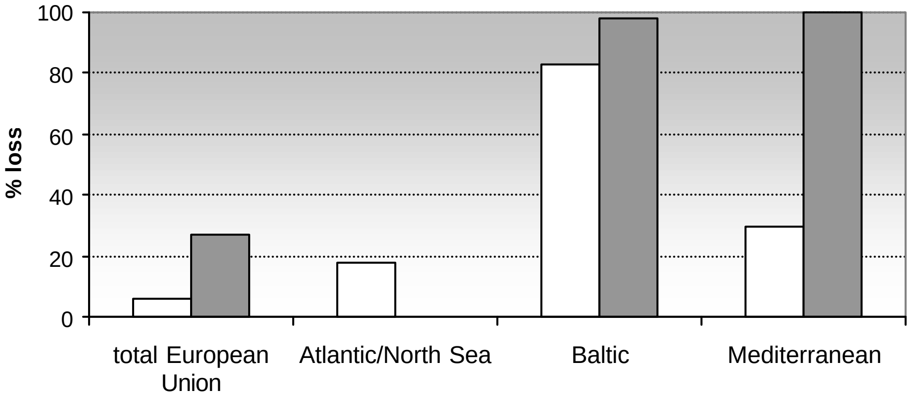
- An increase in the volume of water contained in the lagoon and a less consistent increase in the water exchange with the sea, which could lead to a reduction of the mean daily water recycling ratio;
- An increase in mean wave height due to the wind, as a consequence of greater water depth. This could strongly increase the erosion process of typical lagoon morphologies (shallows, mudflats, salt-marshes);
- Reduced oxygenation of the bottom water as a result of the increase in lagoon water level. The same factor could contribute to causing greater dilution of the pollutants generated by the drainage basin and a greater vivification of the lagoon;
- An increase in mean salinity and a modification of the mean temperature of the lagoon as a consequence of greater exchange with the sea. These two effects are likely to influence the composition and distribution of the animal and vegetation communities of this ecosystem;
- Submersion of part of the lagoon land system, with consequent loss of habitats for animal and plants;
- Increased erosion of shores.

Figure 20: Evolutionary trends of some coasts of the European part of the Mediterranean Sea for both rocky coasts and beaches as % of coasts [*adapted from* EC, 1998].



The interaction between accretion/subsidence phenomenon (determined by rivers and sea sediment transportation) and erosion (due to wind, waves, tide and coastal currents) generally drives the morphology of wetlands and deltaic systems in particular. Mediterranean deltas are inherently fragile zones threatened by erosion and human activities (table 8 and 9) and reflect the high Mediterranean vulnerability to sea level rise. The increase in sea level is likely to modify the morphology of deltas producing local submergence of lower lying areas, erosion increase and would particularly affect areas of low sediment supply.

Figure 21: Range of wetland losses due to sea level rise by 2080s according to ACACIA scenarios. Given the range of uncertainties a high loss estimate (grey) and low loss estimate (white) have been determined [*source*: ACACIA, 1999].



The risk is particularly high for the more important deltas the Nile, the Rhone, the Po and the Ebro which have already been subjected to erosion and shoreline retreat. These problems result both from the aggression from the sea side (due to waves, storms surges and flooding) and the reduction of sediment flow from inland areas due to natural processes and human intervention (construction of dams and dikes, excavation of canals, habitat destruction and river sediment mining).

Table 8: Major sources/causes of the present problems in the major Mediterranean deltas [*source*: Jeftic *et al.*, 1996b].

	Ebro	Rhone	Po	Nile
drought	L	L	L	M
floods and storms	M	H	H	H
change in relative sea level	M	M	H	M
reduction in river discharges	H	H	H	H
depletion/salinisation of aquifers	L	L	H	H
pollution	M	H	H	H
poorly planned development	L	L	M	H
pressure of coastal population	L	L	H	H
pressure of tourism	L	M	H	H
pressure of industry	L	M	H	H
pressure of urban development	L	L	H	H
coastal erosion	H	M	H	H

L = low; M = medium; H = high

The Nile delta and the adjacent areas have been subject of particular attention, and are characteristic of a high vulnerability to climate change due to natural conditions and human intervention [Milliman *et al.*, 1989; Jeftic *et al.*, 1992; El-Raey, 1998]. Egypt is widely dependant on resources from the Nile river and delta, in particular for water resources (90% come from the Nile). Human interventions have completely modified the natural annual cycle of the Nile, the water flow and sediment discharge [Stanley *et al.*, 1993]. The construction of the large dams[60] and the increasing regulation of the Nile have actually de-coupled the delta from the river system [Stanley, 1990]. According to Stanley's studies, as a consequence of the dramatic reduction in transportation of

[60] The construction of the Low Aswan Dam in 1902 and its successive modifications in 1912 and 1934 as well as the building of the High Aswan Dam (1964),

fluvial sediments to the coasts, the Nile can no longer be considered an active delta. It is rather a wave-dominated coastal plain along the Mediterranean coast, subjected to erosion by waves and currents. In addition, overexploitation of the Nile water for irrigation purposes seriously hinders freshwater from reaching the sea. Other negative impacts which can be attributed to the profound modification of the natural cycle of the Nile flow and sediment discharge are: marine intrusion into low-lying areas of the northern delta, curtailment of flood silt deposits that formerly served as natural fertilisers and also offset subsidence, increased soil salinisation, and decline in fish populations as a result of a decrease in fluvial transportation of nutrients to the coast and the lagoons [Stanley *et al.*, 1993].

Table 9: Systems and processes under stress at the present in the major Mediterranean deltas [*source*: Jeftic *et al.*, 1996b].

	Ebro	**Rhone**	**Po**	**Nile**
shoreline dynamics	H	H	L	M
soil erosion	L	L	L	L
aquaculture/fishery	L	L	M	H
agriculture	M	M	L	L
forest fires	L	L	L	L
urban sanitation	L	L	M	H
drinking water supply	L	L	M	H
historic settlements	L	L	H	L
coastal structures	L	M	H	M

L = low; M = medium; H = high

The potential sea level rise could therefore have dramatic consequences. It has been estimated [Khafagy *et al.* 1992] that in the Nile delta a 1 m sea level rise could lead to:

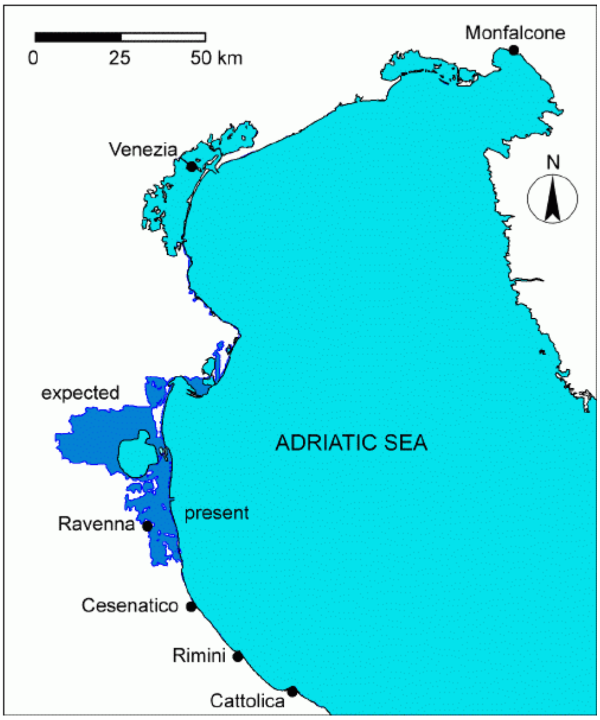
- the inundation of about 2000 km^2 of land in coastal areas;
- a substantial erosion of the deltaic area, possibly leading to land losses of as much as 100 km^2;
- the loss of about 1,000 km^2 (very rough estimate) of agricultural land;
- severe problems of saltwater intrusions and drainage capacity reduction

Similarly to the Nile delta, the Ebro, Po and Rhone deltas have also been profoundly modified and suffer from sediment deficit as a consequence of human-induced changes in their catchment areas. The Ebro is the delta which has experienced the greatest reduction (96%) in its sediment supply [Sanchez-Arcilla *et al.*, 1996]. Locally natural and human-induced subsidence have contributed to determining a high relative sea level rise. Some areas of these deltas therefore already lie below sea level and are protected from inundation by defensive structures. In the case of Po delta, the subsidence locally reached the exceptional value of 30 cm/y and produced a lowering of the land by almost 3.5 m between 1958 and 1967 in the inner part of this system [Caputo *et al*. 1970; Sestini 1992a]. Recent data have shown a stabilisation of subsidence in the Po delta at values lower than 2-3 mm/y but potential sea level rise could contribute to the permanent submersion of a surface area ranging from 690 km2 to 910 km2 by 2100 (table 10). Figure 22 represents the potential regression of the coastline by the year 2100 as a consequence of sea level rise induced by climate change and the pessimistic subsidence scenario. According to the figure the most vulnerable area appears to be that between Ravenna and the Po delta.

Table 10: Surface area of the zones permanently submerged in the Northern Adriatic as a consequence of sea level rise caused by global warming and two subsidence scenarios (optimistic and pessimistic) by the year 2050 and 2100. The area considered in the analysis is the coastal strip between the locality of Monfalcone and Cattolica. Other local studies were conducted in the zones of Rimini, Ravenna and Cesenatico [*source*: Gonella *et al*. 1997].

	Optimistic subsidence scenario		*Pessimistic subsidence scenario*	
Year	2050	2100	2050	2100
Surface area (km^2)	65	690	600	910

Figure 22: Potential regression of the Northern Adriatic coastline by 2100 as a consequence of sea level rise induced by climate change and the pessimistic subsidence scenario [*source*: Gonella *et al*. 1997].



Saltwater intrusion

Saltwater intrusion into freshwater systems and in particular into aquifers is expected to be an impact of great concern in the Mediterranean. Higher sea level and increased frequency and magnitude of storm surges can adversely impact freshwater supplies in coastal areas. Saline water profiles in river mouths and deltas would be pushed farther inland, and coastal aquifers would face an increase threat of salt water intrusion [Frederick and Major, 1997]. In some areas and during specific seasons, the salt wedge could penetrate as far as 10-50 km inland from the coastline [Vallega, 1997]. The implications of an increase in saltwater penetration in terms of decrease in water availability and increase in water stress are evident. For example, it has been calculated that a 1 metre rise in sea level could reduce Malta water availability by 40% [Attard *et al.*, 1996].

Intrusion of saltwater already affects many Mediterranean areas (for example in Italy, Spain, Greece and North Africa) and will be more severe in regions where freshwater flows have been reduced by overexploitation and bad management of water resources. The growth of population and the increase in per-capita demand of water in the last decades have enhanced the human pressure on Mediterranean freshwater reservoirs, favouring the process of saline intrusion [Vallega, 1997]. It has been estimated that 50% of the irrigated land in the Euphrates valley, 30 % in the Nile valley and 33% in Greece are currently threatened by salinisation due to soil degradation and inadequate use of water [Baric and Gasparovic, 1992]. Likewise, in Tunisia, 26% of surface water, 90% of water pumped from water tables and 80% of that extracted from deep aquifers have a salinity of more than 1.5 g/l [Greenpeace].

The severity of the effects produced by saltwater intrusion into aquifers depends on the difference between the densities of fresh and salt water, the hydrodynamic properties of the aquifer and the flow that the aquifer discharges into the sea [Estrella, *et al.* 1996]. In any case, saline intrusion in combination with other climate related factors is likely to affect freshwater supply and to exacerbate risks of water scarcity in the Mediterranean basin. These factors include the reduction in precipitation and in soil moisture, the increase in evaporation and in infiltration rates due to soil degradation and the increase of sedimentation processes in water reservoirs.

The increase in magnitude of saltwater intrusion into freshwater systems is likely to impose other impacts on the natural and human systems. Lower ponds of Camargue (the Vaccares) for example are likely to experience hyper saline conditions in the case of sea level rise (50-70 g/l) [Corre, 1992]. This would have relevant ecological implication, leading to significant modifications in the distribution and relative abundance of various animal and vegetal species. Saltwater intrusion could also negatively influence agriculture through soil salinisation and salt contamination of irrigation water, in particular in arid and semiarid regions of the Mediterranean basin. Excessive concentration of sea water at water intakes could create a public health risk, damage machinery and increase the cost of water treatment [Lindh, 1992].

Land degradation and desertification

Desertification is defined as *“land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities”* [UNEP, 1992; Hulme and Kelly, 1993]. Desertification is thus the result of the combination of climate and non-climate related factors as well as natural and human induced processes such as erosion, salinisation, deforestation and overexploitation of natural resources. Middle Eastern Asian and Northern African countries of the Mediterranean basin, are traditionally affected by desertification, but this process also threatens some parts of Southern Europe, such as Corsica, the Iberian peninsula, Greece, southern Italy and Sicily [UNEP, 1992] with some substantial economic and human costs. It has been estimated that in Spain desertification causes about US$200 million of damages every year [Greenpeace].

The Mediterranean region presents some features that facilitate desertification and erosive processes [Comitato Nazionale per la lotta contro la desertificazione, 1998]. These include: semi-arid and arid climatic conditions, seasonal droughts, high rainfall variability, sudden and violent rainfall events, presence of poor soils which are vulnerable to erosion and crust formation, presence of steep slopes, loss of vegetation cover due to deforestation and fire, crisis of the traditional agricultural system and land abandonment, overexploitation of water resources (in particular of aquifers) and soil salinisation. Climate change is likely to exacerbate and expand desertification. The vulnerability of arid and semi-arid areas can be intensified even by small changes in climatic conditions [IPCC, 1996b][61]. According to Lavee *et al.* [1998] small changes are also sufficient to cause a shift of the borders between Mediterranean and arid areas and to spread the desertification process in regions which are currently affected only in a marginal way [Piervitali *et al.*, 1998b].

The process is generally driven by water availability and therefore by the distribution and intensity of rainfall events. Rainfall is not only important in terms of the annual amount, but also in terms of the duration and length of the intervals between successive events. Lavee *et al.* [1998] have described the influence of climate change on the desertification process as follows. In general, a potential decrease in the amount of rainfall, a decrease in the duration of the rainfall events and an increase in the duration of the interval between successive rainfall events diminish the availability of water for vegetation and micro-biological activity.

Increase in temperature and in evaporation can be additional stresses and are likely to limit water availability. Consequently, the organic matter contained in the soil decreases, while salt concentration may increase. The long-term effects of a decrease in water availability include the reduction in clay content and soil stability, due to modification of soil particles aggregation. All these processes can lead to lower water carrying capacity, lower permeability, crust formation, and decrease in the infiltration rate. Less water will therefore be available for vegetation and more water will run over the surface, contributing to the erosion of the more fertile topsoil. Increased run-off will lead to a decrease in the nutrients content of the soil and to a further reduction of the soil fertility. Indirect factors related to climate change that could intensify desertification include increased fire risk due to higher temperatures and drier conditions, and increased salinisation or salt water intrusion.

Biological effects

Climate changes are able to alter the structure, the functions and the productivity of many terrestrial and aquatic ecosystems. The present section focuses on marine ecosystems and in particular on the two ecosystems, vital for the Mediterranean sea biodiversity: sea-grass meadows and coral communities.

Mechanisms linking climate and marine ecosystems are complex and incompletely understood. It has been demonstrated that even small changes in climatic variables often produce significant changes in the abundance of species because of direct and indirect effects. Direct effects are linked to changes in water temperature and salinity which can affect organism survival, reproduction pattern and biotic interactions. Indirect effects are linked mainly to hydrodynamic variations [Bakun. 1996, Kawasaki *et al.* 1991] such as those affecting ocean circulation, stratification of water, mixing patterns and consequently nutrient availability for marine organisms [Ittekkot, 1996]. According to the UNEP/EEA [1999b] report, warmer water temperatures may act positively on biodiversity, allowing the formation of species enriched assemblages. Nevertheless, major negative ecological impact could occur through the expansion of warm water species, the introduction of new competitors and some changes in inter-specific relation. In addition, warmer water is likely to intensify the invasion of migrants from the red sea through the Suez Canal[62], and the competition

[61] pp. 170-189
[62] The phenomenon is known as Lessepsian migration related to the engineer of the Canal, Ferdinand de Lesseps

between colonisers and native species, implying drastic changes in Mediterranean species distribution at the expense of the more sensitive species.

The most important sea-grass in the Mediterranean sea is the *Posidonia oceanica* which is an endemic species, symbolic of the Mediterranean biodiversity. *Posidonia* beds represent the most important Mediterranean ecosystem, supporting 25% of the Mediterranean flora and fauna, and providing important feeding grounds, nurseries and protective places for many species (fishes, sea turtle, cephalopods, crustaceans, etc.). Sea-grass meadows are also extremely important because of their capacity to function as natural coastal protection agents. They can diminish waves aggression on coasts and contribute in counterbalancing erosion, trough the trapping and stabilisation of unconsolidated sediments. It has been estimated that a loss of 1 m of *Posidonia* bed may cause a shoreline regression of nearly 20 m [Salman and Kooijman, 1998]. *Posidonia* meadows cover about 350 000 square kilometres and have already regressed throughout the Mediterranean (for instance in France the loss is estimated to amount to 10-15%). Climate change can further threaten these ecosystems. It has been noted that shallow and inter-tidal sea-grass in particular will suffer from an increase in sea-surface temperature and in some cases from an enhanced freshwater land runoff [Eduards, 1995]. Sea level rise will affect sea-grass meadows through indirect effects, such as the intensification of erosion and the consequent increase in turbidity as well as through a decrease in light infiltration. Nevertheless, climate change impacts are likely to be less significant than those produced by other human-induced disturbances, such as sediment dredging, water pollution, eutrophication, increase in turbidity, use of highly impacting fishing techniques and excessive marine traffic.

Coral ecosystems are also extremely sensitive to shifts in seawater temperature and salinity, as well as in irradiance. A limited increase in temperature (1-2 °C) for a short period can lead to bleaching, of coral while a substantial temperature elevation over a longer period can provoke a significant mortality of corals and inhibit their reproductive functions [Brown *et al.*, 1990, 1993]. The most extensive coral bleaching event ever reported has occurred during the 1997-1998 period with a high mortality in some particular regions (Maldives, Sri Lanka, Thailand). This unprecedented phenomenon coincided with the El Niño event followed by a strong La Niña. Coral bleaching may occur as a response to many stresses, but the recent apparent increase in incidence and severity of this phenomenon might be linked with global climate change [Wilkinson, C. 1998]. Tropical corals are particularly sensible to temperature changes as many species already live near their tolerance limit of temperature [Goreau, 1992] and are subject to intense human pressures. Nevertheless in the Mediterranean sea, recent observations of coral bleaching have also been reported by the marine laboratory of the university of Nice. High mortality of *gorgoons* have been observed in France (from the Italian frontier to Marseilles), on Italian coasts (Liguria, Portofino), and in a lower magnitude in Corsica. Most of Mediterranean *gorgoon* species appear to be affected *(Paramuricea clavata, Eunicella singularis, Lophogorgia ceratophyta, and Eunicella cavolini*) [Perez, *et al.* 2000]. This recent phenomenon is not well understood and studies are still in progress. Nevertheless, the scientific community maintains that sea water temperature anomalies are undoubtedly implicated.

3.2.2 Socio-economic Impacts

Socio-economic implications of sea level rise and climate change on coastal zones are mainly linked to the increase in the risks of flooding of human settlements, goods, infrastructure and services and to the loss of coastal land and habitats due to inundation of low-lying areas [Klein and Nicholls, 1998; Sterr and Klein, 1999]. Other socio-economic impacts are those directly affecting important economic activities, such as coastal agriculture, fishery and tourism or those concerning water availability and human health (table 11).

Table 11: Qualitative synthesis of direct socio-economic impacts of climate change and sea-level rise on a number of sectors in coastal zones [*source:* Sterr and Klein 1999].

	Biogeophysical Effect					
Sector	Flood Frequency	Erosion	Inundation	Rising Water Tables	Saltwater Intrusion	Biological Effects
Water Resources				✓	✓	✓
Agriculture	✓		✓	✓	✓	
Human Health	✓		✓			✓
Fisheries	✓	✓	✓		✓	✓
Tourism	✓	✓	✓			✓
Human Settlements	✓	✓	✓	✓		

Flooding and permanent inundation of coastal areas

Increase in the risk of flooding and inundation of low-lying coastal areas represent the two most evident impacts of sea level rise. Their socio-economic implications are intuitive, since these impacts are able to negatively affect all human activities located in coastal area. The level of risk will depend on the level of human presence and on the effectiveness of existing defensive structures. Mediterranean coasts, especially those located in European countries, are generally heavily urbanised. As a consequence a great number of human settlements, including large cities, will have to face serious sea level rise implications, such as increased risk of flooding, impeded drainage, inundation of low-lying areas, salinisation of freshwater supplies, higher water tables which may reduce the safety of foundation, beach erosion [Timmerman et al. 1997].

Increase in the frequency and intensity of flooding produced by temporary sea level rise caused by storm surge or wave set up is a particular impact of climate change effects that must be properly taken into consideration. In the Mediterranean, even a small rise in sea level can significantly reduce the return period of a given elevation flood [Nicholls and Hoozemans, 1996]. According to Nicholls and Hoozemans [1996] in 1990 about 10 million people in the basin lived in areas at risk from flooding[63] (table 12). If population growth is not taken into consideration, a 1.0 m sea level rise will produce an increase of the total number of people at risk from flooding by 70%. As a consistent population growth is expected (table 12, the 2020 scenario) for the southern basin countries (especially in Turkey and Egypt) the total number of people at risk by 2020 will rise by 83% with a 0.5 m sea level rise and 132% with a 1 m increase in sea level with respect to 1990 level. However, these estimates could be overestimated in the reality since in many cases natural and artificial defence structures protect the coasts.

According to Nicholls and Hoozemans [1996] on average each year, one million people experience flooding around the Mediterranean and particularly in the southern region. Coasts of Northern regions are generally better protected but a sea level rise could severely limit the effectiveness of their defences. A 0.5 m and 1.0 m sea level rise - through the expansion of the potentially affected area and the decline of the level of protection - will increase number of people experiencing

[63] Defined as the areas beneath the 1000 year storm surge

flooding in the Northern Mediterranean by factor of two and more than six respectively if population growth is not taken in consideration. On a global scale the same sea level rise scenarios would increase the number of people affected by flooding by lower factors (respectively two and three). These data confirm the high vulnerability of the Mediterranean to sea level rise and climate change. The absolute cost of coastal protection will be higher in the northern Mediterranean but in the southern countries the social and human cost will be more significant, since it will represent 7% of the 1990 Gross National Product respect to 2 % of the northern countries (table 12).

The cities of Venice and Alexandria are emblematic examples of potential sea level impacts on historic cities. In Venice, the frequency of floods has increased sharply over the past 100 years as a consequence of a 23 cm relative sea level rise due to the combination of natural eustatism and natural and human-induced subsidence (figure 18) [Carbognin *et al.*, 1981; CVN, 1988; Carbognin *et al.*, 1996]. The latter was mainly due to groundwater over-pumping which occurred between the 50s and the 70s for industrial and tourism purposes. Human-induced subsidence practically stopped after 1970 as a consequence of the end of groundwater exploitation. Subsequently, the relative sea level has shown a constant trend [Carbognin *et al.*, 1996]. However, the 23 cm relative sea level rise which has occurred in the last century emerges as the main cause of the increase in the frequency of flooding. In the case of San Marco square, the lowest part of the city (less than 80 cm above the average sea level) the flooding frequency has grown from 7-8 to 40-45 times per year [Musu *et al.*, 1998; Camuffo, 1993]. A sea level rise of 30 cm would cause San Marco square to be flooded 360 times per year (table 13) [Francia *et al.*, 1993].

Table 12: Some potential sea level rise impacts for the Mediterranean basin: number of people at risk from flooding (the risk zone is defined as the area beneath the 1000 year storm surge) according to different sea level rise scenarios - 0 m, 0.5 m and 1.0 m - and as a consequence of population growth; protection cost against a 1 m sea level rise [*source*: Nicholls and Hoozemans, 1996].

	Risk zone population (millions) by year and sea level rise						**Protection cost against a 1 m SLR**	
	1990	**2020**	**1990**	**2020**	**1990**	**2020**	**US $ (billions)**	**% GNP**
Sea level rise (m)	**0**	**0**	**0.5**	**0.5**	**1.0**	**1.0**		
Northern Mediterranean	4.1	4.1	5.7	5.6	7.2	7.1	25.5	2
Southern Mediterranean	5.6	9.1	7.5	12.2	9.4	15.4	18.1	7
Total	9.7	13.2	13.2	17.8	16.6	22.5	43.6	-

The Consorzio Venezia Nuova [Cecconi, 1997; CVN, 1997] has proposed three sea level rise scenarios - optimistic, realistic, and pessimistic- regarding Venice. The optimistic scenario foresees that no climatic changes will occur and that relative sea level rise will only be produced by the local natural subsidence (4 cm/100 yr). According to the realistic scenario, the relative sea level will increase by about 15.3 cm/100 yr, as a consequence of natural subsidence (4 cm/100 yr) and of eustatism similar to that measured during the present century (11.3 cm/100 yr). Finally, the pessimistic scenario takes the human-induced global warming into consideration with a consequent sea level rise of 49 cm in the period 2000-2100, as calculated by the IPCC [1996a][64]. This increase is superimposed on the natural subsidence rate, producing an overall relative sea level rise of about 53 cm/100 yr. Such sea level rise will cause irreversible damage to buildings due to salt water intrusion. On the basis of previous estimates, the Co.Ri.La[65]. [1999] has elaborated two others scenarios of sea level rise for the period 1990-2100 for the Venice lagoon (table 14). The sea level rise rates foreseen by these scenarios will cause an increase in the annual frequency of tidal events exceeding the level of 100 cm from the present value of 7 to 37 in case of scenario A1, 58 in case of A2 and 128 in case of B [Co.Ri.La., 1999[66]]. The annual frequency of these events, which are able to temporarily submerge about 12% of the city of Venice, has already increased from 1 to 7 during the 20th century.

Figure 23: The effects of subsidence in Venice. Land sinking as related to subsidence and eustatism [*source*: Carbognin *et al.*, 1981].

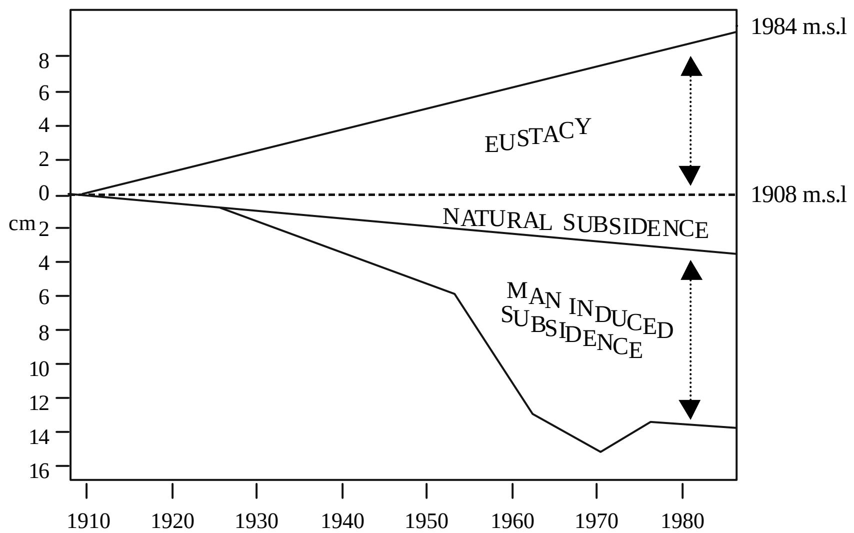


Table 13: Effects of a 10, 20, 30 cm sea level rise on the high water events annual frequency. Peak tidal levels are referred to the average tide level of 1897 measured at Punta della Salute in Venice [*source*: CVN, 1997].

Tidal peaks (cm)	mean annual frequency for current m.s.l	mean annual frequency for m.s.l. +10 cm	mean annual frequency for m.s.l. +20 cm	Mean annual frequency for m.s.l. +30 cm
+80	39	94	204	356
+100	7	16	39	94
+120	1	3	7	16
+140	1/6 yr	1/2 yr	1	3

[64] pp. 359-405
[65] Co.Ri.La.: Consorzio per la Gestione del Centro di Coordinamento delle Attività di Ricerca Inerenti il Sistema Lagunare di Venezia (Consortium for the management of the co-ordinating centre of the research activities concerning the Venice lagoon system)
[66] pp. 26-27

Table 14: Co.Ri.La scenarios of sea level rise for the period 1990-2100 for the Venice lagoon.

Scenarios	Sea level rise	Contributing factors	Comments	Annual frequency of tidal events > 100 cm *
A1	16.4 cm	• Eustacy: 1.13 mm/y • Natural subsidence 0.4 mm/y	• rates similar to those measured during the 20th century • assumption that before 2100, Climate change will exert a significant influence on relative sea level	37
A2	21-23 cm	• Eustacy rate 1.5 mm/y • Natural subsidence 0.4 mm/y		58
B	31.4 cm	• Global warming contribution based on IS92a emission scenario, and advanced models [67] • Natural subsidence 0.4 mm/y		128

*actual annual frequency of 7 tidal events > 100 cm

The Nile valley and delta (figure 24) which occupies only the 4% of the total Egypt surface area, presents one of highest population densities of the world with 1492 inhabitant/km^2 (the average population density of the rest of Egypt is 2 inabitant/km2) [FAO, 1997]. Sea level rise will therefore produce significant socio-economic impacts on this area. According to some authors [Broadus *et al.*, 1986; Milliman *et al.*, 1989] 8 million people would be displaced in Egypt by a 1 m sea level rise, assuming no protection and existing population levels. The city of Alexandria is experiencing a rapid population growth (population of the city was 3 million in 1990 and is now about 5 million [Timmerman *et al.*, 1997]) and a worsening of local environmental problems, such as beach erosion and pollution [Frihy *et al.*, 1996]. This has forced the city to expand towards low-lying areas (the lake of Maryut) and to reclaim wetlands for agricultural purposes. Some studies have quantitatively assessed the Alexandria and adjacent coastal areas vulnerability to sea level rise using geographic information systems, remote sensing, modelling techniques and ground-based surveys [El-Raey *et al.*, 1995, El-Raey *et al.*, 1997, El-Raey, 1998, El-Raey *et al.*, 1998b].

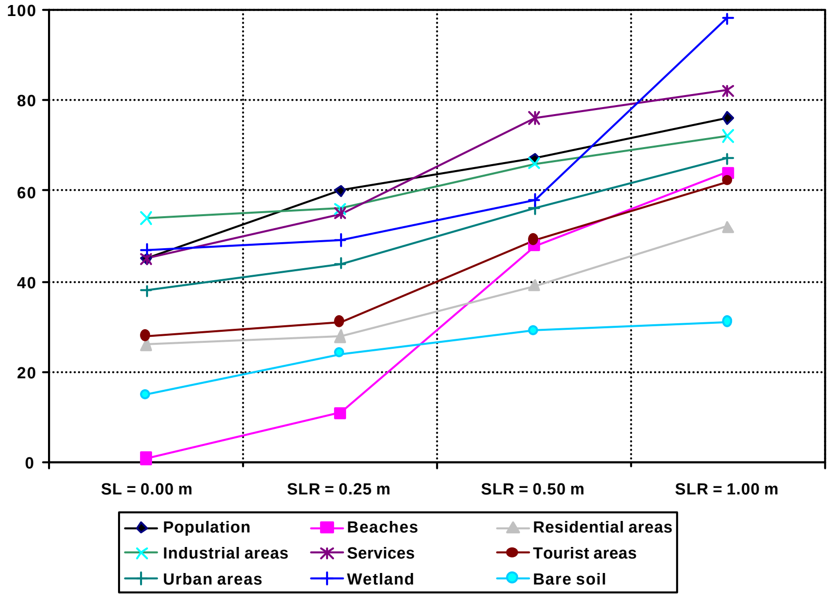
Potential socio-economic impacts in relation to diverse sea level rise scenarios for Alexandria are shown on the figure 25. A significant percentage of population and of area used by humans is already at risk of permanent inundation. In reality natural and artificial defensive structures ensure protection of people and the city. Sea level rise would increase the inundation risk both by increasing the percentage of people and areas potentially affected and reducing the level of safety of defence structures, such as sea walls and drainage systems. The studies have estimated that if no response measure is taken, the 0.50 m sea level rise scenario will cause the displacement of about 1.5 million people, the loss of 195,000 jobs and an economic loss of more than 35 billion American dollars, over the 21th century.

The most vulnerable economic sectors are the agricultural sector which employs 38% of the Egyptian labour force [FAO, 1997], followed by the industrial and tourism sector. The

[67] These models incorporate various advancements in modelling respect to the other models used by IPCC in 1995. The considered climate sensitivity is 2.2 °C, while for glaciers and ice caps a range of values of sensitivity was used. The 27 cm projection assumes changes in aerosol concentration beyond 1990.

intensification of beach erosion combined with the risk of inundation will produce significant negative economical impacts on the tourism sector. A potential sea level rise of 30-50 cm could cause nearly all Alexandria's beaches to disappear [Frihy *et al.*, 1996]. Sea level rise will also negatively affect coastal infrastructures such as harbours, coastal roads, tourist installations, coastal industrial installations, and coastal defence structures.

Figure 24: Percentage of population and areas with different land uses of the city of Alexandria at risk of inundation with no sea level rise (SL = 0.00 m) and with three sea level rise scenarios (0.25 m; 0.50 m; 1.00 m) [adapted from El-Raey *et al.*, 1998a].



Water shortage

Water resources are unequally distributed in the Mediterranean basin. France, Italy, Turkey and the former Yugoslavia account for 2/3 of the total water resources of the region (825 km3/year). Water shortage and deterioration of water quality already represent serious problems in many southern Mediterranean countries. At the catchment level, the rate of water exploitation[68] defined as the ratio between withdrawn water quantities and available resources is already close to 100 % in Egypt, and even higher than 100% for Israel and Libya (figure 25). Likewise, the availability of water per inhabitant presents in the basin a strong north-south imbalance. The per capita water availability falls below the threshold values (defined as 1000 m^3/yr/per capita) in eight Mediterranean countries, Israel, Egypt, Malta, Tunisia, Libya, Lebanon, Syria and Algeria, which therefore appear as the most vulnerable to climatic changes [WRI/IIED/UNEP,1997]. With rapid population growth, the per capita availability is expected to be further reduced. It is predicted by 2025 that only France, Italy, states of the former Yugoslavia, Greece and Turkey would exceed the threshold of per capita water availability (table 15).

It is reasonable to believe that climate changes will exacerbate the problems of water stress and shortage. Higher temperatures and variation of rainfall intensity and frequency, as well as changes in evapotranspiration and soil moisture will influence the magnitude and timing of runoff, floods and droughts. In arid and semi-arid areas a temperature growth will greatly increase the amount of

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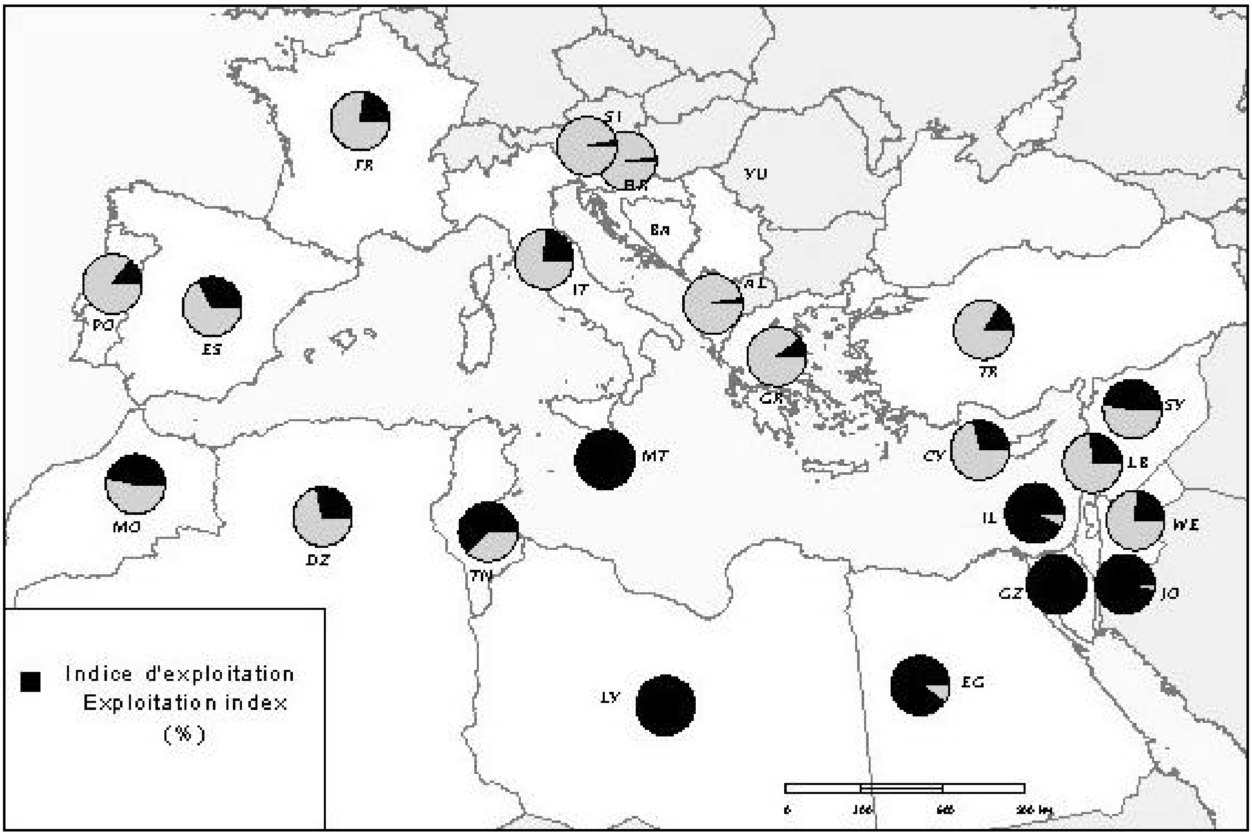
68 Also known as the exploitation index

water which will evaporate from plants, soils, lakes and rivers, reducing soil moisture and affecting groundwater recharge. This latter aspect is very important since groundwater reservoirs often represent the only water supply of arid and semi-arid regions. It has been estimated that a 1-2 °C increase in temperature and a 10% decrease in rainfall would diminish the water availability of arid and semi-arid zones by one-half [UNEP, 1993]. Likewise, a 20% decrease in rainfall in the Acheloos basin (Greece) would increase the risk of water system failure (inability to provide targeted supplies) from the present value of less than 1% to 38% [Mimikou *et al*, 1991].

Figure 25: Exploitation Index in the Mediterranean countries [*source*: Plan Bleu, 2000]



In case of climate change and sea level rise, water quality and availability will be further threatened by the decrease in aquifer recharge due to alteration of soil processes and by saline intrusions into freshwater systems.

Water shortage depends on the ratio of water availability and the scocio-economic demand. Changes in climatic factors in combination with growing population and maladaptive management practices of water resources would increase the water demand and consumption, in particular in urban zones and for agricultural purposes. It has been estimated for example that the increase in urban water demand in Crete could increase the probability of water shortage in this nation from 20% in 1980 to 85% in 2010 [MEDALUS II, 1996]. On the Mediterranean basin scale, the water consumption due to agricultural land irrigation assumes a primary importance. In 1988 this sector accounted for the 72% of the annual water consumption, while only 10% was used for drinking purposes [Blue Plan, 1988]. It is clear that any factors, including those linked to change in climatic conditions will produce significant negative implications for water availability and consumption, in particular in the Southern and Eastern countries of the basin.

Table 15: Water availability per inhabitant in m3/yr/inhabitant in the Mediterranean countries by 2025. The projections consider an average population growth [source: Blue Plan, 1998].

France	
Italy	
Greece	
Former Yugoslavia	
Lebanon	
Turkey	
Albania	
Spain	
Cyprus	

Morocco	
Syria	
Algeria	
Malta	
Israel	
Tunisia	
Egypt	
Libya	

m3/year/inhab

> 1000 Availability
500-1000 Water stress
< 500 Water shortage /moderate demand
< 500 Water shortage/high demand

Problems associated with the deterioration of water quality can also be expected with an increase of water pollution concentrations, due to higher water temperature, reduction of river levels, and pollution by salts. Climate change will clearly increase the severity of problems the water availability and supply with some implications in the whole socio-economic system and especially on the southern side of the basin, where water shortage is already a limiting factor for development. Mediterranean countries need to improve supply and to increase the efficiency of water use. The lack of current efficiency is emphasised by the example of the Syrian coastal zones, where it has been estimated that 40% of water supplied is lost through poorly constructed and maintained mains [Greenpeace]. Like wise, implementation of measures to improved irrigation systems, and to adapt agricultural techniques (in particular for crops' irrigation) to climate change will be required.

Coastal agriculture and fisheries

Agricultural sector has been the focus of interest world-wide by the climate change impact community as it represents a vital economical for many regions. Nevertheless there is a lack of consensus about the potential impact and of consistencies in the application of climate change scenarios in agricultural assessment [ECLAT-2,1999].

The total agricultural area of Mediterranean countries represents about 220 millions ha. Little surface changes have occurred over the last 30 years (decrease of around 1.36% equivalent to 3 millions hectares due mainly to the development of urban infrastructures) [Bindi and Olesen, 1999]. In the Mediterranean coasts intensive agriculture is limited by topographic characteristics and tends to concentrate in the alluvial plains [EEA/UNEP, 1999a]. Yields, in particular those concerning cereals, are generally limited by water availability and heat stress conditions. However, the agricultural production of the basin is important in terms of economic revenue and food consumption. The main crops are cereals, olives, grapes, and fruit.

Increase in the concentration of CO2 and variations in climatic conditions can directly affect Mediterranean agriculture. Higher CO2 concentrations may stimulate the plant productivity and produce benefits on yield quantity and affect yield quality in a way depending on the type of crop. Under controlled conditions, the doubling of present day CO_2 levels can produce an increase in the yields of C3 plants (wheat, rice, soybean) of about 30% [Rogers and Dahlman, 1993]. However, there is no certainty about crop responses in real conditions. Besides the benefits, it is very likely that climate changes will negatively affect agriculture in various ways. An increase in temperature will enhance plants respiration and reduce their growing season. Rainfall reduction would be responsible for moisture stress, particularly during the summer season, with negative effect on crop development, such as in the case of maize, soybean and wheat [Bindi and Olesen, 1999]. In general the response of crop production will depend on the type of crop and the specific agricultural site. However, yields of major crops are expected to decrease in Northern Africa and in the Middle East [Fischer et al. 1994]. In particular some studies suggest sharp decreases in yield for wheat and maize in four sites along the Nile by 2050 [El-Shaer *and al*.1997]. Decrease of yield for Maize could also affect Euro-Mediterranean countries such as Greece and Spain due to reduced duration of the growing period [Kapetanaki and Rosenzweig, 1997].

Indirect impacts of climate changes on agriculture include proliferation of pest and diseases and decrease in the availability of water. Indeed higher temperatures could facilitate the spread of insect pests as a consequence of a longer growing season and of more favourable conditions for their survival. Besides producing direct negative impacts on plant productivity, decrease in water availability could have other consequences in some regions of the Mediterranean basin, such as a growing demand of water for crop irrigation (with a peak in the dryer season), an increase in the risk of soil salinisation and a consequent decrease in soil fertility. All these impacts can further increase water stress conditions for crops. Other indirect impacts on coastal agriculture include: agricultural land inundation due to sea level rise, increased fire risks, increased soil degradation and erosion.

Response measures and policies are necessary to mitigate or avoid negative climate change impacts on agriculture and to exploit possible positive effects. Likely changes in climatic conditions are considered to be sufficiently gradual to be counteracted by adequate response measures. Economic and agronomic adaptation strategies include: changes in crops and crop varieties, improved water management and irrigation schemes, changes in planting schedules prevention of soil erosion and protection of soil fertility [IPCC, 1995][69].

In the planning of mitigation strategies, it is important to consider that impacts on agriculture will probably be more significant in the southern and eastern regions of the Mediterranean basin which are characterised by more traditional crops. As a general indication table 16 reports the different effects of climate change on cereal production in developed and developing countries at the global scale. These data can only been interpreted as an example of the different response to climate change of agriculture existing between these two categories of nations. In these areas, problems of water shortage would be worsened by higher inter-annual variability of precipitation and increase in the frequency of extreme events, such as droughts, which will make the implementation of response measures more difficult.

The combination of population growth and changes in land use as well as water related problems (such as increase in the domestic water consumption) would produce significant impacts on the agriculture of these countries. The vulnerability of the overall economy of Southern and Eastern Mediterranean countries to impacts affecting agriculture will be particularly elevated, since in these nations agriculture represents the most important economic sector and the basis of the national food security. On the contrary, the economy of other countries, in particular European ones (with the

[69] p 449

exception of Albania) will be much less threatened by negative effects of climate change on this specific sector (figure 26).

Figure 26: Contribution of the agricultural activities to the economy of Mediterranean countries (%) [adapted from Bindi and Olesen, 1999].

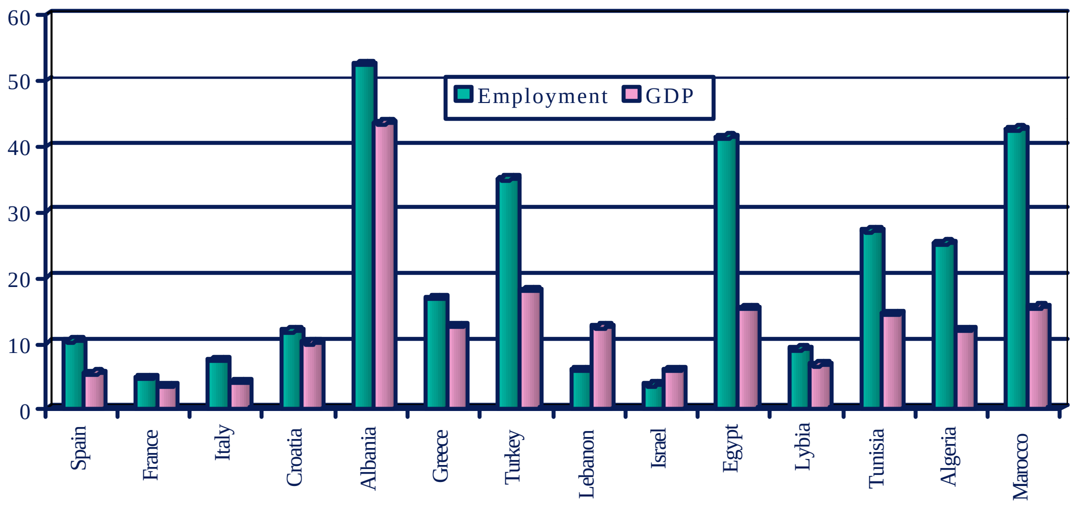


Table 16: Change in cereal production under 3 different equilibrium GCM scenarios (percent from base estimated in 2060) [*source*: Rosenzweig and Parry, 1994].

Regions	GISS[70]	GFDL[71]	UKMO[72]
Global			
Climate effects only	-10.9	-12.1	-19.6
Plus physiological effect of C02	-1.2	-2.8	-7.6
Plus adaptation level 1	0.0	-1.6	-5.2
Plus adaptation level 2	1.1	-0.1	-2.4
Developed			
Climate effects only	-3.9	-10.1	-23.9
Plus physiological effect of C02	11.3	5.2	-3.6
Plus adaptation level 1	14.2	7.9	3.8
Plus adaptation level 2	11.0	3.0	1.8
Developing			
Climate effects only	-16.2	-13.7	-16.3
Plus physiological effect of C02	-11.0	-9.2	-10.9
Plus adaptation level 1	-11.2	-9.2	-12.5
Plus adaptation level 2	-6.6	-5.6	-5.8

Note: **Adaptation level 1** includes: shifts in the planting date of less than 1 month, additional water for crops already irrigated, and change in crop varieties to different varieties that are already available.
Adaptation level 2 includes: in addition, shifts in the planting date of more than 1 month, increase fertiliser application, installation of irrigation, and development of new crop varieties

[70] Goddard Institute for Space Studies
[71] Geophysical Fluid Dynamics Laboratory transient model experiment.
[72] U.K. Meteorological. Office transient model experiment

Climate changes will also exert negative impacts on many marine ecosystems and consequently on living marine resources. The interrelations between climatic factors and marine productivity are complex and the understanding of the potential impact of shifts is limited and often derived from studies on a few important commercial species.

Variations in abiotic factors (physical parameters such as winds, currents, salinity) and in biotic factors (such as food availability and species composition) induced by climate change can have an effect on fish populations. Water temperature is one of the main parameters affecting the abundance and distribution of species. Increase in temperature can have a direct negative effect on fish growth and reproduction rate by acting on the fishes physiological processes, and an indirect effect on food availability through changes of water biogeochimical processes.

General negative climate change impacts on fish stocks and fishing can be induced by:

- Variations in physical and chemical parameters of water;
- Degradation and loss of coastal habitats and nursery areas (sea-grass meadows, wetlands) due to increased erosion and direct impacts exerted by change in climatic conditions;
- Increase in the frequency of alga blooms,
- Increase in UV-B radiation;
- Intensification of eutrophication process in some areas;
- Increase in the diffusion of allochthonous species, in particular through Lessespsian migration, due to change in various variables - such as temperature and salinity - which can negatively affect the ecological balance of ecosystems and inter species relations.

On the global scale, climate change is not expected to generate significant variations of fish stocks, whereas on regional and local scales relevant changes could occur [IPCC, 1996b][73]. The most important effects are expected to affect species distribution, inter species relations (predation and competition), and reproduction patterns [Murawski, 1993]. As a response to changes in temperature, salinity and other chemical-physical parameters, fish species are likely to migrate towards more favourable habitats, producing consequent impacts on regional fishing practice and techniques. Mediterranean fish stocks are already in critical conditions because of over-fishing (the overall increase of total marine catches by Mediterranean countries has been of 17.5% between 1984 and 1996 [UNEP/EEA, 1999b]) and human perturbation (pollution, eutrophication, loss of habitat). The fishing industry will probably experience little additional stress due to climate change impacts [Jeftic *et al.*, 1996b]. However, fishing production could be particularly affected in some specific ecosystems, such as shallow water areas, coastal lagoons and estuaries as a consequence of the increase of water salinity and temperature [Wood and McDonald, 1997].

There have not been significant changes in fishing techniques in the Mediterranean during recent years [UNEP/EEA 1999]. Climate change impacts on marine fisheries productivity will depend on the capacity to improve and adapt the existing techniques and to change current management practices of fish stocks, as well as to reduce fleets conflicts, competitive usage and negative implications of fishing on the natural environment. This could include the acquisition of new devices and equipment for detecting fish, of larger boats with an increased fishing capacity in farther and deeper waters, and new fishing equipment [Baric and Gasparovic, 1992].

[73] p.7

Climate change impacts on human health

Both direct and indirect climate change impacts on human health can be identified. It has been estimated that in the long term, indirect effects will have greater repercussions on health than those acting in a direct manner [IPCC, 1996b][74].

- Direct effects include the increase in heat-related illness (mainly cardio-respiratory diseases) and mortality and the effects associated with extreme events and weather disasters, such as deaths and injuries of people as well as damage to health care infrastructures. Coastal flooding can have serious consequences on human health.

- Indirect effects consist mainly in the potential increase of transmission of vector-borne infectious diseases, such as malaria, dengue, yellow fever and some viral encephalitis. This increase could be caused by the spreading of suitable conditions for vector organisms induced by change in climatic variables, such as temperature or humidity. Furthermore, maturation of some infectious parasites (for example those implicated in malaria) could be accelerated. As far as malaria is concerned, 45% of the world's population presently lives in areas characterised by climatic conditions which permit the transmission of the disease by mosquitoes. Global warming could enlarge the geographical area where malaria would be potentially transmitted. As a consequence of a 3-5 °C temperature increase by the year 2100, the total population living in a potential malaria transmission region would grow to 60% of the world population [IPCC, 1998][75]. Evidence of current changes in the prevalence or distribution of pathogens and their vectors in the Mediterranean has been identified by Jackson [1995]. He has considered the resurgence of Mediterranean spotted fever in Spain and Italy, as a sign of climate-related changes.

- Warm temperatures can increase air and water pollution, which in turn harm human health. Temperatures directly control chemical reactions that produce urban smog (i.e. tropospheric ozone). Further indirect effects on human health include the increase in the cases of asthma, allergies and cardio-respiratory problems caused by the intensification of pollen and spores production or the enhancement of the persistence and respiratory impacts of certain pollutants. A striking example is what occurred in Athens during the summer 1973, where an anomalous heat wave combined to atmospheric pollution was responsible of respiratory problems for more than thousand persons [WHO/UNEP, 1995].

The capacity to implement planned response strategies and mitigation measures to the impacts imposed by climate change generally depends on the availability of technical and economical resources. This is also true in the case of the human health sector. The general lack of resources and the present poor health conditions of Northern Africa and Middle-East Mediterranean countries implies major risks in the health sector for these nations. As in other sectors climate change is then likely to increase the present gap in the quality of human health between richer and poorer countries of the basin [WRI/IIED/UNEP, 1989].

3.2.3 The UNEP/MAP site-specific studies

In 1987 the UNEP's co-ordinating unit for the Mediterranean Action Plan (MAP) launched, within a wider international programme, an important series of site-specific studies, concerning the analysis of the potential impacts of climate change in the Mediterranean basin [UNEP, 1989b;

[74] pp. 37-39
[75] p. 7

Gabrielides, 1998]. The aim of the various studies was to identify the economic, social and environmental problems which already exert stresses on coastal zones of some specific sites of the Mediterranean, as well as to assess the potential impacts induced by climate change and sea level rise. Moreover these studies sought to identify the most vulnerable areas and systems and to suggest some possible response measures and policy options that could be implemented in order to mitigate or avoid the negative impacts induced by climate change. Different site-specific case studies have been addressed because significant differences in the magnitude and distribution of impacts of climate change are expected to occur within the Mediterranean. Until now fourteen sites have been studied in the UNEP/MAP project. The first six, labelled as 'first-generation' site-specific studies include the Ebro Delta, the Rhone Delta, the Po Delta, the Nile Delta, the Thermakois Gulf and the Lakes Ichkeul/Bizerte. The second five as 'second generation' site-specific studies[76] include the Cres/Losinj Islands, the Kastela Bay, the Rhodes Island, the Syrian coast and the Malta Island. The last three as 'third generation' site-specific studies[77] include the Albanian coast, the Fuka-Matrouh region in Egypt and the Sfax coastal area in Tunisia. Further five case studies are in the process of being developed in Morocco, Algeria, Israel, Lebanon and Malta. A more detailed description of the first and the second generation case studies and of the methodology used is contained in Jeftic *et al*. [1992, 1996a]. An overview of the methodology adopted and of the results achieved in the analysis of the implemented case studies is contained in Gabrielides [1998] and Gorgas [1999]. The main likely impacts identified in the studies are briefly summarised in tables 17.

Comparative analysis of the case studies led the authors [Jeftic *et al.*, 1996b] to draw some conclusions:

- The most likely impacts of climate changes and sea level rise common to the studied deltaic zones and to the Thermakois Gulf are: increased erosion, increased flooding, inundation of coastal flatlands, loss of wetlands and salinisation of lagoons and coastal lakes. Factors that will contribute in determining these effects are: relative sea level rise, decreased water and sediment flows from rivers, and increased frequency and intensity of storm event and waves. These impacts are also common to other studied areas.

- Salinisation of aquifers due to sea level rise could be another widespread impact, which will particularly affect the studied islands, Kastela Bay, Sfax region and the Syrian and the Albanian coasts. Salinisation of aquifers, which are important water resources, will contribute to aggravating the water shortage problem that is already experienced by many Mediterranean countries.

- The studies have identified some impacts that will affect specific components of the coastal systems and that will add further stress to the threatened areas. The negative impacts will affect:

[76] The impacts analysis of climate change in the second and third generation site-specific studies was based on the regional (covering the Mediterranean basin), sub-regional and local scenarios for future climatic conditions developed by the Climatic Research Unit of the University of East Anglia (CRU/UEA) [Palutikof *et al*., 1992]. These scenarios express variations of temperature and rainfall conditions at a sub-regional and a local scale as a function of global temperature change. In the case of the 'second generation' studies, the projections adopted by the Second World Climate Conference were considered as the global scenario of reference. This scenario foresaw an increase in temperature of 2-5 °C, and a sea level rise of 65 ± 35 cm by the end of the 21st century [UNEP/ ICSU/WMO, 1990]. For the purposes of the 'second generation studies', the global scenario was modified by the sub-regional and local scenarios developed by CRU/UEA and by the available information on relative local sea level rise trends.

[77] In the 'third generation case studies' a similar methodology was adopted. The 1992 IPCC projections of global temperature increase (0.3 °C per decade e.g a temperature increase of 0.9 °C 2030 and 2100 of and 2.5 °C respectively) [IPCC, 1992][77], were modified by the sub-regional and local scale scenarios prepared by CRU/UEA. A global sea level rise of 16 cm by 2030 and 48 cm by 2100 was assumed on the basis of Wigley and Raper's analysis [Wigley and Raper, 1992], as modified by available information on local relative variation of the sea level.

agriculture, aquaculture and fisheries, coastal infrastructures and harbour installations (such as in Alexandria and Port Said in Egypt or La Golette-Tunis in Tunisia), coastal defence systems (such as in the deltas of Po or Nile) and important historic and artistic places (such as Venice and Rhodes).

- Impacts which are not specific to coastal zones, but typical of Mediterranean areas have been identified. They represent in many Mediterranean countries exacerbation of existing problems: increased soil erosion and decreased soil fertility (for example in the islands of Rhodes and Malta, in the Thermaikos Gulf, in the Fuka-Matrouh region or in the Syrian coast), increased risk of forest fire (for example in Rhodes or in the Cres-Losinj islands) and negative impacts on agriculture due to the projected increase in the intensity and frequency of extreme events, as well as reduced rainfall, increased evapotranspiration and reduced soil moisture.

Table 17. Potential impacts induced by climate change on fourteen Mediterranean coastal areas identified in the UNEP/MAP studies [*sources*: Jeftic *et al.*, 1996b; Gabrielides, 1998].

Delta of Ebro **Spain**	increased coastal erosion; reshaping of coastline; loss and flooding of wetlands; reduced fisheries yield.
Delta of Rhone **France**	erosion of unstable and threatened parts of coastline; reduction of wetlands and agricultural land; increased impact of waves; increased salinisation of coastal lakes; destabilisation of dunes; intensified tourism.
Delta of Po **Italy**	increased flooding and high water events; increased coastal erosion; retreat of dunes; damage to coastal infrastructure; salinisation of soils; alteration to seasonal water discharge regimes; reduced near-shore water mixing and primary production; increased bottom water anoxia.
Delta of Nile **Egypt**	increased coastal erosion; overtopping of coastal defences and increased flooding; damage to port and city infrastructure; retreat of barrier dunes; decreased soil moisture; increased soil and lagoon water salinity; decreased fishery production.
Ichkeul-Bizerte Lakes **Tunisia**	increased evapotranspiration leading to decreased soil moisture; reduced fertility and enhanced salinity; increased salinity of the lakes and shift to marine fish fauna; reduced extent of wetlands and loss of waterfowl habitat.
Thermaikos Gulf **Greece**	inundation of coastal lowlands; saline water penetration in rivers; drowning of marshland; increased sea water stratification and bottom anoxia; decreased river runoff, salinisation of groundwater, decreased soil fertility; damage to coastal protective structures; extension of tourist season.
Island of Rhode **Greece**	increased coastal erosion; salinisation of aquifers; increased soil erosion.
Maltese Islands **Malta**	salinisation of aquifers; increased soil erosion; loss of freshwater habitats; increased risk for human health; increased risk for livestock and crops from pathogens and pests.
Kastela Bay **Croatia**	inundation of Pantana spring and Zrnovica estuary; increased salinisation of estuaries and groundwater; negative impact on coastal services and infrastructure; accelerated deterioration of historic buildings; increase in domestic, industrial and agricultural water requirements.
Syrian coast **Syria**	increased soil erosion; modification of vegetation cover due to increased aridity; increased salinisation of aquifers; erosion of beaches and damage to coastal structures and human settlements due to exceptional storm surges.
Cres-Losinj **Croatia**	increased salinisation of lake Vana; extension of tourist season; increased risk of forest fire.
Albanian coast **Albania**	salinisation of coastal aquifers and shortage of adequate quality drinking water; soil erosion; extension of summer drought; extension of tourist season.
Fuka-Matrouh **Egypt**	increased evapotranspiration and decreased rainfall; extension of summer aridity; increased coastal erosion; flooding in the eastern part; decreased soil fertility.
Sfax coastal area **Tunisia**	salinisation of ground water; increased rainfall; possible flooding.

- Significant impacts will affect the coastal flora and fauna through direct and indirect effects. For example, in the case of the Ichkeul-Bizerte lakes and of large deltaic areas, it is possible to foresee a considerable shift from the present fresh and brackish-water vegetation and animal communities to communities composed by species which are more typical of marine environments. This shift, together with the retreat of wetlands, will affect migratory birds. Mediterranean wetlands and coasts are in fact very important over-wintering and transit areas for many bird species.

- Some positive impacts have been hypothesised. Tourism would benefit from a longer tourist season (e.g. Perry, 1999). In some cases, for example the delta of Ebro and the Cres-Losinj archipelago, a positive influence can be foreseen for agriculture and aquaculture, if appropriate measures are taken into consideration.

3.2.4 Climate change impacts on the Mediterranean islands

Islands are generally considered vulnerable to sea-level rise due to significant socio-economic dependence (settlements, tourism, agriculture) on coastal zones. Increase beach erosion and worsening of water shortage situation are expected to be the most important climate change impacts affecting Mediterranean islands.

Beach erosion is particularly harmful because it can undermine the tourism industry which is often the basic economic activity like in the case of Cyprus where tourism generates 18% of the national GDP [UNEP/EEA, 1999a]. Likewise, an increase in evaporation and a decline in mean summer precipitation, which according to some authors [Wigley, 1992; Palutikof *et al.*, 1996] can be expected in some Mediterranean areas, could create serious problems of availability of adequate water supply and of water resources management, particularly in Malta and Cyprus. The increase in saltwater intrusion into groundwater reservoirs due to sea level rise can represent a synergetic factor which is likely to exacerbate water shortage problems. A 1 m sea level rise could for example reduce water reservoirs in Malta by 40% [Attard *et al.*, 1996]. With regards to the expected increase in water demand, in Crete water demand for urban consumption could increase the probability of water shortage in 2010 by fourfold [MEDALUS II, 1996].

Cyprus can be considered as an example of a Mediterranean island which will particularly suffer from climate change and sea level rise impacts. The Cyprus coastline is 784 km long and presents sensitive areas such as sand-dune systems, banks of shingle, cliffs, and coastal wetlands subject to intense human pressures. Georgiades [1998] has qualitatively identified the following likely climate change impacts for the island of Cyprus which will add to current human pressure (due to tourist infrastructure development, urbanisation, industrial and port development, and development of road infrastructures) on coastal zones:

- Physical impacts on the historical and cultural heritage of the island due to sea level rise;
- Impact on agriculture through changes in the precipitation pattern, increased competition between weeds and agricultural crops, reduced soil moisture;
- Potential eutrophication of the sea environment and consequent impact on fishery;
- Negative impacts on aquaculture due to higher water temperature, increased drought frequency, enhanced wave action and sea level rise;
- Exacerbation of water shortage as a result of drier conditions and enhanced saltwater intrusion into the largely depleted groundwater system;
- Increased erosion of coastal systems, in particular of beaches;
- Reduced effectiveness of existing coastal defences;

- Negative impacts on coastal infrastructures and installations as well as on the central sewerage system and major roads;
- Aggravation of desertification problems and increased soil salinisation;
- Negative impacts (not yet well identified) on important natural systems such as turtles' breeding areas and coastal wetlands of the Akrotiri lake, the Phasouri marsh and the Larnaka salt lake;
- Negative impacts on tourism due to excessive heat and sudden spells of heat waves as well as reduced water supply and disruption of beaches

According to Nicholls and Hoozeman [1996], the relative sea level rise (taking into consideration the counteract effect of natural uplift) in Cyprus will be on the order of 0.4-0.5 m by 2100. The resulting shoreline retreat is likely to range according to the Brunn rule between 40 to 100 metres and could be locally higher as a consequence of possible changes in waves characteristics (for example due to the increase in storm frequency) and changes in river discharges. The catchment regulation and management have already reduced sand supplies in a consistent way for the coast and beaches nourishment increasing the vulnerability to erosion processes of beaches [Nicholls and Hoozemans, 1996]. In order to sustain the Cyprus vital tourist industry, adoption of retreat and protection strategies for coasts are necessary: for instance the beach area should be protected and maintained by erecting hard structures, enforced building set backs and using artificial sand nourishment.

CONCLUSIONS

Climate change is likely to affect coastal systems through the variation of mean sea level, precipitation patterns, sea hydrodynamics (wave height and direction, currents, tides), water salinity and temperature, frequency and magnitude of extreme events (such as floods and storms). The major impacts of climate change on Mediterranean coastal zones include increased erosion - in particular on currently threatened and unstable coastlines - permanent inundation of low-lying coastal areas, increased risk of flooding, loss of wetlands, increased saltwater intrusion into freshwater systems, changes in ecological parameters and consequent effect on marine populations. Mediterranean coasts will also be affected by other impacts which are not limited to coastal systems, such as the intensification and expansion of the desertification process, soil degradation and increased risk of fire.

It is likely that climate change and sea level rise will, rather than generating new impacts, affect Mediterranean coasts through the exacerbation and expansion of existing critical problems due to increasing human pressures such as rapid urbanisation, development of tourist facilities and industries, and overexploitation of marine resource. In both the short and medium term (the next few decades) Mediterranean coasts will probably experience greater stresses produced by non-climatic factors such as population growth, intensification of tourism, poor land and water management, resources overexploitation, urbanisation, coastal infrastructure development. High population densities and overexploitation of coastal resources have already made some sensitive areas particularly vulnerable to hazards - such as storm surges, permanent inundation, and droughts- and exposed human activities and settlements to significant impacts, which could be exacerbated by climate change. This is particularly evident in the case of human expansion into or intense modification of fragile ecosystems (for example the Nile delta) or marginal land, such as arid and semi-arid zones (for example marginal lands close to Alexandria). Nevertheless, the negative impacts of climate change will probably be more significant on the coastal zones in the medium and long term.

The most vulnerable systems are considered to be those with the greatest sensitivity and the lowest adaptability to climate change effects, such as wetland areas (for example the Camargue or the lagoon of Venice), large deltas (Nile, Po, Ebro, Rhone), small islands (for example Rhodes and Malta), low-lying coastal areas, sandy coasts and arid or semi-arid lands. In addition, socio-economic implications of the impacts of climate change on coastal zones will be particularly severe in the context of coastal infrastructures, harbour installations, historic sites, water availability and management, agriculture, tourism and fisheries. Climate change and the impacts of sea level rise are expected to be more severe in the southern and eastern regions of the Mediterranean basin, whose adaptability is generally limited by weaker economic and institutional conditions as well as by poorer availability of financial, technological resources. In these regions, the more affected economic sectors are expected to be the agriculture and the water resources management. Indeed agriculture is increasingly unable to satisfy food demand and water availability is often deteriorating. Climate change could exacerbate these trends and lead to social problems and disruption.

It is recognised that an immediate cut in global greenhouse gas emissions would not prevent completely but rather delay climate changes and resulting impacts because of the inertia of natural systems in response to change in CO2 concentrations [DETR, 1999]. That underlines the importance of combining efforts to control greenhouse gas emissions, which is a priority, with efforts and strategies to minimise damage. International agreement on emissions reduction which sets significant targets with regards to climate change prevention appears at the moment to be impossible. International prevention strategies must then be accompanied by the definition and implementation of adaptation actions and policies at the regional, sub-regional and local levels, which can mitigate, or in some successful cases eliminate, the negative impacts induced by climate changes. Adaptation strategies can be useful to respond both to present-day climatic variability (in particular extreme events, such as drought and storm surges), and to longer term changes produced by the greenhouse effect, not only in climatic variables but also in associated environmental and socio-economic factors. As an example, table 19 reports some possible adaptation measures which can be implemented in response to some key climate change and sea level rise impacts for the Mediterranean basin. In terms of adaptation, the first step is generally represented by the resolution or at least the mitigation of existing critical problems. The latter are often the result of strong human pressures and of a cumulative set of inappropriate practices such as development in hazardous zones and sand mining and which limit the flexibility and adaptability of a considered system in the face of climate change. They have been called 'maladaptation' by Burton [1996] and are defined as human interventions and their effects which are capable of significantly reducing natural coastal system's adaptability and resilience.

The impacts of climate change and vulnerability assessment and the definition of adequate adaptation measures should be included in the broader scheme of Integrated Coastal Zone Management (ICZM). ICZM allows an analysis of the effects of pressures and stressing factors on coastal systems, including climate change and sea level rise, and of their interrelations [EC, 1999]. Furthermore, ICZM, is increasingly recognised as the best way to deal with current and long term coastal problems [WCC, 1993]. The implementation of an ICZM scheme and the realisation of climate change adaptation measures not only requires a relevant change of perspective (long term rather than short term; prevention rather than emergence, integrated approach rather than sectoral interventions) but, at least in some national contexts, radical modification of institutions, legal and regulatory aspects and socio-economic development plans. Given the political, cultural, economic and social differences existing within the Mediterranean basin, international co-operation and the transfer of technology and know-how are extremely important in order to allow a sustainable future for the whole region.

In this context, scientific communities are important in order to provide decision makers with scientific support. As regards climate change impacts assessment, it emerges from the analysis conducted that the spatial scale of the studies should be narrowed down to the sub-regional and local level. The quantification of main impacts is a difficult task which requires the modelling of the interrelations between climatic changes and sea level variations, and of potential effects on natural and human sub-systems. Efforts should be concentrated on the elaboration of future local reliable scenarios which describe how critical parameters will change in future. Nevertheless, the reliability of current scenarios are limited by the uncertainty which increases moving from a global to a regional, a sub-regional or a local scale. Regional and local studies are also constrained by other factors, such as the greater natural variability of climatic conditions at these scales; the non-uniform distribution of atmospheric aerosols and of its 'cooling' effect; and the influence on the climate system exerted by variations in local characteristics, such as those concerning land use.

Not only climate change and sea level rise scenarios are required. According to Klein and Nicholls [1998; 1999] since vulnerability is a multi-dimensional concept which embraces biogeophysical, economic, institutional, and socio-cultural factors, it is important to generate various scenarios which can be grouped in four classes: scenarios of climate-induced change in environmental variables (e.g. sea level, rain and temperature pattern), scenarios of non climate-induced change in environmental variables (e.g. vertical land movement), scenarios of climate-induced change in socio-economic variables (e.g. autonomous and planned adaptation), scenarios of non climate-induced change in socio-economic variables (e.g. population, land use). In addition, it is important to consider a wide spectrum of scenarios which are able to include in the evaluation process the uncertainty of the future. Since at the moment our knowledge on future climate change scenarios are far from definitive, it is very important that defensive and mitigation structures are projected to be flexible and to function in a wide range of options (for example different values of sea level, frequency of intense rain events or length of dry spells). A gradual evolution of the vulnerability study which, as suggested by Klein and Nicholls [1998], is firstly performed through a screening assessment, secondly through a vulnerability assessment and finally through a planning assessment should also be considered. In the perspective highlighted above, the final vulnerability and planning assessments should be included in a wider ICZM scheme.

Table 19: Key Impacts Possible adaptive measures [adapted from WISE, 1999 and Gabrielides, 1998].

Sectors	Key Impacts	Possible adaptation measures
Water	❑ Variability of water supply ❑ Prolonged summer season drought ❑ Reduction of water availability from aquifer and surface resources ❑ Increased uncertainty in the planning of water resources management ❑ Increased flood risk from rivers and streams ❑ Deterioration of water quality	• More flexible planning of water resource management • Improvement of the efficiency of supply networks • Investment in increased supply (reservoirs) and transfer options (pipelines) • Improvement of irrigation schemes • Investment in improved waste water/ storm flow management • Investment in leakage reduction • Improvement of flood plain/ river catchment management
Coastal zones	❑ Increased flood risk from the sea (due to SLR and increased frequency of storm surges events) ❑ Change in flood return periods ❑ Permanent inundation and consequent loss of land (coastal habitats, in particular wetlands and dunes) ❑ Saltwater intrusion into freshwater systems ❑ Change in sea water temperature and salinity ❑ Change in river discharges into the sea ❑ Increase in algal blooms frequency and consequent intensification of associated health and environmental impacts ❑ Increased coastal erosion	• Elaboration of climate change scenarios and their integration into coastal management plans • Improvement in the prediction of extreme events occurrence (such as storm surges or intense precipitation) • Managed retreat where coastal development is not too dense • Elaboration of flood monitoring system and mapping of high risk areas • Readjustment of present flood defence • Plantation of suitable protecting plant species in coastal zone • Protection and artificial sand nourishment of beaches • Hard engineering intervention for the protection of coasts, where no other options are possible • Definition of *Integrated Coastal Zones Management Plans*, in particular through the collaboration between different local stakeholders

Ecology	❑ Loss and deterioration of designated protected areas ❑ Loss of habitat (for example salt marshes and dunes) ❑ Change in ecological parameters (such as temperature, salinity, availability of nutrients, etc.) ❑ Change in species composition and distribution ❑ Introduction of marine alien species (in particular through the Canal of Suez) ❑ Increased fire risks ❑ Water quality related impacts, such as intensification of eutrophication and toxic blooms of algae	• Re- evaluation of designated protected areas and definition of new strategy for the protection of relevant ecosystems • Planning of new reserves and wildlife corridors between fragmented habitats • Changes in scale and type of habitat management • Investment in and application of measures against forest fire (monitoring, mapping of high risk areas, prevention)
Agriculture	❑ Decreased water availability and quality – in particular in the southern basin - as a result of lower precipitation, higher temperature and evapotranspiration rates, increased drought frequency and salt water intrusion. ❑ Increased soil erosion ❑ Soil salinisation ❑ Livestock stress as a result of hotter summers and decreased water availability ❑ Increase in pest and disease outbreaks ❑ Increased yields and new agricultural opportunities in some specific regions	• Adoption of better adapted crop varieties • Development of new adapted crop varieties, for example with greater drought resistance or delayed maturity • Adoption of better adapted animal breeds • Monitoring of crop responses to change in climatic conditions • Adoption of techniques which allow the protection from and prevent of soil erosion • Physical protection of coastal agricultural land from sea level rise and storm surge • Continued monitoring of plant pests and disease and development of reliable forecasting systems. • Development of weed, pest and disease control strategies and techniques • Development and adoption of appropriate and low- cost water conservation and water- efficient irrigation methods
Health	❑ Direct impacts due to changes in mean temperature, precipitation and air circulation ❑ Impacts due to change in the frequency and distribution of extreme events and weather disaster ❑ Increased risk of food related diseases ❑ Increased risk of waterborne diseases ❑ Increase risk of malaria ❑ Increase in heat related deaths and illnesses ❑ Increase in the incidence of illness related to air pollution	• Strengthening of public health defences • Strengthening of infectious disease surveillance programmes, which also take into account climate related issues and the spreading of new diseases • Training of health professionals in the specific field of climate related disease • Health education in order to reduce exposure to heat stress • Development of heat early warning systems • Promotion of food hygiene related issues

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