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CLIMATE PHENOMENA AND VULNERABILITY: THE ECUATION DETERMINING DISASTERS

The Case of Small Island Developing States

This documents was prepared by Jairo Escobar R., a consultant with the Natural Resources and Infrastructure Division. The opinions expressed herein are those of the author and do not necessarily reflect the views of the Organization. This documents has not undergone formal editing but has been checked for correct terminology and references.

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SUMMARY

This document provides an outline of the main uncertainties surrounding the vulnerability of Caribbean Small Island States (CSIS) to extreme events such as hurricanes and tropical storms. The analysis includes the possible effects of El Niño in the light of the main uncertainties surrounding the management of the marine environment and climate change in the context of Chapter 17 of Programme 21. Also taken into consideration for this purpose is the work of the Intergovernmental Panel on Climate Change (IPCC), specifically its predictions regarding the average global sea-level rise brought about by global warming.

We have set out to analyse a number of ecological, environmental, social and economic variables in the light of the experience built up in different countries over a given period, and then to relate fragility to other scenarios not linked to climate change.

This work should provide a basis for the production of integral, interdisciplinary public policies that aim to include precautions against the effects of natural phenomena among the issues incorporated into national and local sustainable development strategies.

I. INTRODUCTION

Like their counterparts in other latitudes, CSIS are small developing States, and they are made up of the Antilles, the Lesser Antilles and other islands, with different cultures, customs, languages and traditions and with valuable ecosystems in common, such as coral reefs, mangrove forests, marine prairies, sandy beaches, considerable biodiversity and endemism and dazzling landscapes. All of them are within the Caribbean Basin (see **Figure 1** in **Annex 3**). CSIS, like their peers in Africa, Europe, Asia and the Pacific, represent a "special category" of States owing to the "special conditions" that present there in respect of a number of the major environmental issues that are of concern today. As is very apparent, these special conditions create a high degree of "vulnerability", which is accentuated by the limited ability of CSIS to respond to the effects of extreme natural events.

Generally speaking, CSIS are exposed to four types of extreme natural event, all of them recurrent, unpredictable, variable in duration and intensity and capable of producing profound social, economic and environmental effects. These are *volcanic eruptions*, *hurricanes*, *tropical storms* and *storm surges* and *tsunamis*. Of these, the most frequent are hurricanes and tropical storms. Owing to the rise in sea level, they have been linked in a special way with global warming. Like their counterparts in other latitudes, CSIS have been judged to be "extremely vulnerable to global warming and sea-level rise", and in particular to the possible "increasing frequency of hurricanes associated with climate change" (United Nations, 1992). The Declaration of Barbados, which came out of the Global Conference on the Sustainable Development of Small Island Developing States (Bridgetown, 26 April to 6 May 1994), reaffirmed this vulnerability, and also recognized the limited capabilities of Small Island Developing States when it came to responding to and recovering from the disasters caused by these events.

Among the special types of vulnerability characteristic of Small Island States, the Barbados Summit (United Nations, 1994a) drew attention to the following:

- The global change referred to will lead to an increase in sea level, which will have a profound effect on the economy of the islands, with negative consequences for fishing, tourism, coral reefs and the fresh water supply.
- Natural phenomena such as hurricanes and cyclones that already devastate the society of the islands will increase in frequency and intensity as a result of climate change.
- The fragile economies of the islands, which are heavily dependent on imports, with exports of their products limited or otherwise, will be subject to external shocks and fluctuations in

the external market. The isolation and small scale of their economies make it difficult to attract investors or diversify.

- Development will put a new type of pressure on scarce land, water resources and energy and will destroy the balance of vulnerable ecosystems.

Section I "Climate Change and Sea-level Rise" of the Barbados Programme of Action states that "the increased frequency and intensity of the storm events that may result from climate change will also have profound effects on both the economies and the environments of small island developing States. Small island developing States require all available information concerning those aspects of climate change". For its part, the First Caribbean Ministerial Meeting on the Implementation of the Barbados Programme of Action (Bridgetown, 13-14 November 1997) affirmed the need to participate actively in the adoption of sustainable development principles to lessen the consequences of inherent vulnerabilities and improve the quality of life of the Caribbean peoples (ECLAC/CDCC, 1997). On the international level, the ministers expressed their desire to have the Caribbean declared a **special area** at the special session of the United Nations Assembly which will review implementation of the Barbados Programme of Action in 1999, and also voiced the need for attention to be focused on the peculiarities and vulnerabilities of Small Island Developing States.

Again, the Second Summit of Heads of State and/or Government of the States, Countries and Territories of the Association of Caribbean States (ACS) (Santo Domingo, Dominican Republic, 16 and 17 April 1999) recognized the differences in size and development levels between the economies of the ACS countries and paid special attention to the vulnerability of the smaller economies in the region. In the context of enhanced international cooperation, the Summit agreed that there was a need to promote cooperation through concerted action between member States to implement regional cooperation mechanisms in natural disaster areas (ACS, 1999).

II. THE CONCEPT OF VULNERABILITY AS APPLIED TO CSIS

Vulnerability is the main criterion used by the international community to categorize the way society responds to climate change. It literally means the capacity to be affected or changed for the worse (Kates, 1985). It is, then, a *multifaceted concept that includes physical, biological, political and socio-economic factors.* It is also a *concept that is difficult to measure in qualitative or quantitative terms, one that is changeable and demanding in terms of information, and that can be affected by exogenous and endogenous variables.* It is furthermore a concept that is *subject to many problems deriving from the many different interpretations of it.* Although small low-lying islands have been recognized as "supremely vulnerable", particularly to the rapid rise in sea level and to the likely increase in the frequency and intensity of tropical storms, no quantitative estimate has yet been reached of "how vulnerable they actually are". Importance also needs to be attached to other climate changes, such as rising temperatures and changes in precipitation and evaporation, when the vulnerability of coastlines is assessed.

For the purposes of IPCC (1995), vulnerability is defined as "the degree to which climate change may be detrimental or harmful to the system", something that depends not only on the sensitivity of the system, but also on its capacity to adapt to the new conditions. This criterion embraces both sensitivity and adaptability. In this context, sensitivity is defined as the extent to which the system reacts to a change in climate conditions, while vulnerability means both the degree to which the climate change may be detrimental or harmful to the system and the capacity of the system to adapt to the new conditions, and it varies depending on the magnitude of the changes, and the speed with which they occur. Adaptability means the degree to which it is possible to make adjustments to the practices, processes and structures of systems in the light of expected or actual changes in the climate (IPCC, 1995). The most vulnerable systems are those whose sensitivity to climate change is greater and whose ability to adapt is smaller. Vulnerability increases as the ability to adapt diminishes. *Within the context of global warming, it is very likely that measurements of vulnerability, on any of the scales currently used for this purpose, will change considerably as and when the uncertainties currently surrounding climate models come to be resolved.*

There is as yet **no global consensus on the meaning of vulnerability** within the context of climate change, or **on how it should be measured**. There is an unmet need for indicators that can identify all aspects of vulnerability while being widely acceptable, verifiable, measurable, capable of quantitative and qualitative expression and applicable over time. Nor is there **an accepted general typology** of the types of coasts that will be affected by the increase in sea level brought about by climate change. Hitherto the emphasis of studies on vulnerability by coast type has varied greatly, and there are no studies on clastic quartz coastlines, gravel banks, marine prairies, etc.

Vulnerability has commonly been measured in terms of loss of human life, property and services. The modern conception of vulnerability, associated with climate change, is multifaceted and centres more on response capabilities, and it includes physical, biological, social and economic factors. Modern methodologies approach the task of assessing vulnerability, on different scales and in a more integral way, by linking the natural system with the social and economic ones.

There are many criteria, methods and approaches for measuring the vulnerability of coasts, such as those of Van der Weider (1993), Pernetta (1998), Pernetta and Milliman (1995) and Gornitz (1991). One of the methodologies is the **common methodology** proposed by IPCC, which defines vulnerability as "the degree of incapacity for dealing with the consequences of climate change and the rapid increase in the average sea level" (IPCC/CZMS, 1991). It is used to illustrate the ability of States to handle the consequences of a rapid rise in sea level. This methodology takes into account the information available for assessing and evaluating the degree of risk involved in a rapid increase in sea level for the population, property and social, economic and natural systems and identifies the capacity of States for doing this. In this case, vulnerability is expressed as a "vulnerability profile". This methodology assumes a degree of adjustability in losses, hazards and damages depending on the rise in sea level. According to Nicholls and Vreés (1995), three variable scenarios are included in it: global climate change, regional development and the response option. In the case of ecosystem responses, a distinction is drawn between adaptive and non-adaptive responses. Non-adaptive responses occur if the rapidity of the rise in sea level exceeds a certain critical value which leads to a non-gradual irreversible loss of the ecosystems concerned. This would be the case with hurricanes that brought about the complete destruction of sand dunes, when this impact was deemed to constitute "permanent damage".

The methodology considers regional and local development over a 30-year time horizon, starting with the current situation, and works with the current sea level and increases in the global sea level of 0.3 and 1.0 metres by 2100. In 1994, 46 case studies on vulnerability analysis were reviewed using the common methodology, those for Antigua and Nevis among them. The studies showed that the increase in the average sea level was often not the most critical aspect, especially in the most vulnerable areas where long-term climate changes may ultimately interact with or exacerbate existing problems and threats, where overpopulation, the pressure for urbanization, overexploitation of resources, etc., already amount to a critical problem (World Coast Conference, 1993). Although vulnerability indices have not yet been developed for CSIS, pilot studies are advancing in some Caribbean countries, one example being the Caribbean Planning for Adaptation to Climate Change (CPACC) project to evaluate the "vulnerability profile" using the "common methodology" proposed by IPCC, which is being carried out in Guyana, Barbados and Granada (OAS, 1995).

Among the criticisms of this "methodology", attention is drawn to its uncertainty, the information required to analyse it and difficulties in identifying impact zones. In many areas, the relative increase in sea level and the spatial distribution of this increase are unknown. Another criticism is that it has little power of resolution, as it does not enable other effects produced by the increase in sea level to be identified. Given the time horizons included in vulnerability assessments carried out using this methodology, projections for vulnerability in economic and demographic systems **are not realistic**. These projections, produced for different scenarios over long time horizons, **are very subjective and full of uncertainties**; nonetheless, they are a very useful tool that can be employed by States to ascertain, albeit cautiously, the **vulnerability of their coasts** in the face of a rapid increase in the sea level over short time horizons, so that they can consider different response options.

In other studies, vulnerability is expressed in the form of "environmental vulnerability indices", as has been done for some Small Island States in the Pacific (Kaly *et al.*, 1999). Environmental vulnerability indices combine environmental factors with economic and social ones to produce **composite indices**. In these studies, vulnerability indicators are identified and selected. Among their weaknesses, attention is drawn to the difficulty these indices have in identifying all aspects of vulnerability, particularly its social and economic components. All vulnerability indices are strongly influenced by the indicators selected, so that when they are integrated serious problems of evaluation and interpretation arise. The concept of ecosystem integrity is highly complex and cannot be summed up in a single index (Pernetta and Elder, 1993). In these studies, vulnerability is defined as "the potential for attributes of a system to respond adversely to the occurrence of hazardous events and the resilience of this potential of attributes to minimize or absorb the impact of extreme events". Attention has been drawn to the advisability of each country developing its own vulnerability indices; given that the rapid rise in the sea level is a "common problem", however, the use of different indices **raises numerous problems of interpretation**. Logically, for a given level of vulnerability, such as "extreme vulnerability" for example, as found in CSIS, the indices could be very similar; but we would obviously expect to find that, within this category of extreme vulnerability, there were countries that were more vulnerable than others, and this is in fact the case.

III. STEPS TOWARDS A MORE ACCURATE APPRAISAL OF THE VULNERABILITY OF CSIS

Hitherto, as far as we know, the vulnerability of CSIS has not been expressed in quantitative terms. Nonetheless, **there are inherent conditions** which mean that these States can be characterized as "supremely vulnerable" to climate warming and other kinds of environmental hazards. Among these special inherent conditions, reference is made to the following, among others:

1. CSIS are situated in the Caribbean, in the Atlantic basin, one of the seven areas in which tropical storms regularly arise, which includes the North Atlantic, the Gulf of Mexico and the Caribbean (see **Tables 1** and **2**). In this area, the conditions for the formation of hurricanes (tropical and subtropical cyclones) arise on a regular basis: low pressure systems, i.e. masses of warm water with a temperature of around 26.5°C going down to a depth that is still unknown but is at least 50 metres, proximity to the equator, evaporation of seawater as a result of strong winds, low surface pressure, condensation associated with concentrated convective clouds and other specific meteorological and oceanographic conditions such as pre-existing disturbances close to the surface with a sufficient vertex and convergence (Landsea, 1998b; León and Zea, 1997). Generally, when the winds reach 37 km/h the cyclone that has developed is classified as a "tropical depression". When they reach 65 km/h the system is called a "tropical storm". If they exceed 119 km/h it is officially designated a "hurricane" (León and Zea, 1997). The form of the storm surge, the strength and speed of the winds and other factors in combination determine the destructive power of the hurricane. For Atlantic hurricanes, the Saffir-Simpson scale is normally used to estimate their destructive potential and the flooding that can be expected along the coast (see **Annexes I** and **II**). Hurricanes move like whirlpools, generally from east to west with a tendency towards the north. They are characterized by strong winds in excess of 119 km/h and bands of spiral-shaped clouds which produce heavy rain over distances of 300-500 km from the centre of the hurricane.

The time of year when tropical cyclones are most likely to form is summer and autumn (July-October) in the northern hemisphere and December-March in the southern hemisphere, with differences between basins where cyclogenesis takes place. The summer-autumn peaks are due to the fact that all the factors required for the formation of cyclones are at their most favourable then. These factors are warm waters in the ocean (around 26°C), a calm tropical atmosphere in which convection can easily begin, and a substantial and large-scale increase in the spin available. All these factors in isolation can mean different things. For example, in the Caribbean, at times of year when surface pressures are below average, there is an increase in cyclonic activity, while the opposite occurs at times of year when surface pressures are above average. These high pressures indicate that the Intertropical Convergence Zone (ITCZ) has either weakened or has moved into a more equatorial position, or both. Similarly, the zonal wind anomalies of 200 mb (millibars) seen in the Caribbean may show either that an El Niño event is in progress, or that there is a situation of rain in the western Sahel.

Table 1

RECORD FOR NUMBER OF STORMS BY CYCLONOGENIC BASIN BETWEEN 1968 AND 1989[a]

Basin	Tropical storm (Sustained wind speeds of over 17 metres/second)			Hurricanes/typhoons/cyclones severe tropical hurricanes (Sustained wind speeds of over 33 metres/second)		
	Highest	Lowest	Average	Highest	Lowest	Average
Atlantic[b]	18	4	9.7	12	2	5.4
North-east Pacific	23	8	16.5	14	4	8.9
North-west Pacific	35	19	25.7	24	11	16.0
North Indian	10	1	5.4	6	0	2.5
South-west Indian	15	6	10.4	10	0	4.4
South-east Australia	11	1	6.9	7	0	3.4
South-west Australia	16	2	9.0	11	2	4.3
World	103	75	83.7	65	34	44.9

Source: Landsea, 1998a. [a] 1968-1969 to 1989-1990 for the southern hemisphere. [b] Includes subtropical storm.

Table 2

REPORTING PERIODS FOR NAMED TROPICAL STORMS (TROPICAL STORMS AND HURRICANES) IN THE ATLANTIC BASIN

Period-years	Named tropical storm	Tropical/ subtropical storms	Hurricanes	Hurricane days	Strong hurricanes
1944-1950	72	72	44	186	22
1951-1960	98	98	62	242	27
1961-1970	96	97	62	301	23
1971-1980	83	96	63	187	16
1981-1990	93	95	54	168	16
1991-1996	46	36	21	79	10
Total:	488	494	306	1163	114
Average	9.11	9.32	5.77	21.94	2.15

Source: Compiled on the basis of information from Landsea (1998a).

The location of CSIS means they are in a situation of high risk owing to their position on or close to the paths of the tropical storms that form in that basin, where the gulf stream provides a constant source of warmth (fuel) to help sustain hurricanes (see **Figure 2** in **Annex 3**). Some of these turn into hurricanes before reaching the Caribbean, as is the case with Cape Verde type hurricanes. On average, 10 tropical storms form in the Atlantic, Caribbean and Gulf of Mexico each year, of which six turn into hurricanes, while others remain over the ocean; of these, at least three reach CSIS with some regularity, and of these, at least one or two measure more than 3 on the Saffir-Simpson scale. Atlantic hurricanes account for around 38% of the world hurricane average. There is also evidence that some tropical cyclones originating in the Atlantic go over to the Pacific and vice versa. The Atlantic basin has a very marked season for tropical storms (officially from 1 June until 30 November). During this time, around 78% are days of tropical storm, 87% are days of minor hurricanes (1 and 2 on the Saffir-Simpson scale) and 96% are days of strong hurricanes (3, 4 and 5 on the Saffir-Simpson scale) (Landsea, 1998c).

CSIS suffer not only from hurricanes but from volcanoes as well; however, it is the former that cause the greatest and furthest-reaching effects. CSIS are exposed to the passage of hurricanes on a number of occasions in a single season. This "repetition" makes it impossible to single out the effects of each individual storm and increases vulnerability considerably. In 1989, for example, hurricane Hugo, with a strength of 4, passed among the islands of the eastern Caribbean, affecting Dominica, Nevis and the British Virgin Islands. Later, in 1995, the tropical storm Iris and hurricanes Luis and Marilyn passed among the islands of the eastern Caribbean in a period of three weeks (26 August to 16 September 1995). Luis was strength 4 and Marilyn strength 3. All the islands from Grenada to Puerto Rico were affected by these two storms, with severe damage in Dominica and other islands such as Saint Thomas, Antigua and Saint Martin. The Government of Saint Thomas put the damage wrought by the hurricanes at over US$ 3 billion. Hundreds of people stayed away from their homes for a lengthy period of several months, around 2.7 million square feet of plastic were used to cover around 3,600 buildings on Saint Thomas and many tourist hotels could not reopen until the spring of 1996. The effects on the tourism industry were considerable (Towle, 1999). For the Caribbean, this hurricane season (1995) had the greatest average frequency and intensity since the beginning of the century. In 1996, hurricane Bertha passed to the north of Montserrat and was followed by tropical storm Hortensia which later turned into a hurricane, passing to the south of Montserrat in September. **Table 3** shows the statistics for the main hurricanes passing close to Montserrat between 1989 and 1996.

The damage caused by hurricanes in CSIS varies greatly, but includes loss of life and property and disruption to the water supply, and is the main cause of beach deformation in the Caribbean.

2. Although volcanic activity and the events associated with it are not linked to climate change, it is an important factor in determining the vulnerability of the regions exposed to seismic risks. Earthquakes and tsunamis occur less frequently and are separated by long periods, but historical records show that many of these events have the potential to be more catastrophic than tropical storms. The Caribbean is a region with a considerable history of earthquakes, with known events dating from the sixteenth century. According to the Intergovernmental Oceanographic Commission (IOC) Association for the Caribbean and Adjacent Regions (IOCARIBE) (Lander, O'Loughlin and Whiteside, 1999), around 88 tsunamis have taken place in

the region over the last 500 years, at a rate of one or more severe events per century and "an average of one destructive tsunami every 26 years", even though there has now been a period of "calm" lasting for 53 years. CSIS are also particularly vulnerable to the effects of tsunamis, as the Caribbean is a seismically and volcanically active region surrounded by the edges of tectonic plates (Institute of Technology of Florida, 1999). See **Figure 3** in **Annex 3**.

Table 3

MAIN HURRICANES PASSING CLOSE TO MONTSERRAT FROM 1989-1996[a]

Name	Category	Date	Distance from Montserrat
Hurricane Hugo	4	17-18.09.89	The centre passed over the island.
Tropical storm Iris	N	26-27.08.95	50 km
Hurricane Luis	4	04-06.09.95	100 km
Hurricane Marilym	3	15-16.09.95	50 km
Hurricane Bertha	1	07-09.07.96	150 km
Huracane Hortensia	1	08-10.09.96	80 km

[a] Taken from COLSAC (Coast and Beach Stability in Lesser Antilles).

The arc of the Lesser Antilles **seems to be the most likely source of a tsunami disaster in the Caribbean**, the evidence for this being, on the one hand, the growth in the dome of the active volcano of Montserrat, which suggests a potential tsunami danger resulting from landslips and, on the other, the undersea volcano Kick'em Jerry, situated 8 km from the north coast of Grenada, which represents a threat to the islands of the eastern Caribbean. We know of 30 tsunamis that have produced significant damage; combined with tsunamogenic earthquakes, these have been responsible for around 9,600 fatalities. According to IOCARIBE, the number of deaths in the region in the last 150 years has been "around five times higher" than in Hawaii, Alaska and the east coast of the United States combined (see **Table 4**).

3. Except in a very few limited cases, the populations of CSIS live entirely on their coasts. Many islands have reached such high population densities **that future increases in population represent a hazard** (Vicente, Singh and Botello, 1993). Some CSIS are, in a sense, "nothing but coasts" (Obasi, 1994), with high population densities, in some cases among the highest in the world. As the above implies, both the economy and activities related to tourism are concentrated around the coast. From the point of view of the human population too, CSIS have been described as "extremely vulnerable" to the rise in sea level (Izrael, 1991). The population of CSIS virtually doubles in the peak tourist season. According to UNEP (1998), in 1996 the Caribbean received 25.5 million visitors (14.8 million holidaymakers and 10.7 million cruise tourists) who used 183.6 thousand hotel rooms in 36 countries. Of these, around 70% were CSIS tourists, which may have meant the local coastal population temporarily increasing **roughly twofold**.

Table 4

TSUNAMIS WITH FATAL RESULTS IN THE CARIBBEAN[a]

Date	Place	Maximum height of wave (in m)	Notes
April 16, 1692	Port Royal, Jamaica	?	Probably earthquake leading to tsunamis because of landslips. An unknown proportion of the total of 2,000 fatalities was produced by the tsunami. Some 90% of all buildings were destroyed. A two metre high wave crossed the bay. Along the Liganee coast (possibly Liguanea Plain) the sea withdrew between 183 and 274 m, exposing the sea bed. When it came back in, it flooded much of the coast.
October 2, 1781	Jamaica	?	Ten tsunami deaths. A series of disastrous waves and earthquakes devastated the island of Jamaica.
July 26, 1824	Port-de-Paix, Haiti	5	200-300 earthquake and tsunami deaths. In Port-de-Paix, the sea withdrew 60 m then came back in as a wave that covered the city to a depth of 5 m of water.
November 18, 1867	Virgen Islands, United States	7.6	11-12 deaths near Charlotte Amalie, St. Thomas, when the USS De Soto was damaged; five deaths in Fredericksted, St. Croix. In Charlotte Amalie the sea was 2.4 m above its normal level. The sea withdrew around 100 m and came back in as a 4.5 to 6 m high wave which penetrated 76 m inland. In Fredericksted the sea withdrew and came back in as a wall of water 7.6 m high, carrying the USS Monongahela on its crest.
October 11, 1918	Puerto Rico	6	34 deaths in Aguadilla; eight deaths in Punta Agujereada, plus 100 missing, presumed dead. Waves between 5.5 and 6 m high swept away several hundred palms and other trees and many small houses in Punta Agujereada. In Aguadilla, a wave rising 2.4 to 3.3 m above sea level destroyed 300 huts.
August 8, 1946	Matanzas, Dominican Republic	2.4	The city was seriously affected and 1,700 people died. The wave was probably 2.4 m high.

[a] Taken from IOCARIBE (Tsunami Steering Group of Experts), San José, Costa Rica, April 1999.

High population density, combined with a small land area, means that a rapid rise in sea level and the likelihood of an increase in the intensity and frequency of storms can be expected to lead to serious problems. In particular, withdrawal from the coast is impossible in most cases, investment in defensive structures is out of the question owing to the small size of these countries' economies, and relocation raises serious problems of culture shock, adaptation and competition. In this respect, Sarma (1993) says that "the relocation of individuals, planned or not, will cause traumatic damage. The impact of the people relocated on those native to the areas where they are relocated will be high, and could cause major conflicts. When relocation crosses national borders, it results in conflicts."

It has been asserted that, owing to regional differences in storm systems, the increased risk of flooding produced by the rise in sea level is higher for the Caribbean and other Small

Island States in other regions than the average for Asia (World Coast Conference, 1993). Reductions of between 20% and 30% in gross national product owing to the effects of hurricanes are common. Obasi (1994) points out that in 1980 hurricane Allen completely destroyed banana crops and seriously affected most hotels situated close to the coast in Saint Lucia. The crops took around a year to recover, as did tourism, with consequent losses in the form of lost earnings and the associated social ills.

Owing to their vulnerability to storms, CSIS have been classified for insurance purposes as "high risk areas", and since the effects of hurricane Gilbert in Jamaica in 1988 and hurricane Andrew in the Bahamas in 1992, the cost of insurance has risen by 300% to 400% in many places (Obasi, 1994).

The second evaluation by the IPCC (1995) gives an estimate of 50 cm for the increase in sea level between now and 2100, which is 25% better than the 1990 estimate. This represents an improvement in climate models. Combining the scenario of the lowest emissions with the lowest climate sensitivity, a rise in sea level of 15 cm by 2100 is obtained. The projection for the opposite scenario (with no reduction in aerosol emissions) gives an increase of 95 cm by 2100. IPCC (1995) says, furthermore, that "the sea level will carry on rising at a similar rate over the centuries following the year 2100, even if greenhouse gas emissions have been stabilized". These increases could leave most CSIS "almost underwater". However, **at present we do not know enough to say whether there will be changes in the rapidity with which the sea level rises, and regional projections are still untrustworthy**. We know that whatever the rise in the sea level might be, it will not be the same around the world, as there are large regional variations owing to the thermal expansion of oceans and to changes in oceanic circulation, among other things. Two of the main effects of a rising sea level on CSIS are the loss of coastal land below the new level and the permanent flooding of flat, low-lying land, which means there is also likely to be an impact on fresh water resources owing to salt water infiltration. **Table 5** shows some general characteristics of CSIS as regards population density on the coast.

4. The economies of CSIS are small and extremely fragile, and generally depend to a large extent on imports more than on exports. Tourism has become one of the most important activities for CSIS economies, and it relies heavily on beaches, diving, infrastructure and the natural landscape. Beaches and landscape, in turn, form part of the natural heritage. Beaches are one of the most dynamic and vulnerable resources of CSIS coasts, and ensuring their stability has come to be a priority. In general, they have been affected by erosion resulting from human activities and natural causes. In the case of CSIS, it seems that the main causes of beach erosion are storms and hurricanes. A project on coasts and beach stability in the Lesser Antilles (Hurricane Impact on Beaches in Eastern Caribbean 1989-1995 COLSAC-1), started in 1980 by UNESCO and refocused in 1996, which involves many CSIS, supplies important information on the effects of hurricanes on beaches, including information on changes in beaches after hurricanes (UNESCO, 1999).

Tabla 5

LENGTH OF COASTLINE OF CERTAIN CSIS. POPULATION DENSITY AND MAIN ENVIRONMENTAL PROBLEMS[a]

CSIS	Area (km)^2	Population B	Length of coastline (km^2)	Inhab. /km^2	General aspects	General environmental problems
Antigua and Barbuda	440	65.000	153.0	147.7	Flat, low-lying islands of volcanic origin, with narrow shelf, fine sandy beach, fringing coral.	Excessive removal of beach sand, overfishing of lobster, construction of hotels on the beach..
Barbados	432	261.000	97.0	607.0	Flat, low-lying island of volcanic origin on a coral shelf, narrow submarine shelves, beaches of white sand, mangroves, fringing coral.	Resources near the coast are over-exploited, erosion of the coast by dredging, with effects on the coral, changes in the pattern of coastal circulation and pollution by waste and fertilizers.
Dominica	751	71.000	148.0	95.4	Does not have a coastal plain; is wooded with high steep mountains of volcanic origin.	Destruction of coral by hurricanes, erosion, pollution by oil and rubbish from ships.
Grenada	334	92.000	120..3	267.4	Islands of volcanic origin, with mangroves, marine prairies and coral.	Overfishing, erosion of the coast near tourist centres, removal of trees on the coast, removal of sand and erosion.
Puerto Rico	8.897	3.646.000	704.0	409.8	Has a ridged topography, wooded mountains, a narrow 1 to 11 mile shelf and coasts exposed to the wind with highly localized areas of coral.	Destruction of coral by hurricanes and human activity, sedimentation and alteration of the dynamics of sediments, severe and moderate erosion, accidental oil pollution, pollution from onshore activities.
Montserrat	102	11.000	?	107.8	High, steep volcanic island, beaches of white sand, wooded, rainy.	Overfishing.
Antilles Curacao Bonaire Aruba	992 193	179.000 69.000	68.0	246.3 357.5	Low-lying coral islands with bays and mangrove swamps. Fringing coral, steep volcanoes. Marine prairies and coral reefs.	Overfishing; pollution, particularly on the Saba bank.
Turks and Caicos	430			32.6	8 large islands and 40 small ones, semi-arid with mangrove forests, caves, coral reef, sandy beaches with salt flats	Problems with uncontrolled tourism, removal of sand from beaches.
St. Kitts and Nevis	261.6 235.0	40.000		152.7	High islands of volcanic origin with narrow coastal shelves, many large coral reefs, beaches of white sand.	Overfishing and overcatching of lobster and sea snail, exploitation of sand dunes for construction.
St. Lucía	617	41.000	158.0	228.5	Volcanic origin; high, steep with marine prairies, large coral reefs, few beaches.	Erosion from removal of plant cover, exploitation of beach sand.
St. Vincent and thes Grenadines	338	111.000			Volcanic, mountainous islands with beaches of white sand, coral reefs, large, wide shelf.	Oil pollution, excessive mining of beach sand.
Trinidad and Tobago	5.130	1.257.000	362.0	245.0	Flat island with high mountains, many rivers. Exposed open beaches. Mangroves, coral reefs, marine prairies.	Oil pollution, erosion, destruction of coral.
Dominican Republic	43.803	7.769.00	1.288	150.8	Coral reefs, estuaries, coastal wetlands, entire coast fringed with coral, mangroves, marine prairies.	Pollution, overfishing, destruction of coral by hurricanes.
Haiti	27.750				Occupies 2/3 of island of Hispaniola, with low mountains, many beaches, bays, mangroves and coral reefs.	Destruction of mangroves, overfishing, alteration of beaches.
Jamaica	10.991	2.496.000	1.022	227.1	Large mountainous island. Flat, low-lying coastal areas. Mangroves and coral reefs.	Excessive overfishing, high sedimentation, coastal erosion, collection of coral.

[a] Amended and suplemented by IOCARIBE, 1997.

[b] 1994 data.

The impact of nine tropical systems on Dominica between 1979 and 1995 was evaluated by Arlington (1996). All the hurricanes affected beaches, the most severe being hurricane David in 1979, hurricane Klaus in 1984, hurricanes Gabriel and Hugo in 1989 and hurricane Luis in 1995. Most of the beaches were severely eroded and on many of them the sand was replaced by stones and pebbles; one beach was completely washed away. The loss of protective vegetation left beaches bare in many places and more vulnerable to subsequent storms. On the beaches of Nevis, the combined effects of hurricane Hugo in 1989 and hurricane Luis in 1995 led to the beach line retreating, this being considered "a permanent change". Similarly, the effects of the 1995 hurricanes were evaluated on Anguilla, Antigua and Barbuda, Saint Kitts and Nevis, Montserrat and Dominica. Here, beaches were severely eroded and lost some 20% in volume. Subsequent analyses of the beaches affected by hurricane Hugo showed a very limited degree of recovery for every two to three years after the hurricane. The scientific literature on the subject points to an imbalance between the speed of beach loss (erosion and loss of beach sand) and subsequent redistribution and the speed of recovery and formation, which are generally very limited and slow. Experience has shown that a beach does not recover to pre-hurricane conditions. This could be the cause of a "probable crisis" in the construction industry of CSIS and of an excessive rise in the "beach sand trade". In addition to changing the beach line, hurricanes also affect the sand dunes and sandbanks of many islands.

It was found that 40 km away from the centre of hurricane Luis in Montserrat, the beach line had retreated by an average of 5 to 18 m, the maximum recorded being 30 m, and that 40 to 180 km from the centre of the same hurricane the beach line had retreated by between 2 and 5 m. Although there appears to be a good correlation between the distance from the centre of the hurricane and the severity of the damage, there are other highly variable factors that prevent this correlation being treated as a general rule. Among the factors that influence hurricane-related beach erosion are the particular characteristics of the hurricane, the shape of the coast, the width of the shelf and particular environments. It is still not very clear how much erosion in CSIS is linked to the rise in the sea level, or how the adjacent reefs can contribute to increasing the area of islands in response to the erosion caused by that rise and the effect of the storms connected with it. It would seem that **there are gaps in our knowledge of the effect warming has on the inherent factors determining the stability and permanence of islands.**

Different methods and models have come to be used to predict the profiles taken on by beaches in response to withdrawal and the associated erosion resulting from the impact of storms. With these methods, it is argued that the erosion produced by storms can be determined from the knowledge available on beach profiles pre- and post-storm, and it has been proposed that, for regulatory purposes, when safety zones are being decided on for beaches in some CSIS, "these zones should be reviewed and determined on the basis of the worst case analysis", given the forecasts for stronger and more frequent hurricanes as a result of global warming. The limitation of these methods, according to Azus (1995), stems from their assumption that the potential erosion from the highest level of storm "is realized instantaneously", when we know that the response of beaches to stable conditions is roughly exponential over time.

Table 6 shows the changes experienced by the beaches of Montserrat between 1990 and 1996 after hurricane Hugo (Ministry of Agriculture, 1997). According to what it shows, between 1991 and 1993 the island's beaches showed a tendency to grow, but this tendency went into reverse after 1994, when erosion continued even though there had not been any significant hurricane activity. In 1995 there was very strong erosion which coincided with the very marked hurricane season of that year. Erosion continued during 1996 without any significant recovery. Hurricanes are reported to be possibly the greatest cause of beach alteration in Montserrat.

Table 6

CHANGES IN THE BEACHES OF MONTSERRAT

Years	Average change in the perimeter of the area (in %)	N^0 of sites undergoing erosion	N^0 of sites undergoing accretion	Total N^0 of sites
1990-1991	+12.8	2	7	9
1991-1992	+10.5	3	6	9
1992-1993	+07.8	2	8	10
1993-1994	-07.9	8	2	10
1994-1995	-11.4	8	2	10
1995-1996	-01.0	8	6	14

Source: Taken from COLSAC (Coast and Beach Stability in Lesser Antilles).

As part of the "Environment and Development in Coastal Regions in Small Islands" initiative launched by UNESCO in 1996, studies are being carried out to examine current "setbacks" and propose new ones, setbacks being areas of beach that can contract or expand naturally without there being any need for protective structures, providing a buffer zone between coastal construction areas and the active beach zone. In CSIS that have established setbacks, these are normally defined from the line of the highest tide. There are problems with this definition, as tides change daily, and with the different interpretations used to define this zone. Setbacks vary in distance from one CSIS to another, and are generally too short if strong hurricanes occur. According to Cambers (1996), it will be **necessary to use a determining factor for setbacks**, considering that **any island in the eastern Caribbean could be struck by a strong hurricane passing directly over or close to it in the next 30 years**, particularly in the case of those islands that have been affected by more than one severe hurricane. By and large, hurricanes higher than 4 on the Saffir-Simpson scale would be expected to alter sand dunes and the beach line. It has also been suggested that the idea of variable setbacks be used to ensure that new developments are sustainable, and "safe setbacks" have been used in three islands. Variations in the response of beaches to hurricanes seem to depend on the lie of the coast, the width of the shelf, the past history of anthropogenic changes and the nature of the hurricane itself. Some CSIS have begun a review of their setbacks. Nevis, for example, has developed a setback policy for the main beaches used by tourists which prescribes a greater distance between new hotels and the highest tideline. An understanding of how storms and the rising sea level are affecting beaches can provide an important yardstick for forecasting the physical stability of CSIS and the tourism they receive. Collins (1995) has indicated that "there is a need to understand the response of beach profiles to extreme events and the short-term effects of storms on the control base, evolution and development with the associated coastal morphology".

5. Also contributing to the inherent vulnerability of CSIS are their limited natural resources and "their highly fragile ecosystems". CSIS, like other Small Island Developing States, are characterized by their high biological diversity and high level of endemicity, mainly owing to their coral reefs, marine prairies, etc. (see **Figures 4** and **5** in **Annex III**).

Storms affect coral through mechanical damage, breaking them, increasing turbidity and bleaching them. Coral reefs are one of the most productive ecosystems known (with primary productivity that is 30 to 250 times higher than that found out to sea and with output of between 1,500 and 5,000 g/c/m^2 *x* year-1 (IUCN, 1993)) and have some (still debatable) degree of tolerance to rapid rises in sea level. Many coral species live very close to their limit of thermal tolerance. A slight increase in temperature over the maximum tolerance can kill the coral. Small increases in sea temperature can result in the "bleaching of some species of coral", something that a number of experts view as "an early sign of warming". There are still doubts over the extent to which the bleaching of coral is an effect of global warming or is naturally occurring, as when the El Niño event takes place. It may be that global warming is affecting corals in this way. It has been calculated that in the 14 years since the 1997-1998 Phenomenon, 40-50% of coral has suffered decoloration. It has been observed that "scientists do not yet have sufficient data to draw linkages between coral bleaching and climate change" (United Nations, 1999). Tropical water coral is normally found in areas where the sea water temperature is within the 20-30°C range, and does not develop well below 20-30 m, because its symbiotic alga (*zooxantella*) depends on light for photosynthesis. It also has a very limited salinity range (if salinity drops below 20‰ for more than 24 hours, the coral dies). Among others, these conditions –very narrow temperature and salinity ranges, growth near the surface of the sea and non-occurrence in turbid waters– make coral a fragile ecosystem that is highly vulnerable to a rising sea level, and particularly to two key manifestations of this: a large increase in rainfall and subsequent erosion and sedimentation during large storms, and an increase in the frequency and intensity of storms and hurricanes. Many of the "necessary" conditions for storm formation that already exist in the Caribbean are very close to the thermal and saline tolerance limits of coral.

Since 1980 there have been reports of coral in the Caribbean becoming bleached, and in extreme cases dying, in association with abnormal increases in the sea temperature or with prolonged periods of maximum temperature in summer (IUCN, 1993). In any event, there is still no clear understanding of this relationship. The Caribbean Coastal Marine Productivity Programme (CARICOMP) is carrying out monitoring studies on this possible effect (IUCN, 1993). Other initiatives in this area are being pursued within the framework of the Action Plan for the Wider Caribbean. It has been forecast that a change in the frequency and strength of tropical cyclones will have "its greatest effect on the structure and growth rates of coral reefs". Studies on the effects of storms on coral suggest that these can recover, but recovery speeds are highly variable, ranging from between 20 and 50 years for complex coral reefs to five years or less for simple reefs in a state of succession subclimax. Some species, such as *Acrophora palmata*, recover even more quickly than this (IUCN, 1993).

Although there has been no systematic, sustained long-term study of the effects of hurricanes on coral reefs, it is known that in CSIS they can destroy large areas, both by increasing the amount of fresh water and by causing mechanical damage to branching corals, especially fringing corals. Hurricanes Federico and David in 1979 and Allen in 1980 caused serious damage to reefs around most of the islands. It was observed that shallow water corals (*Acrophora palmata* and *Acervicornis*) tended to die at a great rate. **Table 7** gives an account of the destruction of coral by hurricanes around some Caribbean islands.

6. Another factor making CSIS particularly vulnerable is connected with the availability of the information needed for their own regional climate prediction models and storm and weather models. Some of the necessary meteorological information is gathered through the national meteorological and hydrological services of the area, which monitor and exchange immediate information via a world telecommunications system under the auspices of the World Meteorological Organization. Much oceanographic information is still in the process of being produced and is not readily available for regional prediction models. At the Chapman Conference on the Circulation of the Intra-Americas Sea (La Parguera, Puerto Rico, 1995), the IOCARIBE regional Group of Experts on Ocean Processes and Climate identified a number of studies that were needed to improve understanding of the circulation of the Caribbean (Intergovernmental Oceanographic Commission (IOC), 1995).

Table 7

DESTRUCTION OF CORAL BY HURRICANES AROUND SOME CARIBBEAN ISLANDS

Island	Hurricane/storm-year	Bleaching	References
Anguilla	Shoal Bay – Island Harbour, (H) David, 1979.		Regers, 1985.
Antigua and Barbuda	Goat Head reef, (H) David, 1979.		Weiss M. and G. Multer, 1984.
Bahamas	New Providence, (H) Betsy, 1965.	Great Bahama Black, 1963	Easton, 1968; Glynn, 1984.
Barbados	Nort Bellaris, (H) Allen, 1980.		Mah and Sterns, 1985.
Bermuda	(H) David, 1979.		Morris *et al,* 1997.
British Virgin Islands	Virgen Gorda, Donna 1960; Anegada, (H) David, 1979; Little Juast Van Dyke, (H) Allen 1980, The Indians.	David, 1979	Rogers, 1985.
Cayman Islands	(H) Allen, 1980.		UNEP/IUCN, 1988.
Dominica	(H) David, 1979.		UNEP/IUCN, 1988.
Grenada	South coast; (H) David, 1979.		UNEP/IUCN, 1988.
Guadeloupe	Gran Cul de Sac (H) David, 1979		UNEP/IUCN, 1988
Jamaica	Ocho Ríos, North and South coast, (H) Edith, 1963; (H) Allen, 1980		UNEP/IUCN, 1988
Trinidad and Tobago	Bucoo Reef, (H) Edith, 1963		UNEP/IUCN, 1988
Saint Kitts and Nevis	(H) Klaus, 1984		UNEP/IUCN, 1988
Saint Lucia	(H) Allen, 1980		UNEP/IUCN, 1988
Martinica	(H) David, 1979		UNEP/IUCN, 1988

Source: Compiled on the basis of information from UNEP/IUCN (1988).

IV. UNCERTAINTIES ABOUT CLIMATE CHANGE AND THE ROL OF THE OCEAN

The uncertainties about the effects of climate change on CSIS are linked to those conditions that bear on the special vulnerability of CSIS, namely the increase in the sea level, changes in the frequency of storms and hurricanes and changes in their paths. Changes in the variability of the weather, such as longer winters and shorter and hotter summers, are equally important. The ability of CSIS to measure, monitor, communicate and respond appropriately to these is a very important tool for helping them to set a policy to deal with their own vulnerability. There is a real need for them to have the information, instruments and training they require to construct their own regional climate models. Oceanography is not yet readily available in the area. There will be a need for specific programmes for regional purposes that recognize the special conditions of CSIS and enable the smaller ones to become more involved.

Most of the severest effects on the climate are produced by the ocean: storm surges, storms, cyclones, hurricanes, El Niño. Consequently, there is a need for oceanic information if predictions about the future climate are to be improved. Accordingly, the international community has agreed, within the framework of Chapter 17 of Programme 21, to carry out activities aimed at responding to the main uncertainties about the role of the oceans in climate change. **Among the greatest of these uncertainties are those involved in predictions about the rapid rise in the average sea level and the effect of this rise on tropical storms and their paths and on other ocean-atmosphere interaction phenomena, such as El Niño**. The causal relationship with the temperature at the sea surface (TSS) suggests that the intensity and frequency of tropical storms could increase in future. The gases connected with the greenhouse effect seem to be contributing to a rise in the surface temperature of tropical seas and to the rainfall associated with the intertropical convergence zone (ITCZ). The pattern of TSS and its associated warmth and mixing flows are known to affect these climatic events. It is also known that any change in cyclonic activity is intimately linked with long-term changes in the tropical atmosphere. On the global scale, the ocean stores and transports heat and acts as a heat source that produces atmospheric convection and winds. The TSS pattern with its associated warmth and the mixing of flows affect climatic events such as storms and hurricanes and are key elements in climate change.

Information about forecasts of global warming-related changes in the frequency, size and paths of tropical cyclones generally derives from observation and modelling. General circulation models (GCMs) are used to make these predictions, along with statistical probability models and combined ocean-atmosphere models. In general circulation models, climate scenarios consistent with an increase of CO_2 in the atmosphere have been produced. In these, it has been shown that if the concentration of CO_2 were doubled, the number of simulated tropical disturbances would increase by roughly 50%, as would the number of severe disturbances, when the wind speed increases by 20% (Ryan, Walterson and Evans, 1992; Stein and Hense, 1994). GCMs also indicate changes in the paths of storms in response to global warming. At present, "the models do not give indications consistent with an increase or diminution in tropical storms", and it has been necessary to make empirical adjustments to GCMs for flows on the ocean surface in order to reduce the errors in simulated climates. With the present state of knowledge, the description of the main problems involved in the models shows that they are still very crude owing to the high level of uncertainty surrounding predictions of climate change, as clearly demonstrated by the wide range of values yielded by GCMs. Even the most recent ones do not resolve small-scale disturbances, which means that they cannot be used to evaluate changes in the diminution of storms, "and nor is there any evidence that this has occurred in the past". Among the main drawbacks of these models are that the results they produce are very general, which limits the scope for selection and specific application, they are not very suitable for future climate projections, and their results are similar and relatively undifferentiated, which limits the choice of models available for impact forecasting.

Exceptionally, IPCC has found that a number of GCMs consistently predict a high frequency of convective precipitation in regions situated in the middle and high latitudes, which could mean more local rainfall. This in turn could interact with the rise in sea level, giving rise to increased flooding in low-lying coastal areas. There are many uncertainties surrounding the rapid rise in sea level, among the main ones being "when the new rapid rise in sea level dates back to", "whether there is a correlation with the recent climate record" and "whether there have been other periods in the recent geological history of the earth when rapid rises in the sea level have occurred, and what gave rise to them".

The 2 *x* CO_2 simulation models set out from a single hypothetical situation in which the concentration of CO_2 in an atmosphere in equilibrium is assumed to double, and are based on a statistically averaged climate with resolutions of several thousand kilometres, so that their results are currently applicable to global regions and on very large scales, rather than to particular spots. "Climate inversion" is the main drawback of these models when it comes to regional application, since regional information is modified to regulate the general model, resulting in a "modified climate" which is used in impact studies. According to Bolin (1991), the IPCC forecasts for detailed regional changes are low, and the ones for the tropics and the southern hemisphere are inconsistent. The main uncertainties with IPCC forecasts relating to weather, scale and regional patterns are the result of information gaps in areas such as the identification of greenhouse gas sources and sinks affecting forecasts of future concentrations, particularly the role of the oceans as gas sinks. In this respect, attention is drawn specifically to the gap in information about the effect of warming on the natural process of coral decalcification. It is known that over periods of decades coral can put around 0.02 to 0.08 gt/year (gigatons per year) of CO_2 into the atmosphere (Warew *et al.*, 1992). The effects of clouds on the scale of climate change, the distribution and flow of heat across the oceans and the size of the ice cap, which affects the sea level forecast, are also among the information gaps.

Storms whose paths cross the Atlantic, and those that form in the middle latitudes, are driven by the contrasts in temperature between the equator and the pole. This contrast could shift in a "warm world", which would entail "an unknown path shift and an as yet uncertain risk as regards the number of hurricanes reaching land". It has also been argued that storms could be weakened, and there are indications from climate simulation models of some lessening in the variability of winter storm paths. As yet, however, there is no strong evidence of any such change in paths. These are known to be governed by the location of the cyclogenesis and by the prevailing meteorological and oceanographic conditions. Among the other great uncertainties at present is the "possible change in the circulation of the monsoons". If the monsoons become more active, it is possible that there might be more cyclones in the same areas as them. Unfortunately, all current information from numerical, theoretical and observed information models **is incomplete**. The theoretical models of storms that have been used to examine maximum storm activity in relation to TSS cannot be expanded to respond to changes in the intensity and frequency of storms under conditions of climate warming. Current numerical prediction models are effective only for very short periods of three or four days, except in areas where the weather changes very little. Mitchell and Quirguen (1991) suggest that predictions are subject to the following uncertainties, among others:

- Little is known about the processes involved in the formation and dissipation of clouds and in the determination of their radioactive properties;

- Very little is known about the processes involved in the vertical mixing of heat on the ocean surface, particularly at high latitudes;

- Little is known about the parameterization of tropical convections, which seem to be associated with a factor of uncertainty that is greatest in the tropics;

- Little is known about the processes of the earth's surface and about the interaction between the climate and ecosystems which bring additional uncertainties to simulations of important surface hydrological characteristics such as soil humidity and evaporation;

- Greenhouse gases, quantification of the take-up and release of greenhouse gases, their chemical reactions in the atmosphere and the way they might be affected by climate change.

Generally speaking, the key to predicting the climate is the very consideration that the climate is in itself a "chaotic system".

The increase in the frequency of tropical storms suggests this could be linked to pre- and post-Niño conditions. In some cyclogenic areas a decline in tropical storms has been reported. Nicholls (1992), cited by Landsea (1998e), states that the number of tropical storms around Australia (105°E) has decreased considerably since 1980, with the reduction appearing to be due to the existence of more El Niño events in that same period (1986-87, 1991-92, 1993 and 1994-

95). Even taking into account the El Niño effect, however, "there has been an as yet unexplained reduction that could be due to changes in the monitoring of tropical cyclones". There is evidence, based on observations over recent decades, that in certain areas (more westerly part of the north-east Pacific, easterly part of the north-west Pacific and south of the eastern Pacific) there has been a real tendency for the frequency of tropical cyclones to increase owing to the occurrence of more frequent El Niño events. More tropical cyclones arise during El Niño and more tropical storms form after El Niño in the more westerly part of the Pacific basin (140°W of the international date line). However, **this is not yet well documented**.

A number of authors cited by Landsea (1998a and e) report that a smaller number of tropical cyclones are arising in the western Pacific, the frequency increasing from 160°E towards the international date line during the El Niño event. The opposite occurs during the cold phase (La Niña). These observations match the predictions of climate simulation models for a $2 x CO_2$ world, the forecast being that if the warm phase of El Niño occurred more frequently and was more intense "there would be fewer tropical cyclones in the Atlantic basin and Australia", but there would be more storms in Hawaii and the central Pacific Ocean. The opposite would occur if the cold phase (La Niña) came to prevail. There is also a tendency, on average, for tropical cyclones to form near the equator during El Niño. As regards the Atlantic basin, Enfield and Enfield (1998) report that, as a result of long-distance connections, the "extinguishing of the spin" of El Niño in the Pacific translates into a signal that gives rise to an increase in the number of hurricanes in the Atlantic in El Niño years. It is owing to this connection that the Atlantic experiences a number of anomalous warm seasons (more than the Pacific) after the peak of warming in the Pacific.

In a $2 x CO_2$ world, El Niño is the most important factor in controlling, year by year, the global variability of tropical cyclones. It has been mentioned that there has probably been no increase in the frequency and intensity of tropical cyclones in the world as a whole. In fact, Landsea (1998d) reports that in the Atlantic basin the number of strong hurricanes (magnitudes of 3, 4 and 5 on the Saffir-Simpson scale) declined between 1970-1980. The period 1990-1994 has been recorded as being the calmest four-year period. Nonetheless, the active seasons in 1994 (19 tropical storms, 11 hurricanes and 4 strong hurricanes) and 1995 (one storm and two strong hurricanes in less than four weeks) suggest a "tendency towards greater cyclonic activity". Part of this probable increase seems to be linked with the warm phases of El Niño. Landsea (1998b and d) suggests that during the warm phases of El Niño the genesis and intensification of tropical cyclones are inhibited, something that is probably due to an increase in the tropospheric wind scissor-effect. Similarly, Enfield and Enfield (1998) agree that "more often than not, El Niño reduces the maturation of storms because El Niño produces an increased scissor-effect" over the tropical north Atlantic, in the region where hurricanes are produced in the north-western part of Africa. This effect breaks up many of the storms forming in the Atlantic before these can turn into hurricanes. Regarding a period over which the frequency of hurricanes in the United States was examined, Landsea (1998e) reached the following conclusion:

- There has been no significant change in the overall frequency of tropical storms and hurricanes over the period of 52 years examined (1944-1995);

- A decline in the number of intense hurricanes has been observed;

- There have been no changes in the intensity and strength of the hurricanes observed each year;

- There has been a tendency for the maximum intensity attained by all storms during the hurricane season to diminish;

- No hurricanes were observed over the Caribbean in the years 1990-1994, this being the longest hurricane-free period in the area since 1899. This period was followed by three hurricanes in 1995, which affected the entire area;

- The period 1991-1994 was the calmest (in terms of the total frequency of storms: 7.5/year; hurricanes: 3.8/year; strong hurricanes: 1.0/year).

Working within the framework of the World Meteorological Organization (WMO) and the UNESCO Intergovernmental Oceanographic Commission (IOC), the international community is currently implementing two major international programmes to improve future climate and extreme event prediction capabilities, which incorporate many existing programmes relating to the role of the ocean in the global climate system, such as those connected with the International Geosphere-Biosphere Programme (IGBP): Land-Ocean Interactions in the Coastal Zone (LOICZ), the Global Ecosystem Dynamics Programme (GLOBEC), etc.

One of these is the Climate Vulnerability and Predictability Research programme (CLIVAR, 1998), which is a joint IOC/UNESCO/WMO and International Council for Science (ICSU) programme dealing with the variability and predictability of the world climate system and forms part of the World Climate Research Programme. This programme will use combined ocean-atmosphere-ice models in which the atmosphere and ocean are suitably represented. Three basic types of model will be used; some to make forecasts for the development of El Niño and the monsoons on an annual and seasonal basis, others to make forecasts for the increase in greenhouse gases and dust in the earth's atmosphere and for regional temperatures, rainfall patterns and rises in the sea level. The models will also seek to represent past climates. CLIVAR is also looking to reduce the uncertainties surrounding the forecasts identified by IPCC in its Second Evaluation Report (1995), particularly as regards the scale of the sea level rise, and to assist in the production of regional forecasts.

The other international programme is the Global Ocean Observing System (GOOS), created in 1991 to improve climate change forecasts, reduce natural hazards and improve environmental protection in coastal areas. It began as a system connecting up a number of existing observation systems such as the Ship of Opportunity Programme (SOOP), meteorological observations from the network of Voluntary Observing Ships (VOS), the Data Buoy Cooperation Panel (DBCP), the Tropical Oceans Ocean-Atmosphere Observation Network (TAO), the Global Sea-level Observing System (GLOSS), the Global Temperature and Salinity Pilot Project (GTSSP), the Global Coral Reef Monitoring Network (GCRMN), etc. (UNESCO, 1998). It is hoped that with the results from these studies the current uncertainties surrounding future climate predictions will lessen.

The scientific community is moving in the direction of filling in the current gaps in its understanding of climate change. Although the focus on climate change is very recent, the information derived from the observation records available suggests possible tendencies that fit in with current forecasts. We do not have "much information" to increase the weight of forecasts based on observations, and this is perhaps the only argument against forecasts grounded in such observations. It is very likely that the way we have been able to see "the planet" since the arrival of satellites is substantially altering our attitude towards global climate change. The United Nations (1998) has said that "the galloping greenhouse phenomenon occurring on Venus as a result of the presence of an excess of carbon dioxide in the atmosphere has made us understand the dangers of this gas accumulating on earth and of the resultant world climate change. The antiseptic surface of Mars, which is lacking in any sign of life or organic matter because there is no ozone layer to protect it, provides a chilling vision of what could happen if the earth's ozone layer were destroyed. The discovery of aerosols in the atmosphere of Venus and observation of the way they interact with molecules there has raised awareness of what happens when aerosols are introduced into the earth's atmosphere. It is clear that the "space age" introduced an important and permanent change in the way the climate is monitored. Today's combined ocean-atmosphere models have enabled weather forecasting to be improved greatly, but the models by no means explain "the natural logic of hurricanes, storms and even El Niño". These extreme events could well be interpreted as "natural responses" or natural reaction mechanisms, the way the ocean and atmosphere interact to respond to high natural stored heat gradients. Could El Niño be concealing a further-reaching phenomenon? What would happen if neither storms nor El Niño existed? What mechanisms would the planet use to respond to warming? This is the other side of the current uncertainties. The key point in the problem is that we may be forcing a natural response mechanism from the planet.

Obviously, there is a need for much more information, research and integration of oceanic data with meteorological information, including research into how the circulation and processes of the Caribbean affect the coasts of CSIS and the processes of their shelves, and an effort to obtain estimates for momentum, flows of heat between the ocean and the atmosphere, for scales smaller than a few kilometres or miles. Oceanography and marine meteorology need to be available to CSIS on the required scale. In situ measurements need to be taken of the sea surface (marine topography), salinity, thermal structure and bed depth (bathymetry). Coordinated systems need to be developed to observe the region's sea and to evaluate the vulnerability of coasts using integrated indices derived from the relevant social and cultural conditions of CSIS. There needs to be more access to the oceanography of the area. It is clear that, regardless of how we look at climate change and its effect on the frequency, intensity and paths of hurricanes, alarm systems and response mechanisms could be strained to the point of collapse if storms occurred more frequently and continuously, even if they broke off for periods of time during a given season, or if there were one or two hurricanes higher than 4 on the Saffir-Simpson scale in certain seasons. "Worst case" analyses for different responses need to regard "frequency and intensity" as the worst case.

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ANNEX I

SAFFIR-SIMPSON HURRICANE INTENSITY SCALE

(By categories of intensity, sustained wind speed and surface pressure)

Category	Miles/hour	Metres/second	Knots	Millibars	Feet	Metres
1	74-96	33-42	64-83	>980	3-5	1.0-1.7
2	97-111	43-49	84-96	976-965	6-8	1.8-2.6
3	112-131	50-58	97-113	964-945	9-12	2.7-3.8
4	132-155	59-69	114-135	944-920	13-18	3.9-5.6
5	156+	70+	136+	< 920	19+	5.7+

<u>Source</u>: W.C. Landsea, "Tropical cyclone winds", Part D, *FAQ Hurricanes, Typhoons and Tropical Cyclones*, Miami, Florida, National Oceanic and Atmospheric Administration (NOAA), Atlantic Oceanographic and Meteorology Laboratory (AOML), 10 November 1998.

ANNEX II

DESCRIPTION BY CATEGORY OF THE SAFFIR-SIMPSON HURRICANE SCALE

Category	Parameters	Effects
One (1)	Winds from 74 to 95 mph.Barometric pressure 980 millibars or greater.	Damage is primarily to shrubbery and unanchored mobile homes. Slight damage to other structures. Partial or total destruction of poorly constructed signs, storm surge 4 or 5 feet above normal. Low-lying coastal roads are inundated, minor pier, marina and wharf damage occurs, some small craft in exposed anchorages break moorings.
Two (2)	Winds from 96 to 110 mph. Barometric pressure 965 to 976 millibars.	Considerable damage is done to shrubbery and tree foliage, some trees are blown down. Slight damage to other structures. Extensive damage occurs to poorly constructed hanging signs. Some damage is done to roofing material, windows and doors; no major damage occurs to building structures. Storm surge 6 to 8 feet above normal. Coastal roads and low-lying escape routes inland are cut by rising water 2 to 4 hours before arrival of centre. Considerable pier and wharf damage occurs and marinas are flooded. Small craft in unprotected anchorages break moorings. Evacuation of some low-lying coastal areas is required.
Three (3)	Winds from 112 to 130 mph. Barometric pressure 914 to 964 millibars.	Extensive damage. Many branches are blown off trees and large trees are blown down. Signs that are not solidly constructed are blown away by the wind. Some roofing material damage occurs with some window and door damage. Some structural damage occurs to small buildings. Mobile homes are destroyed. Storm surges of 9 to 12 feet above normal. Serious flooding occurs at the coast with many smaller structures near the coast destroyed. Larger structures are seriously damaged by battering of waves and floating debris. Low-lying escape routes inland are cut by rising water 3 to 5 hours before the centre arrives. Flat terrain lower than 5 feet above sea level may be flooded inland 8 miles or more. Complete evacuation of low-lying residences along the shoreline may be required.
Four (4)	Winds from 131 to 155 mph. Barometric pressure 920 to 944 millibars.	Extensive damage. Shrubs and trees are blown down and signs are blown away and destroyed. Extensive roofing material damage occurs with complete failure of roof structures and some wall damage on many small residences. Extensive window and door damage occurs. Most mobile homes are destroyed or severely damaged. Storm surges of 13 to 18 feet above normal. Terrain continuously lower than 10 ft above sea level may be flooded inland as far as 6 miles. Major damage occurs to lower floors of structures near the shore due to flooding and battering by wave-borne debris. Low-lying escape routes inland may be cut by rising water 3-5 hours before the storm centre arrives. Massive evacuation of all residences within 500 yards of the shoreline may be required and residences on low ground within 2 miles of the shoreline may need to be evacuated.
Five (5)	Winds over 155 mph. Barometric pressure less than 920 millibars.	Catastrophic damage. Shrubs and trees are blown away completely. Many large trees are uprooted. Very considerable damage to the roofs of buildings. Signs are torn down and destroyed and blown considerable distances by the wind, causing more destruction. Very severe and extensive window and door damage occurs. Complete collapse of many residences and industrial buildings. There is great destruction of door and window glass. Many small buildings are overturned and blown away. Massive destruction of mobile homes. Surges well in excess of 18 feet above normal. Major damage occurs to lower floors of all structures located less than 15 ft above sea level and within 500 yards or more of the shoreline. Low-lying escape routes inland are cut by rising waters 3 to 5 hours before the storm centre arrives. Massive evacuations of all residential areas situated on low ground within 5 to 10 miles of the shoreline may be required. Situation of chaos.

<u>Source</u>: National Weather Service, United States, 1999.

ANNEX III

FIGURES*

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* The frontiers and names appearing in each of the figures do not imply official endorsement or acceptance by the United Nations.

Figure 1

THE SMALL ISLAND STATES OF THE CARIBBEAN

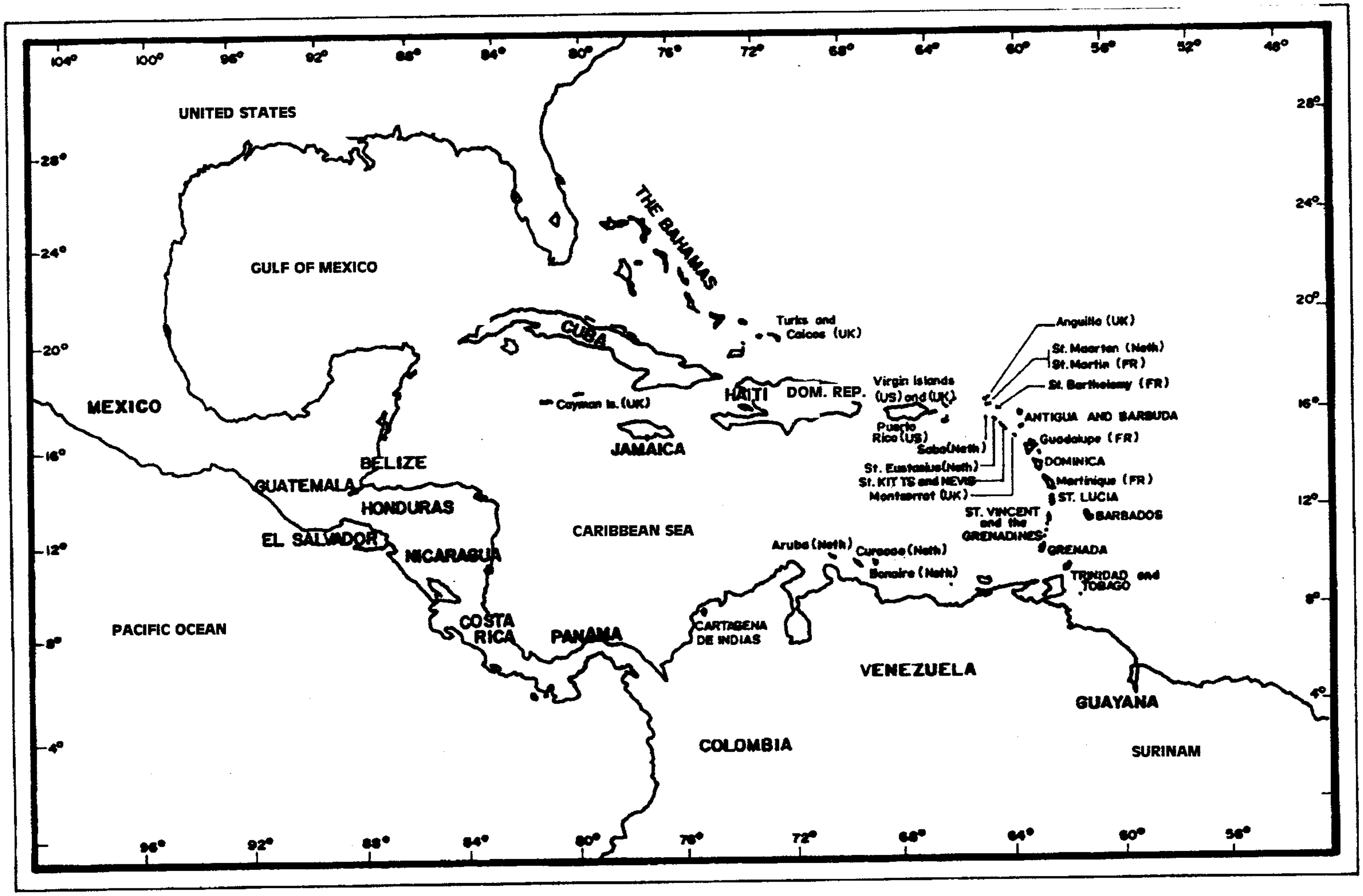
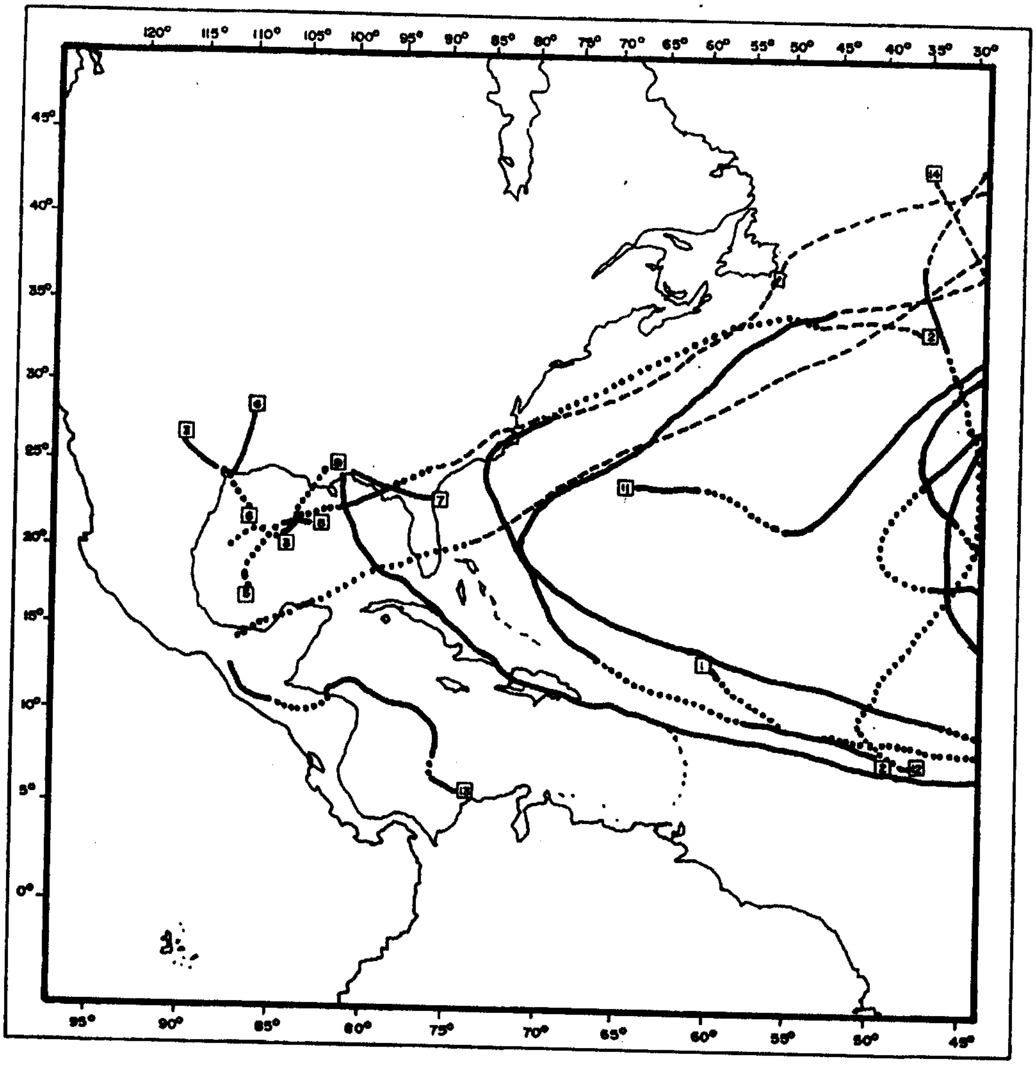


Figure 2

MAP OF HURRICANE PATHS IN THE CARIBBEAN DURING THE 1998 SEASON

(Source: National Hurricane Center, 1999)

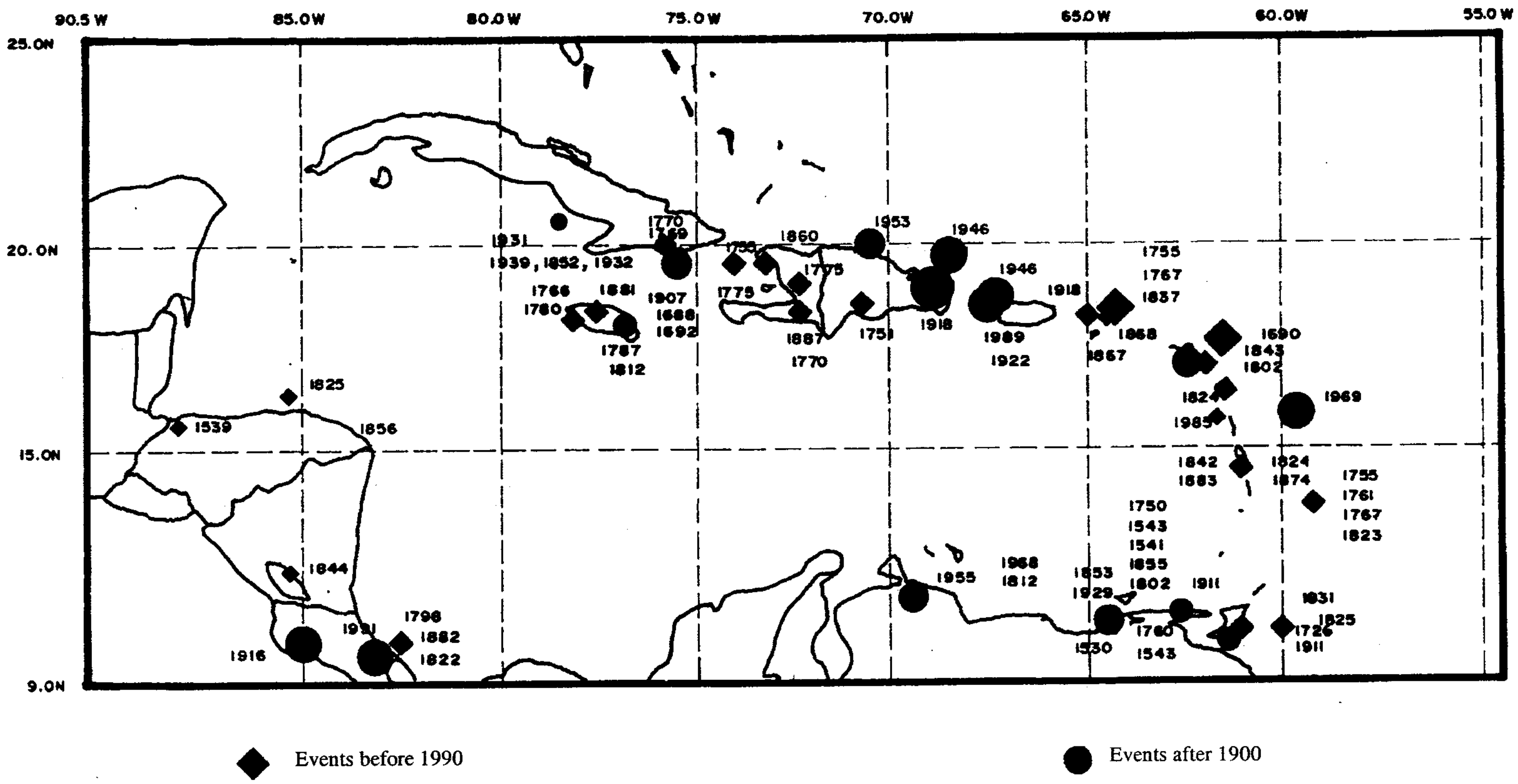


Number	Type	Name	Date
1	S	Alex	27Jul-02Ago
2	H	Bonnie	19-30 Ago
3	S	Charley	21-24 Ago
4	H	Danielle	24Ago-03Sep
5	H	Earl	31 Ago-03.Sep
6	S	Frances	06-13 Sep
7	H	Georges	15Sep-01Oct

Number	Type	Name	Date
8	S	Hermine	17-20 Sep
9	H	Ivan	19-27 Sep
10	H	Jeanne	21Sep-01Oct
11	H	Karl	23-28 Sep
12	H	Lisa	05-09 Oct
13	H	Mitch	22 Oct-05Nov
14	H	Nicole	24 Nov-01 Dic

Figure 3

TSUNAMIS IN THE CARIBBEAN SEA (1530-1998)
(Source: IOCARIBE Tsunami Group 1999)



(Symbols proportionate to magnitude)

Figure 4

MARINE PRAIRIES IN THE CARIBBEAN
After IUCN in Maul 6 (Ed.), 1993

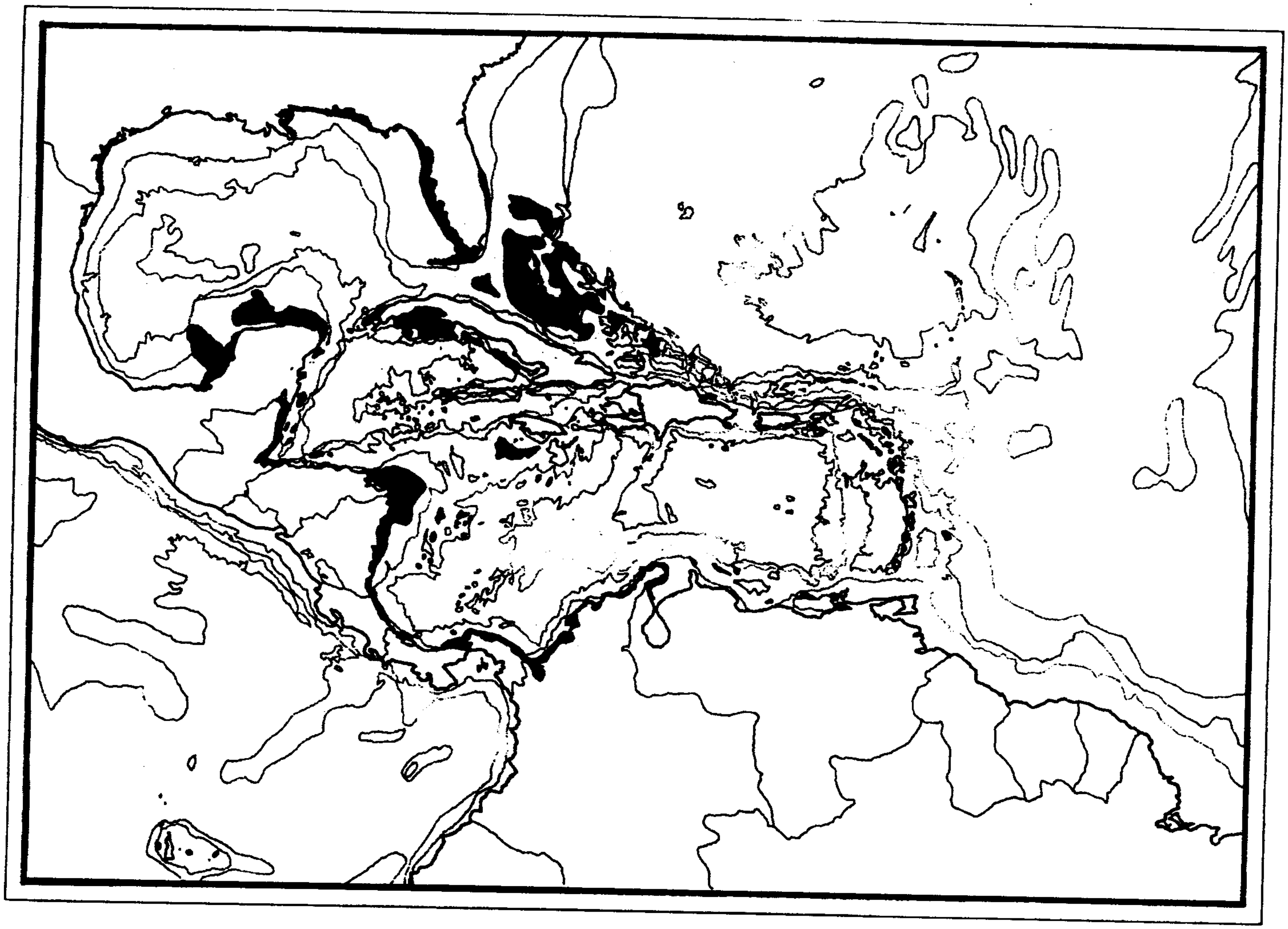


Figure 5

REEF SYSTEMS IN THE CARIBBEAN, AFTER IUCN 1970 AND HURRICANE IMPACTS
Modified from Maul 6 (1993)