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Hearing on the State of Climate Change Science 2007:
The Findings of the Fourth Assessment Report by the
Intergovernmental Panel on Climate Change (IPCC), Working Group II:
Climate Change Impacts, Adaptation and Vulnerability
April 17, 2007

Mr. Chairman and Members of the Committee, as a Lead Author of the Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), Working Group II, I am pleased to present a summary of the findings found in Chapter 6, "Coastal Systems and Low-Lying Areas," of the report. First, I want to acknowledge my co-authors, with whom I have collaborated over the past three years to develop this assessment of climate change impacts, adaptation and vulnerability in coastal systems:

> Robert J. Nicholls (UK), Poh Poh Wong (Singapore), Jorge Codignotto (Argentina), John Hay (New Zealand), Roger McLean (Australia), Sachooda Ragoonaden (Mauritius), and Colin D. Woodroffe (Australia)

Dr. Nichols and Dr. Wong served as Convening Lead Authors for the coastal chapter.

I deeply appreciate being nominated by the United States Government to serve as a Lead Author of the Fourth Assessment Report, as well as the prior assessment report published by the IPCC in 2001. The charge to the authors of the Fourth Assessment Report by the IPCC was to develop a balanced, comprehensive and policy-relevant assessment of current knowledge, which:

- evaluates the full range of knowledge (e.g., positive and negative effects),
- is policy relevant, not prescriptive,
- is supported by clear evidence,
- is clear about underlying assumptions, and confidence levels,
- emphasizes new knowledge since the IPCC's Third Assessment Report,
- is more concise than the Third Assessment Report, with better connections to Working Groups I and III, and with wider use on non-English sources of knowledge,
- and is lucidly written.

The IPCC Working Group II contribution to the Fourth Assessment Report was guided by a complex, open and peer-reviewed process that engaged several hundred authors and roughly 50 review editors from 47 countries; and well over 800 expert reviewers. The coastal chapter authors responded to roughly 1500 comments received during external peer and government reviews, and many of these comments led us to additional new literature about coasts and climate change. I estimate that our coastal chapter writing team reviewed between 500 and 700 scientific journal articles, books and scientific proceedings published since 2000.

For each chapter of the IPCC report, two or three Review Editors were selected by the IPCC from the lists of experts nominated by the governments. The three Review Editors assigned to the coastal chapter were: Job Dronkers (Netherlands), Geoff Love (Australia), and Jin-Eong Ong (Malaysia). The main duty of these scientists was to ensure that we responded appropriately to comments on our draft chapter from experts and the governments during two separate cycles of review. With each review the scope of the material contained in the chapter expanded and the consensus of the authors emerged fairly easily in our case as we identified the key drivers and their impacts.

Please note that we indicated our confidence levels in these statements and many of our scientific findings by using endnotes (e.g., High Confidence) or by using the IPCC accepted terminology for assessing the likelihood of an outcome having occurred or occurring the in the future. When IPCC authors use the term "very likely" in a sentence, for example, the authors have reached a consensus that an outcome has an estimated probability of 90 to 99 percent. This terminology was used across all of the IPCC Working Group II chapters. Also, please note that for every statement made, there is supporting literature cited in the coastal chapter.

Key Policy-Relevant Findings

Since the Third Assessment Report was published in 2001, our understanding of the implications of climate change for coastal systems and low lying areas (henceforth referred to as 'coasts') has increased substantially. In the Executive Summary of the coastal chapter, we identified six important policy-relevant findings, which are extracted below from our text:

1. Coasts are experiencing the adverse consequences of hazards related to climate and sea level rise (very high confidence). They are highly vulnerable to extreme events, such as storms which impose substantial costs on coastal societies. Annually, about 120 million people are exposed to tropical cyclone hazards which had killed 250,000 people from 1980 to 2000. Through the 20th century, global rise of sea level contributed to increased coastal inundation, erosion and ecosystem losses, but with considerable local and regional variation due to other factors. Late 20th Century effects of rising temperature include loss of sea ice, thawing of permafrost and associated coastal retreat, and more frequent coral bleaching and mortality.

2. Coasts will be exposed to increasing risks over coming decades due to many compounding climate-change factors (very high confidence). Anticipated climate-related changes include: an accelerated rise in sea level of up to 0.6 m or more by 2100; further rise in sea surface temperatures by up to 3°C; an intensification of tropical and extratropical cyclones; larger extreme waves and storm surges; altered precipitation/run-off; and ocean acidification. These phenomena will vary considerably at regional and local scales, but the impacts are virtually certain to be overwhelmingly negative. Corals are threatened with increased bleaching and mortality due to rising sea surface temperatures. Coastal wetland ecosystems, such as salt marshes and mangroves, are especially threatened where they are sediment starved or constrained on their landward margin. Degradation of coastal ecosystems, especially wetlands and coral reefs, has serious implications for the well-being of societies dependent on the coastal ecosystems for goods and services. Increased flooding and the degradation of freshwater, fisheries and other resources could impact hundreds of millions of people and socio-economic costs will escalate as a result of climate change for coasts.

3. The impact of climate change on coasts is exacerbated by increasing human-induced pressures (very high confidence). Utilization of the coast increased dramatically during the 20th century and this trend is virtually certain to continue through the 21st century. Under the Special Report on Emissions Scenarios (SRES), the coastal population could grow from 1.2 billion people (in 1990) to 1.8 to 5.2 billion people by the 2080s, depending on assumptions about migration. Increasing numbers of people and assets at risk at the coast are subject to additional stresses by land-use and hydrological changes in catchments, including dams that reduce sediment supply to the coast. Populated deltas (especially Asian megadeltas), low lying coastal urban areas, and atolls are key societal hotspots of coastal vulnerability, occurring where the stresses on natural systems coincide with low human adaptive capacity and high exposure. Regionally, south, south-east and east Asia, Africa and small islands are most vulnerable. Climate change therefore reinforces the desirability of managing coasts in an integrated manner.

4. Adaptation for the coasts of developing countries will be more challenging than for coasts of developed countries, due to constraints on adaptive capacity (high confidence). While physical exposure can significantly influence the vulnerability for both human populations and natural systems, a lack of adaptive capacity is often the most important factor that creates a hotspot of human vulnerability. Adaptive capacity is largely dependent upon development status. Developing nations may have the political or societal will to protect or relocate people who live in low-lying coastal zones, but without the necessary financial and other resources/capacities, their vulnerability is much greater than a developed nation in an identical coastal setting. Vulnerability will also vary between developing countries, while developed countries are not insulated from the adverse consequences of extreme events.

5. Adaptation costs for vulnerable coasts are much less than the costs of inaction (high confidence). Adaptation costs for climate change are much lower than damage costs without adaptation for most developed coasts, even considering only property losses and human deaths. As post event impacts on coastal businesses, people, housing, public and private social institutions, natural resources, and the environment generally go unrecognized in disaster cost accounting, the full benefits of adaptation are even larger. Without adaptation, the high-end sea level scenarios combined with other climate change (e.g., increased storm intensity) are as likely as not to render some islands and low-lying areas uninhabitable by 2100, so effective adaptation is urgently required.

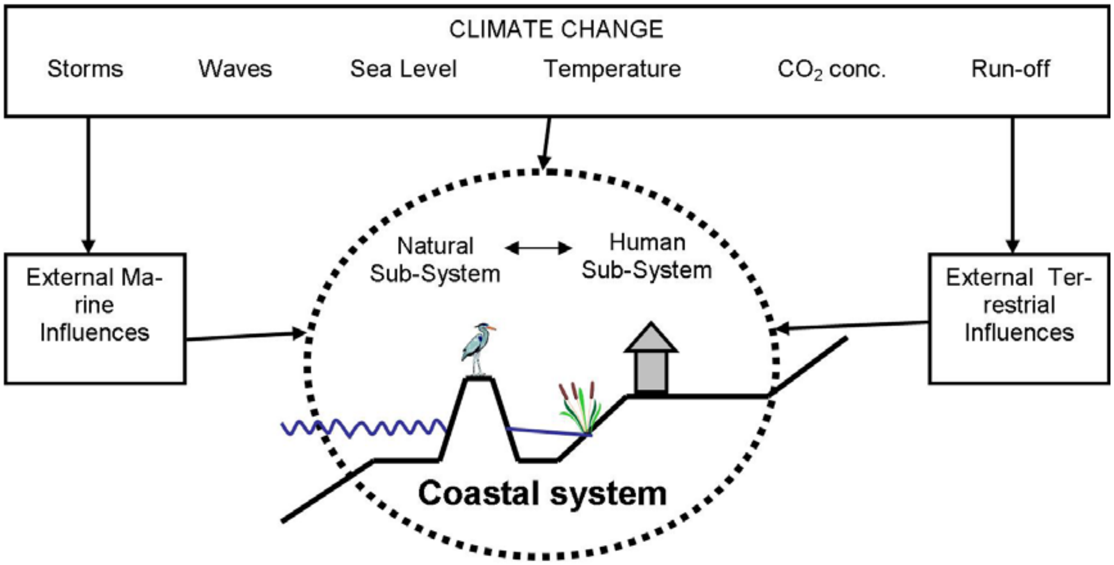
6. The unavoidability of sea level rise even in the longer-term frequently conflicts with present day human development patterns and trends (high confidence). Sea level rise has substantial inertia and will continue beyond 2100 for many centuries. Irreversible breakdown of the West Antarctica and/or Greenland ice sheets, if triggered by rising temperature, would make this long-term rise significantly larger, ultimately questioning the viability of many coastal settlements across the globe. The issue is reinforced by the increasing human use of the coastal zone. Settlement patterns also have substantial inertia, and this issue presents a challenge for long-term coastal spatial planning. Stabilization of climate could reduce the risks of ice sheet breakdown, and reduce but not stop sea level rise due to thermal expansion. Hence, it is now more apparent than in the Third Assessment Report that the most appropriate response to sea level rise for coastal areas is a combination of *adaptation* to deal with the inevitable rise, and *mitigation* to limit the long-term rise to a manageable level.

Human Development Patterns Interact with Climate Drivers and Impacts on Coastal Systems

Coasts are very likely to be exposed to increasing risks due to climate change and sea level rise and the effect will be exacerbated by increasing human-induced pressures on coastal areas. One of our main conclusions is that the influence of human development activities in coasts and adjacent watersheds generally had a more important influence on coastal systems than did climate change during the past century. Utilization of the coast increased dramatically during the 20th Century, a trend that seems certain to continue through the 21st Century. Coastal population growth in many of the world's deltas, barrier islands, and estuaries has led to widespread conversion of natural coastal landscapes to agriculture, aquaculture, silviculture, as well as industrial and residential uses. It has been estimated that 23 percent of the world's population lives both within 100 km distance of the coast and less than 100 m above sea level, and population densities in coastal regions are about three times higher than the global average.

The top bar in the figure below lists the six climate change drivers that are likely to affect coastal ecosystems, which are generally influenced by a combination of natural processes and human development activity. During the preparation of the coastal chapter of the IPCC Third Assessment report, sea level rise was the focus of the available literature relating to climate change and coastal impacts. Sea level rise still dominates the literature on coastal areas and climate change, but our review shows that more information is now available regarding the effects of increases in temperature, storm intensity and waves, increased carbon dioxide (CO_2) concentration, and changes in run-off.

Figure 6.1 in the Coastal Chapter, IPCC Fourth Assessment Report, 2007.
Climate change and the coastal system showing the major climate change factors, including external marine and terrestrial influences.



Increases of extreme sea levels due to changes in storm characteristics are generally of more concern for populated coastal areas than mean sea level rise. The coastal chapter reports that climate models suggest both tropical and extratropical storm intensity will increase as the temperature of the atmosphere and sea surface rise -- this implies additional coastal impacts than attributable to sea level rise alone, especially for tropical and mid-latitude coastal systems. An increase in the intensity of tropical cyclones entering the Gulf of Mexico, for example, is consistent with the observed changes in sea surface temperature in the equatorial Atlantic Ocean where Gulf of Mexico hurricanes form. Changes in other storm characteristics are less certain and the number of tropical and extra-tropical storms might even reduce. Similarly, extreme wave heights will likely increase with more intense storms. Changes in run-off driven by changes to the hydrological cycle appear likely, but the uncertainties are large. Increases in atmospheric CO_2 concentrations can enhance photosynthesis and productivity of plant communities, but because plants respond differently to the increase in CO_2, competition among plant species may alter the structure of coastal plant communities. Increasing atmospheric CO_2 levels can adversely affect coral reefs by decreasing the pH of the ocean, which decreases the carbonate saturation of seawater. The table below summarizes some of the impacts on coastal systems that are discussed in our chapter.

Table 6.2 of the Coastal Chapter, IPCC Fourth Assessment Report, 2007.
Trend in climate drivers identified in Figure 6.1 due to climate change and their main physical and ecosystem effects on coastal systems and low-lying areas.
(Nature of Change: ↑ increase; R regional variability; ? uncertain).

Climate Driver (change)		**Main Physical and Ecosystem Effects (discussed in Section 6.4.1)**
CO_2 concentration (↑)		Increased CO_2 fertilization; Decreased seawater pH (or 'ocean acidification') negatively impacting coral reefs and other pH sensitive organisms.
Sea surface temperature (SST) (↑, R)		Increased stratification/changed circulation; Reduced incidence of sea ice at higher latitudes; Increased coral bleaching and mortality (see Box 6.1); Poleward species migration; Increased algal blooms.
Sea level (↑, R)		Inundation, flood and storm damage (see Box 6.2); Erosion; Saltwater Intrusion; Rising water tables/ impeded drainage; Wetland loss (and change).
Storm	Intensity (↑, R)	Increased extreme water levels and wave heights; Increased episodic erosion, storm damage, risk of flooding and defense failure (see Box 6.2);
Storm	Frequency (?, R)	Altered surges and storm waves and hence risk of storm damage and flooding (see Box 6.2).
Storm	Track (?,R)	
Wave climate (?, R)		Altered wave conditions, including swell; Altered patterns of erosion and accretion; Re-orientation of beach planform.
Run-off (R)		Altered flood risk in coastal lowlands; Altered water quality/salinity; Altered fluvial sediment supply; Altered circulation and nutrient supply.

We considered how these climate-related variables would influence the sustainability of each major coastal system and coral reefs. A summary with examples from our chapter is presented below (note: the specific examples highlighted here comprise only a few of the impacts described in the chapter):

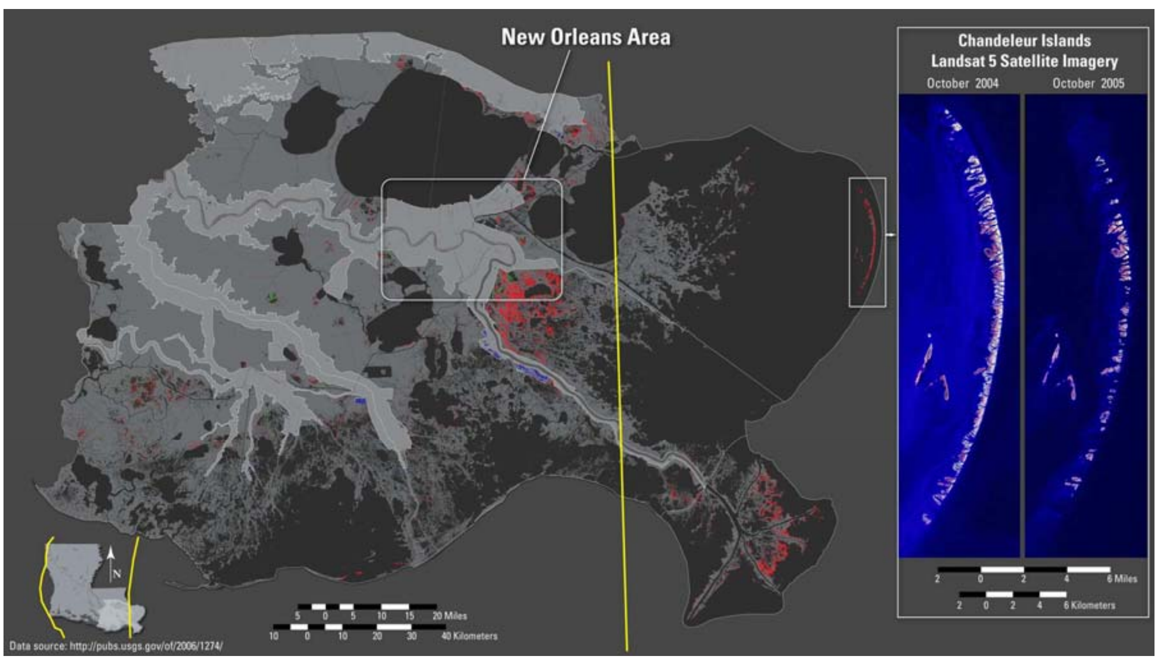
Beaches, rocky shorelines, and cliffed coasts **-** Most of the world's sandy shorelines retreated during the past century and sea level rise is one underlying cause. One half or more of the Mississippi and Texas shorelines eroded at average rates of 3.1 to 2.6 m/yr since the 1970s, while 90 percent of the Louisiana shoreline eroded at a rate of 12.0 m/yr. In Nigeria shoreline retreat rates up to 30 m/yr are reported and in the United Kingdom 67 percent of the coastline experienced a landward retreat of the low-water mark over the past century. An acceleration in sea level rise will widely exacerbate beach erosion around the globe, although the local response will depend on the total sediment budget. Even gravel beaches and soft rock cliffs are vulnerable to climate change via changes in storm intensity, sea level rise and changes in precipitation patterns, which affect the physical processes that govern the evolution of these coastal systems. The combined effects of beach erosion and storms can lead to the erosion or inundation of other coastal systems as well. For example, an increase in wave heights in coastal bays is a secondary effect of sandy barrier island erosion in Louisiana, and increased wave heights have enhanced erosion rates of bay shorelines, tidal creeks, and adjacent wetlands.

Deltas **–** Deltas have long been recognized as highly sensitive to sea level rise. Rates of relative sea level rise can greatly exceed the global average rate of sea level rise in many heavily populated deltaic areas due to subsidence, including the Chao Phraya delta, the Mississippi River delta, and the Changjiang River delta because of human activities. Natural subsidence due to autocompaction of sediment under its own weight is enhanced by sub-surface fluid withdrawals and drainage, which increases the potential for inundation, especially for the most populated cities on these deltaic plains (i.e., Bangkok, New Orleans, and Shanghai). Most of the land area of Bangladesh consists of the deltaic plains of the Ganges, Brahmaputra, and Meghna rivers. Accelerated global sea level rise and higher extreme water levels may have acute effects on human populations of Bangladesh (and parts of West Bengal, India).

Sea level rise poses a particular threat to deltaic environments, especially when coupled with the synergistic effects of other climate and human pressures. These effects are best illustrated in large deltas with an area greater than 100,000 km^2 (called "megadeltas" in the IPCC report) due to their often large populations and important environmental services. The problems of climate change in megadeltas are reflected throughout the IPCC Working Group II Fourth Assessment Report where a number of chapters considered their vulnerability from complementary perspectives. The coastal chapter describes the vulnerability of people living in delta systems across the globe, and concludes that the large populated Asian megadeltas are especially vulnerable to climate change. The Mississippi River delta is another megadelta that is considered highly vulnerable to the impacts of climate change. Chapter 10 (Asia Region) examines the Asian megadeltas in more detail, while Chapter 5 (Food, Fiber, and Forest Products) examines the threats to fisheries in the lower Mekong and Mekong delta due to climate change. Hurricane Katrina made landfall on the Mississippi delta in Louisiana, and the text box below from the coastal chapter considers different aspects of this important event, which gives an indication of the likely impacts if tropical storm intensity continues to increase. Lastly, the Polar Chapter (Chapter 15) considers the specific problems of Arctic megadeltas where the advance/retreat of Arctic marine deltas is highly dependent on the protection afforded by near-shore and land-fast sea ice, which is disappearing rapidly in the Arctic Ocean. The Mackenzie and Lena river deltas are fed by the largest Arctic rivers of North America and Eurasia, respectively. In contrast to non-polar megadeltas, the physical development and ecosystem health of these deltaic systems are strongly controlled by cryospheric processes and hence highly susceptible to the effects of climate change.

Hurricane Katrina impacts on coastal ecosystem services in the Mississippi Delta (excerpts from Box 6.4 in the IPCC Fourth Assessment Report, Coastal Chapter)

Whereas an individual hurricane event cannot be attributed to climate change, it can serve to illustrate the consequences for ecosystem services if the intensity and/or frequency of such events were to increase in the future. One result of Hurricane Katrina, which made landfall in coastal Louisiana on August 29, 2005, was the loss of 388 km^2 of coastal wetlands, levees, and islands that flank New Orleans in the Mississippi River Deltaic Plain. (Hurricane Rita, which struck in September 2005, had relatively minor effects on this part of the Louisiana coast). The Chandeleur Islands, which lie southeast of the city were reduced to roughly half of their former extent during Hurricane Katrina. Collectively, these natural systems serve as the first line of defense against storm surge in this highly populated region. Over 1300 people lost their lives during Hurricane Katrina and the economic losses totaled more than $100 billion. Roughly 300,000 homes and over 1,000 historical and cultural sites were destroyed along the Louisiana and Mississippi coasts. The Chandeleur Islands serve as an important wintering ground for migratory waterfowl and neo-tropical birds; a large population of North American redhead ducks, for example, feed on the rhizomes of sheltered sea grasses leeward of the Chandeleur Islands. Historically the region has ranked second only to Alaska in U.S. commercial fisheries production and this high productivity has been attributed to the extent of coastal marshes and sheltered estuaries of the Mississippi River delta.



Areas in red were converted to open water during the hurricane. Yellow lines on index map of Louisiana show tracks of Hurricane Katrina on right and Hurricane Rita on left (Figure source: U.S. Geological Survey).

Estuaries and lagoons - Sea level rise will generally lead to higher water levels and salt water intrusion in coastal estuaries, thereby tending to shift existing coastal plant and animal communities inland. A globally-intensified hydrologic cycle and regional changes in run-off also portend changes in estuarine water quality. Some of the greatest potential impacts of climate change on estuaries may result from changes in physical mixing characteristics caused by changes in freshwater runoff. Changes in the timing of freshwater delivery to estuaries, for example, could lead to a decoupling of the juvenile phases of many estuarine and marine fishery species with available nursery habitat. Freshwater inflows into estuaries influence water residence time, nutrient delivery, vertical stratification, salinity, and control of phytoplankton growth rates in estuaries. Increased water temperature could affect algal production and the availability of light, oxygen and carbon for other estuarine species. As estuarine water temperature increases, algal blooms are likely to become more common.

An effect of rising sea level in some hypersaline lagoonal systems, such as the Laguna Madre of Mexico and Texas, will be greater water depths, leading to increased tidal exchange and hence reduced salinity. As an analogue, the lowering of salinity in the Laguna Madre since 1949, attributed primarily to the dredging of the Gulf Intracoastal Waterway and increased drainage from agricultural lands, has shifted seagrass species from the highly salt tolerant shoalgrass (*Halodule wrightii*) to manatee grass (*Syringodium filiforme*), which has a lower salinity tolerance.

A projected increase in the intensity of tropical cyclones and other coastal storms could alter bottom sediment dynamics, organic matter inputs, phytoplankton and fisheries populations, salinity and oxygen levels, and biogeochemical processes in estuaries and lagoons.

Mangroves, Salt Marshes and Sea Grasses - Coastal vegetated wetlands are sensitive to climate change because their location is intimately linked to sea level. Several global and regional analyses suggest significant losses of coastal vegetated wetlands during the 21st Century under scenarios of accelerated sea level rise, with global losses in one study estimated at 33 percent and 44 percent given a 36-cm and 72-cm rise in sea level from 2000 to 2080, respectively. However, wetland processes are complex and the impacts on any particular tract of marsh or forest will depend upon local rates of sediment accretion, elevation, vertical land motion (such as subsidence) and other local processes. Changes in storm intensity can also affect vegetated coastal wetlands (see box on Hurricane Katrina effects).

Climate change will likely have its most pronounced effects on coastal marshes through the alteration of hydrologic regimes, specifically, changes in the timing and volume of water delivered to the coast. Other variables - altered biogeochemistry, altered amounts and pattern of suspended sediments loading, fire, oxidation of organic sediments and the physical effects of wave energy - may also play important roles in determining regional and local impacts. Regional losses of coastal marsh are expected to be most severe on the Atlantic and Gulf of Mexico coasts of North and Central America, the Caribbean, the Mediterranean, the Baltic and most small island regions due to their low tidal range.

Mangrove communities are likely to show a blend of positive (e.g., from higher levels of CO_2 and temperature) and negative (e.g., increased saline intrusion and erosion) effects, which will largely depend on site specific factors. Increasing salinity has played a role in the expansion of mangroves into adjacent marshes in the Florida Everglades and throughout southeastern Australia during the past 50 years. Increased salinity of coastal waters since 1950 has contributed to the decline of cabbage palm forests in Florida and baldcypress forests in Louisiana.

Changes in salinity and temperature and increased sea level, atmospheric CO_2, and storm activity will alter seagrass distribution, productivity, and community composition. Increases in the amount of dissolved CO_2 and, for some species, (bicarbonate) HCO_3^- present in aquatic environments will lead to higher rates of photosynthesis in submerged aquatic vegetation, similar to the effects of CO_2 enrichment on most terrestrial plants, but these changes in aquatic carbon availability can also increase the growth of suspended or epiphytic algae that reduce light needed for sea grass survival.

Coral Reefs - Coral "bleaching" refers to the loss of symbiotic algae and/or their pigments and has been observed on many reefs since the early 1980s. Slight paling occurs naturally in response to seasonal increases in sea surface temperature and solar radiation. Corals bleach white in response to anomalously high sea surface temperature (about 1°C above average seasonal maxima, often combined with high solar radiation). If bleaching is prolonged, or if sea surface temperature exceeds 2°C above seasonal maxima, corals die. The most severe world-wide bleaching events appear to be associated with El Niño events. Major bleaching events were observed in 1982-83, 1987-88, 1994-95, and most extensively in 1998. Since 1998 there have been several extensive bleaching events. For example, in 2002 bleaching occurred on much of the Great Barrier Reef and reefs in the eastern Caribbean experienced a massive bleaching event in late 2005, one of the hottest years on record.

There is very limited evidence that corals can adapt to increases in temperature; corals and other calcifying organisms (e.g., molluscs, foraminifers) are considered extremely susceptible to increases in sea surface temperature that are likely during the coming decades. Bleaching events reported in recent years have already impacted many reefs, and their more frequent recurrence is very likely to further reduce both coral cover and diversity on reefs over the next few decades. There are other threats to reefs associated with climate change apart from coral bleaching, in addition to non-climatic stresses such as overfishing, pollution and sediment influxes. Increased concentrations of CO_2 in seawater will lead to ocean acidification, which will affect aragonite saturation state and reduce calcification rates of calcifying organisms such as corals. An increase in tropical storm intensity would further endanger coral reefs with impacts ranging from minor breakage of fragile corals to destruction of the majority of corals on a reef.

The bleaching of corals above a certain sea surface temperature is a threshold-type response that illustrates the complex, nonlinear behavior of coastal systems to changes in climate. Another temperature-related threshold is the melting of polar permafrost which results in coastal erosion. Several other types of thresholds characterize the response of coastal systems to climate change and are reported in the IPCC coastal chapter. The key message is that while some coastal systems do not appear to be vulnerable to the rates of change experienced during the 20th century, they each have a limited capacity to adapt to changes in climate and in many cases there are thresholds at which rapid changes in coastal systems are likely to occur.

Consequences for Human Society

I understand that Dr. Roger Pulwarty from the National Oceanic and Atmospheric Administration is testifying today on Chapter 17 of the IPCC report, titled *Assessment of Adaptation Practices, Options, Constraints and Capacity*. Dr. Pulwarty focuses on adaptation strategies that society can use to adjust to climate change, to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

As Dr. Pulwarty points out, adaptation procedures could increase societal resilience to the negative consequences of climate change in the future. That said, since much of the world's population is located at or near the coast and coastal systems provide many valuable goods and services globally, the changes that we anticipate in coastal systems will have widespread societal consequences. In our chapter we presented a synthesis of current knowledge about coastal impacts of climate change for six different socio-economic sectors, as highlighted below:

1. *Freshwater resources* – Saltwater intrusion due to sea level rise alone will have serious economic effects for many coastal communities. Although the coast contains a substantial proportion of the world's population, it has a much smaller proportion of the global renewable water supply, and the coastal population is growing faster than elsewhere, exacerbating this imbalance. Freshwater supply problems due to climate change are most likely in developing countries with a high proportion of coastal lowland, arid and semi-arid coasts, coastal megacities (particularly in the Asia-Pacific region), and small island states.

2. *Agriculture, forestry, and fisheries* – Climate change is expected to have impacts on agriculture and, to a lesser extent, on forestry. Climate variability and change also impacts fisheries in coastal and estuarine waters. More frequent extreme climate events, together with higher rainfall intensity and longer dry spells, may impact negatively on crop yields. Cyclone landfall causing floods and destruction, have negative impacts on coastal areas, e.g., coconuts in India, or sugar cane and bananas in Queensland. Rising sea level is predicted to have negative impacts on coastal agriculture. Detailed modelling of inundation implies significant changes to the number of rice crops possible in the Mekong delta under 20-40 cm of relative sea level rise. Rising sea level potentially threatens inundation and soil salinization of palm oil and coconuts in Benin and Cote d'Ivoire and mangoes, cashew nuts and coconuts in Kenya.

3. *Human settlements, infrastructure, and migration* - Climate change and sea level rise affects coastal settlements and infrastructure in several ways. Sea level rise raises extreme water levels with possible increases in storm intensity portending additional climate impacts on many coastal areas, while saltwater intrusion may threaten water supplies. The degradation of natural coastal systems due to climate change, such as wetlands, beaches and barrier islands removes the natural defenses of coastal communities against storm surge. Hundreds of millions of people are vulnerable to flooding due to sea level rise, especially in densely populated and low-lying settlements where adaptive capacity is relatively low and which already face other challenges such as tropical storms or local coastal subsidence. The numbers affected will be largest in the

mega-deltas of Asia. Africa is also likely to see a substantially increased exposure, with East Africa (Mozambique) having particular problems due to the combination of tropical storm landfalls and large projected population growth in addition to sea level rise.

4. *Human health* - Coastal communities, particularly in low income countries, are vulnerable to a range of health effects due to climate variability and long-term climate change, particularly extreme weather and climate events (such as cyclones, floods, and droughts). Communities that rely on marine resources for food are vulnerable to climate-related impacts, in both health and economic terms. Temperature changes play a role in determining human health risks, such as from cholera and other enteric pathogens (*Vibrio parahaemolyticus*), harmful algal blooms, and shellfish and reef fish poisoning.

5. *Biodiversity* – The distribution, productivity, and diversity of species in coastal ecosystems is sensitive to variations in weather, climate, and sea level. Changes in the ranges of invertebrates and waterfowl have already been observed in some coastal regions in response to increases in temperature. It is clear, however, that responses of intertidal and shallow marine organisms are more complex than simply latitudinal shifts related to temperature increase, with complex biotic interactions superimposed on the abiotic.

6. *Recreation and tourism* - Climate change may influence tourism directly via the decision-making process by influencing tourists to choose different destinations; and indirectly as a result of sea level rise and resulting coastal erosion. In general, air temperature rise is most important to tourism, except where factors such as sea level rise promotes beach degradation and viable adaptation options (e.g., nourishment or recycling) are not available. Other likely impacts of climate change on coastal tourism are due to coral reef degradation. Temperature and rainfall pattern changes may impact water quality in coastal areas and this may lead to more beach closures.

Key Vulnerabilities and Hotspots

A comprehensive assessment of the potential impacts of climate change must consider at least three components of vulnerability: exposure, sensitivity, and adaptive capacity. The coastal chapter broadly characterizes the sensitivity and natural adaptive capacity (or resilience) of several major classes of coastal environments to changes in climate and sea level rise. Differences in geological, oceanographic, and biological processes can lead to substantially different impacts for a single type of coastal system (mangroves for example) at different locations. Some global patterns of vulnerability among systems became evident, however, and are listed below, with the first three generally at a higher level of risk:

- deltas/estuaries (especially populated megadeltas)
- coral reefs (especially atolls)
- ice-dominated coasts
- low-lying coastal wetlands
- small islands
- sand and gravel beaches
- soft rock cliffs

Our understanding of human adaptive capacity is less developed than our understanding of responses by natural systems, which limits the degree to which we were able to quantify societal vulnerability in the world's coastal regions. Nonetheless, several key aspects of human vulnerability emerged. It is apparent that multiple and concomitant non-climate stresses will exacerbate the impacts of climate change on most natural coastal systems, leading to much larger and detrimental changes in the 21st Century than those of the 20th Century. The table below summarizes some of the key hotspots of vulnerability that arise from the combination of natural and societal factors. Note than some examples such as atolls and small islands and deltas/megadeltas recur in this table, stressing their high vulnerability.

Table 6.6 of the Coastal Chapter, IPCC Fourth Assessment Report, 2007.
Key hotspots of societal vulnerability in coastal zones.

Controlling factors	**Examples from this Chapter**
Human communities in low-lying coastal areas, especially those facing major technical or economic constraints with respect to adaptation	Atolls and small islands, New Orleans
Coastal areas where adaptation will deliver great benefits but where substantial barriers to implementation exist (costs, institutional, environmental, etc.)	Venice, Asian megadeltas
Coastal areas that are subject to multiple natural and human-induced stresses, such as subsidence or declining natural defenses	Mississippi, Nile and Asian megadeltas, Netherlands, Mediterranean, Maldives
Coastal areas already experiencing adverse effects of temperature rise	Coral reefs, Arctic coasts (USA, Canada, Russia), Antarctic peninsula
Coastal areas exposed to significant storm surge hazards	Bay of Bengal, Gulf of Mexico/Caribbean, Rio de la Plata/Parana delta, North Sea
Coastal areas where freshwater resources are likely to be particularly and adversely affected by climate change	W. Africa, W. Australia, Atolls and small islands
Coastal areas where economies are highly dependent upon tourism and major adverse effects on tourism are likely	Caribbean, Mediterranean, Florida, Thailand, Maldives
Highly sensitive coastal systems where the scope for inland migration is limited.	Many developed coasts, Low small islands, Bangladesh

The coastal chapter contains an assessment of the costs of sea level rise, storm damage and erosion in the world's coastal regions. Since the IPCC Third Assessment Report there has been significant progress in moving from classical cost–benefit analysis to assessments that integrate monetary, social, and natural science criteria. Under current climate conditions developing countries bear the main human burden of climate related extreme events, but it is equally evident that developed countries are not insulated from disastrous consequences.

Tropical cyclones have major economic, social and environmental consequences for coastal areas. Up to 119 million people are on average exposed every year to tropical cyclone hazards. Worldwide, from 1980 to 2000, a total of more than 250,000 deaths have been associated with tropical cyclones, of which 60 percent occurred in Bangladesh. (This is less than the 300,000 killed in Bangladesh in 1970 by a single cyclone.) The death toll has been reduced in the past decade due largely to improvements in warnings and preparedness, wider public awareness and a stronger sense of community responsibility. The most exposed countries have densely populated coastal areas, often located on megadeltas (China, India, the Philippines, Japan, Bangladesh).

Between 1980 and 2005, the United States sustained 67 weather-related disasters each with an overall damage cost of at least US$1 billion. Coastal States in the southeast United States experienced the greatest number of such disasters. The total costs including both insured and uninsured losses for the period, adjusted to 2002, were over US$500 billion. There are differing views as to whether climatic factors have contributed to the increasing frequency of major weather-related disasters along the Atlantic and Gulf coasts of the United States, but the 2007 IPCC Working Group I report and several independent experts support the view that storm intensity has increased in some ocean basins (such as the North Atlantic) and this will continue with global warming. Whichever view is correct, the damage costs associated with these events are undisputedly high, and will increase into the future, especially if development in coastal areas continues. The following figure from the coastal chapter shows the differential vulnerability of developed and developing nations to the effects of sea level rise:

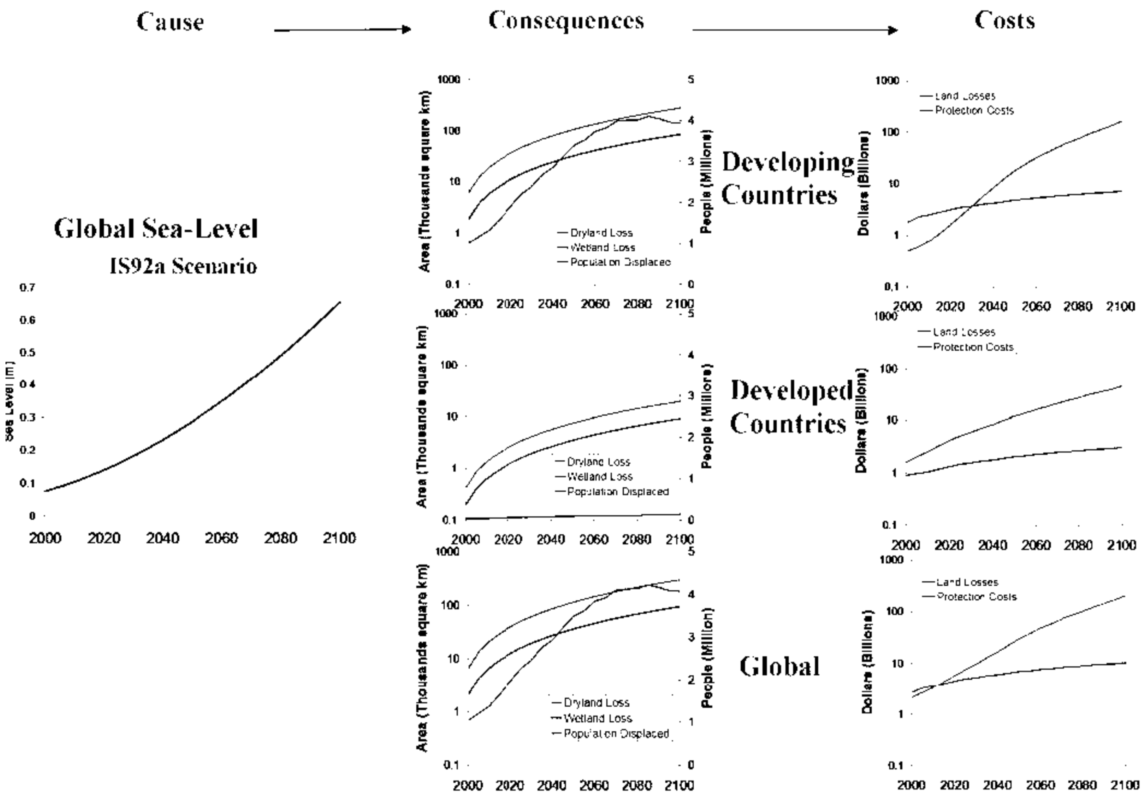


Figure 6.10 of the Coastal Chapter, IPCC Fourth Assessment Report, 2007.
Causes, selected consequences (dryland and wetland loss, people displaced) and the total costs of an assumed sea level rise, for developing and developed countries, and as a global total (based on Tol 2006).

Our chapter concludes with a review of adaptation practices, options and constraints for human settlements in coastal zones. The concept of integrated coastal zone management is discussed with many examples given to illustrate adaptation practices that will help sustain natural coastal systems, their ecological services and the human communities that depend upon them. We do note, however, that recent studies suggest that there are limits to the extent to which natural and human coastal systems can adapt even to the more immediate changes in climate variability and extreme events. For example, short of mitigation, there is little that humans can do to ameliorate the effects of increased sea surface temperature on coral reefs -- other than reduce the non-climate related pressures of human activity. Without either adaptation or mitigation the impacts of sea level rise and other climate change such as more intense storms will be substantial, suggesting that some small islands and low-lying coastal areas may become uninhabitable by 2100.

Two things became immensely clear to us as we concluded this assessment: 1) it is much more costly to consider the effects of climate change after the fact than to incorporate climate change into adaptive coastal management now and 2) poor communities (and the poorer parts of communities) and developing coastal and island nations are particularly vulnerable to the impacts of climate change. Poorer coastal societies have a limited ability to adapt or cope with change because they tend to be concentrated in relatively high-risk areas, they have more limited financial and institutional capacities needed for adaptation, and they are often more dependent on climate-sensitive resources such as local water and food supplies.

Thank you, Mr. Chairman, for inviting me to summarize our coastal chapter findings. I will be happy to try and answer any questions that you may have.