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SEA LEVEL OBSERVED AND PROJECTED AND IMPACT ON INDIAN AND PACIFIC TROPICAL ISLANDS

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Abstract

The aim of this paper is to show that the positive trend to sea levels rise is not a linear phenomenon and that across the twenty-first century the role of cyclones - whose simulation for the future is very difficult to establish with numerical climate models - will be the main cause of coastal flooding. The societal implications of sea levels rise on floodplains are also of human responsibility that landscape areas are vulnerable by not incorporating enough this hypothesis, often out of ignorance but also for economic reasons.

Keywords: climate change, coastal erosion, sea level rise, vulnerability

1. INTRODUCTION

The global mean sea level shows an upward trend since the XIX middle century, with acceleration since the 1980's. This trend, which varies in time and space, is expected to continue in the future decades on the main effect of expansion by warming water and decrease volume of continental ice (Cabanes and *al*., 2001; Duyrgerov and Meier, 2005) and for many authors, as Levitus and *al*. (2005), this acceleration should continue in the future. This phenomenon adds to the effects of marine submergence resulting of atmospheric disturbances episode, specially, in phase with a high tidal coefficient, will cause a major coastal flooding of the lower cost. The tropical islands constitute a pertinent location to observe this evolution and its consequence on sandy beaches, atolls and wetlands which are also affected by the effects of other anthropogenic activities, with an economic, environmental, social and political consequence. The increased marine submergence, especially during strong disturbed weather (Hurricane), will weaken sandy beaches, atolls and wetlands already affected by various anthropogenic activities. Although the uncertainties of General Climatic Model concerned authorities have different possibilities of response between mass population displacement and protection from the elements.

2. POSITIVE TREND, INTER-ANNUAL VARIABILITY OBSERVED AND SEA LEVEL PREDICTION FOR THE XIX CENTURY

Since the XIX middle century, the sea level is measured by few tide gauges whose number has increased specially after the second half of the XX century (no show), and since 1993, TOPEX-Poseidon (until 2006), Jason-1 (2001-08) and Jason 2 (since 2008) altimetric satellites have regularly been measuring the sea level with an estimated average of 2cm accuracy over a month after correction. These data showed that the mean global ocean sea level rose by about 3.4 mm/y (Cazenave and *al*., 2008), which is significantly higher than that calculated from measurements by tide gauges over the twentieth century. However these measurements also showed that the increase in water level is not uniform (Fig. 1): for example, actually the increase is less important and more variable in the Pacific Ocean, where ocean-atmosphere phenomena such the El Niño-Southern Oscillation has an important role on the sea level.
At multi-decade's scale (excluding locally perceptible descendant or ascendant of the continental mass), two factors may explain a large part of the sea level rise:

- Those resulting from water temperature variation expressed by density and volume
- Those resulting from water exchanges between reservoirs (atmosphere, inland waters, mountain glaciers…).

Using the latest satellite measurements, the sea level rise seems occurring at a faster rate than the estimated rise made for decades prior to the twentieth century using tide gauge measurements. To explain this recent trend, Duyrgerov and Meier (2005) indicated that contribution of fresh water is more important since the early 1990s, partly due to the mass loss from Greenland. According to calculations by Rignot and Kanagaratnam (2006), ice surface for the Greenland icecap was reduced by 91 km^3 in 1996, 138 km^3 in 2000 and 224 km^3 in 2005. Two third of these losses are due to acceleration of flow velocities of glaciers, the other

part to their melting. Cazenave and *al*. (2007) estimate that the mean elevation of the ocean current level would equally be due to thermal expansion of warming ocean and to melting of polar ice caps and mountain glaciers.

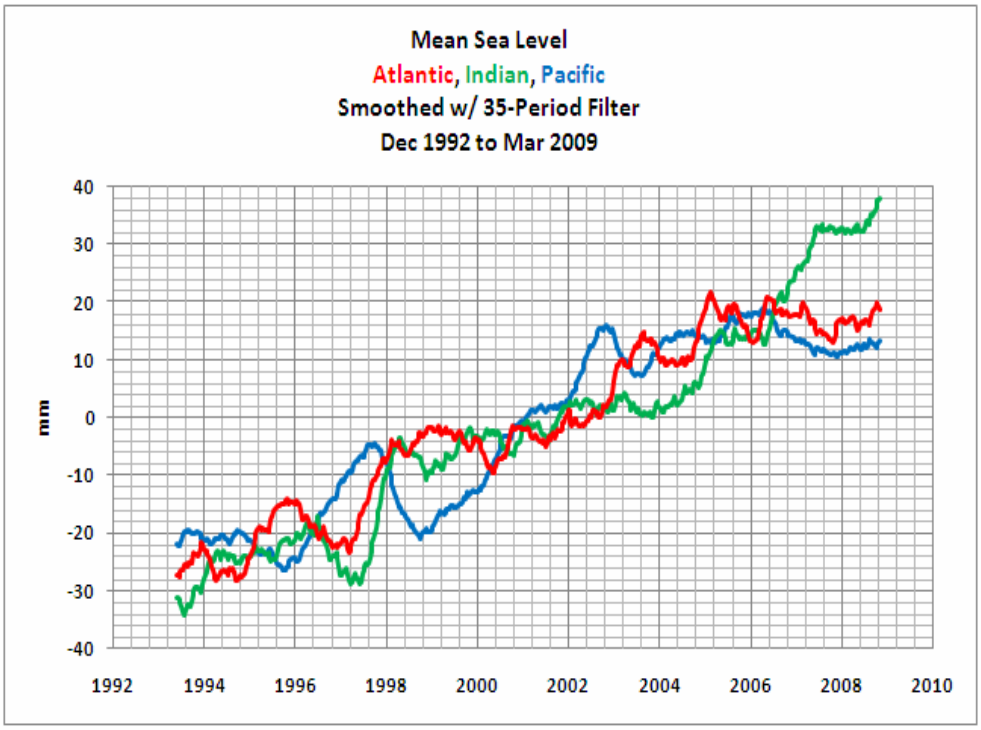

Figure 1: Atlantic, Indian, and Pacific Ocean Sea Levels from December 1992 and March 2009. Data has been smoothed with a 35-month filter. Notes from Bob Tisdale on Climate Change and Global Warming Newest technology used by researchers (numerical models, satellite observation…) revealed the existence of regional (and seasonal) variability of sea level. However factors that explain variability at regional scales and over periods of few years, are not sufficiently understood (part of salinity and density of water for example). This result show that, it's difficult to perform numerical simulations of the sea level regional evolutions over the future decades and quality of forecasts for the current century varies greatly from a variable to another.

2.1 A very likely rising of sea level

The extreme range of recent sea level rise estimation of the International Panel of Climatic Change (IPCC, 2007) for the end of the XXI century varies between 18-38 cm and 26-59 cm (with mean around 39 cm) depending on scenario (values are the average difference between the 1971-2000 period and the 2071-2100 period). However, recent publication of Grinsted and *al*. (2009) showed that the 2090-2099 IPCC projections of sea level rise are underestimated by roughly a factor 3 (Fig. 2).

2.2. For tropical turbulence, a lack of consensus at the climate scale

The response of tropical disturbances to global warming is being investigated although no scientific conclusion has yet been released. The IPCC reports (2007) underscore the lack of convergence in the responses of various (GCM) used in the scientific community. This reflects the complexity of cyclonic activities (typhoon, hurricane…), which involves massive ocean-atmosphere coupled system mechanisms that cannot be properly represented in the models currently available. Some simulations provided an overall increase in the frequency and / or intensity of typhoons for the twenty-first century, while others predicted a decrease (Kushnir and *al*., 1997; Wang and Swail, 2001; Loranzo and *al*. 2004, Chauvin and *al*., 2004). Indeed these uncertainties have been the current foundation for scientific debate.

These results showed that GCM are able to integrate part of the physical variability but they were not able to incorporate all local processes. A margin of incertitude is always present.

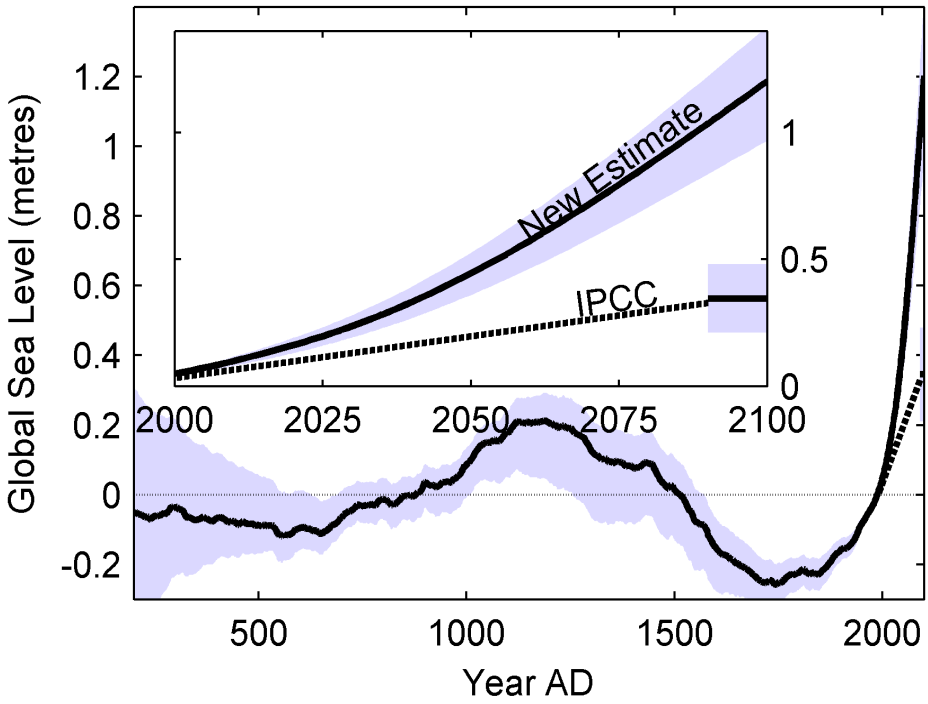

Figure 2: Projected sea level based on IPCC scenario A1B using temperature reconstructions by Moberg and *al.* (2005) (In Grinsted and *al.*, 2009)

3. SOME POSSIBLE CONSEQUENCES OF SEA LEVEL RISE AND HUMAN

If the XXI century projection for the evolution of level rise is confirmed, several millions of people living on the coasts will be forced to adapt, to protect themselves or to abandon the coastal regions before they get submerged. In some cases, this rise will extend salt areas in groundwater, causing a decline in freshwater resources, which may be source of conflicts and economic recession.

3.1 The case of Maldives archipelago

In the Maldives archipelago (more than 200 indigenous islands, 87 tourist islands and between 800 and 900 uninhabited islands), flooding has long been known. Low islands are characterized by small sizes (0.2 to 5 km^2 in general) and low altitudes (<4 m in most cases). Similar to other archipelagos, these islands represent a type of sedimentary body, particularly vulnerable to flood risk. Malé, the capital city, occupies the entire island surface (a 2 km long by 1.5 wide rectangle) situated at the reef coral barrier level. The city is surrounded by ports and dykes that protect the 80 000 inhabitants from the 2 to 3 m high waves. Concerned about this risk, the government has begun the construction of a new artificial island at 2 m above sea level, Hulumalé, intended for future transfer of residents from the lowest and most vulnerable atolls, including some of the capital inhabitants, which is currently one of the most densely populated cities in the world. In the longer term, such high cost involved measures will certainly be difficult to generalize and transfer of population to other territories may have to be considered.

In this country, planning is exclusively designed for tourism, which may lead to important economic and environmental consequences. Rufin-Soller (2005) showed that the natural uninhabited islands were traditionally used by the indigenous population because they provide first need materials: coconut, sand for construction (although this is theoretically forbidden) or "*alevins*" (for non-industrial tuna fishing). Damage to uninhabited islands may have an impact on the economic chain and the island environment.

3.2. The case of Tuvalu

Tuvalu, a small island state consisting of nine tiny atolls near Fiji Islands, is a vulnerable territory to environmental changes. Medias largely used the case of these islands to often hold climate change solely responsible for increase in flooding. However Xue (2004) showed that the loss of land in Tuvalu was mainly

the results of inappropriate human activities with coastal development and exploitation of aggregates in addition to the effects of cyclones. Moreover, all recent satellite altimetry measurement and tide gauge data do not confirm a rise in sea levels around Tuvalu islands. Rising sea level is certainly an aggravating factor, but it's not certainly the main factor. Consequence on Human activities and hurricanes are surely more responsible of damage on these islands where an important demographic growth rate is recorded and natural resources are limited.

4. CONCLUSION

The average sea level rise, estimated by IPCC (2007) between 18 and 59 cm (or recent reviews provide larger estimates between 90 and 120 cm…) for the end of the XXI century begins to worry population and economic actors. The forecast announced about the mean elevation of sea level, shouldn't hide that in the short term are the phenomena of surges due to atmospheric turbulence (Hurricane) and who have by far the greatest danger to the coastline. Science is far from a consensus on some points but questions remain unanswered: with climate change, strong atmospheric disturbance will be more active? Will they always occur at latitudes where they occur today? Etc... In all cases, even with the continuing uncertainty of GCMs, flooding by the sea on the part of the land is a risk that must be considered and some communities are already taking steps to adapt the territory or ask questions for best anticipation.

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