EPISODIC PROCESSES (STORM SURGES AND TSUNAMIS)

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Contents

Note on Units

The International System of Units (SI) was employed throughout the text. Letter symbols include quantity symbols and unit symbols. Symbols for physical quantities were set in italic type, while symbols for units were set in roman type, as indicated in: Nelson, R.A., 2000. Guide for Metric Practice, Physics Today, BG 2000, p.15-16.

Summary

This article deals with some special phenomena involving anomalous elevations of sea level which cause significant impacts on coastal systems. The two major processes addressed are storm surges and tsunamis. Because of their short duration and fairly unpredictable nature, both storm surges and tsunamis are regarded as "episodic phenomena".

Tropical and extra-tropical storm surges are analyzed in terms of their physical background and of their effects when they strike the coast. Tropical storms are generated in low latitudes, approximately between 5° and 25°, whilst extra-tropical storms develop at higher latitudes, between 25º and 60º. The former are common in the Indian Ocean, the southeast coast of USA and Caribbean Sea and the latter are typical of the North Sea, the northeast coast of USA and Canada, and southwest Atlantic Ocean.

Selected examples of their effects on world coasts are provided. Tsunami generation, propagation and impact on coasts are also discussed. Most are produced by seafloor displacements of seismic origin, others are generated by underwater landslides, and a small number are the result of volcanic eruptions. Calving of glaciers and the extremely rare meteorite or asteroid impact in the open ocean can also be considered among possible generation mechanisms.

The most exposed areas to tsunami are the tectonically-active zones. However, because tsunami waves travel long distances, their effects can be felt in distant areas. An account of several historical tsunamis and of their (mostly-devastating) effects is provided, and regional examples are illustrated for various parts of the world. A brief consideration of future perspectives in the framework of global climate change is also addressed. A possible increase in the frequency and intensity of tropical and extra-tropical storm surges, and ENSO-linked processes associated with accelerated global warming would imply an exacerbation of destructive processes on the world´s fragile coastlines.

1. Introduction

"Naturam expellas furca, tamen usque recurret"

Quintus Horatius Flaccus: Epistles, Book I, Ep. X, v. 24

Apart from tides, which cause periodic and regular changes of the world sea level, there are other factors capable of producing significant changes in sea level, although their action is restricted to time periods ranging from a few minutes to a few days: they are, basically, storm surges and tsunamis. In spite of their brief occurrence, their consequences can be highly destructive in human lives and property.

On the other hand, these events are a major factor in coastal morphodynamics and ecosystem development, mainly because of the sharp changes they induce. Due to their short duration, both storm surges and tsunamis can be regarded as "episodic phenomena". They imply anomalous elevations of sea level, at times with superimposed effects, such as enhanced wave energy.

Since the formation of the world ocean in remote geologic times, the relative level of the sea has not ceased to fluctuate. Changes in the volume of the ocean waters due to thermal effects, basin shape and structure, tectonic dynamics, glacial isostasy, hydraulic and sedimentological processes, and the consequent subsidence and elevation of terrestrial masses have been, and are, among other effects, responsible for the permanent fluctuation of sea level.

Although geological records show that enormous relative variations of the land-sea interface have occurred through millions of years, it is usual to refer to slow sea-level variations as those produced in the last 15 000 years as a consequence of the progressive melting of continental glaciers. These long term changes in sea level, which are on the order of 10 to 20 cm per century, are known as secular variations, and regardless of the geological period, they are characterized for being much smaller than those produced by tides, storm surges or tsunamis.

Detailed references to various aspects of coastal systems, including their morphology, dynamics, sedimentary processes, sea-level changes and coastal evolution, tectonics and general environmental features can be found elsewhere in EOLSS.

2. Sea level

When measuring sea level at any given instant, the result of three basic processes is actually observed: (i) a slow mean sea-level variation; (ii) the astronomic tide, and (III) the action of meteorological agents. Mathematically, the observed level at time t, X(t), can be expressed by:

$$X(t) = Z_0(t) + T(t) + S(t) \qquad (1)$$

where $Z_0(t)$ represents the slow variation of sea level, T(t) the astronomic tide, and S(t) the meteorological action.

The second term of Eq. (1) refers to the astronomical tide. This is due to the simultaneous action of the gravitational forces of the Moon, the Sun and the Earth, and to the revolution of the systems Moon-Earth and Sun-Earth around their respective centers of mass. Such forces are the most regular and more precisely defined in the field of geophysics, and their action is coherent at a global scale. Tidal tables for numerous ports in the world have been produced as a result of the understanding of these forces.

The third term of Eq. (1) describes the meteorological effects. These can change considerably the predicted sea-level height. As opposed to the precision of tidal forces, the prediction of meteorological forces due to atmospheric pressure and wind stress has the same degree of confidence as a meteorological forecast.

The effects of these forces during a particular storm are restricted to a regional, or even local area, and the duration ranges between few minutes and several days. It is within this category where climate-driven episodic phenomena, such as storm surges, are classified.

However, other phenomena related to ocean-atmosphere interactions, such as El Niño Southern Oscillation (ENSO), with a duration on the order of one year, can also be included into this category. Also, tsunami events involve anomalous sea-level positions, although they usually last tens of minutes.

3. Storm surges

3.1 General features

A storm surge is a rise in sea level above normal tidal variations due to the action of strong winds blowing towards the land. When storm surges are the result of severe storms such as hurricanes, the low atmospheric pressure at the center of the depression can additionally raise the sea level.

Thus storm surges are usually the result of two different physical processes, namely wind shear stress acting on the water surface and changes in the atmospheric pressure. Storm surges have been responsible for extensive flooding of low-lying regions in many parts of the world, and have caused great loss of lives and property damage.

Storm surges can be more severe if they coincide with a high tide or if they bracket several tidal cycles, particularly in the case of a perigean tide. The term storm tide is used by some researchers to denote the sum of the astronomical tide and storm surge.

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Biographical Sketches

Enrique J. Schnack received both his bachelor degree in Geology (1964) and doctoral degree in Natural Sciences (1968) from the National University of La Plata, Argentina. He received postdoctoral experience at the University of Reading, U.K., and at Stanford University, California. Since 1971 Dr. Schnack has been a career scientist for the Province of Buenos Aires Research Council and currently works at the Laboratory for Coastal Oceanography, University of La Plata. He was the founding director of the Center for Coastal Geology at the National University of Mar del Plata (1979-89), where he also taught as a professor of Geological Oceanography. During the last 25 years, he has been an active member of various international working groups, particularly with the International Geological Correlation Programme, in projects related to Quaternary sea-level changes. He has published over 50 papers on coastal geomorphology, processes and evolution.

Jorge L. Pousa received both his bachelor (1972) and doctor degrees in Physics (1980) from the National University of La Plata. During the first 10 years after his graduation, Dr. Pousa worked on molecular physics. Afterwards, he became progressively engaged in physical oceanography. He is currently a career scientist from the Argentine National Research Council at the Laboratory for Coastal Oceanography, University of La Plata, and a lecturer in physical oceanography at the Faculty of Natural Sciences and Museum. He has published over 40 papers on molecular physics and coastal oceanography.