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TROPICAL COASTAL ENGINEERING IN INDONESIA ADAPTING TO NEAR-TERM OCEAN-CLIMATE CHANGES

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ABSTRACT: Bali Coastal Experimental Station, Public Works of ROI is seeking Tropical Coastal Engineering (TCE) in Indonesia. As a near-term perspective of ocean climate changes in the western tropical Pacific, there are three major effects concerning to TCE. One is the decadal oscillation of North Pacific Ocean (PDO) that is related to long-term changes in ENSO, such as La Nina dominant and El Nino dominant periods. Based on multivariate ENSO index (MEI), it is indicated that El Nino dominant period may shift to La Nina dominant around 2007 that will increase rainfall in the Indonesian archipelago. The second one is lunar nodal tide of 18.6 year period. In 2007, an extreme flood modulated by coastal tide occurred in Jakarta and some coastline cities in Indonesia. Its next peak is expected in 2025. Heavy rainfalls caused by El Nino dominant period and the peak of lunar nodal tide may cause the estuary flooding in the next 25 years. The third effect is the changes in solar activities. Observations of "Sunrise", a solar observation satellite in January 2012, found that the solar magnetic field becomes "quadrupole structure" that may reduce solar energy and increase of galaxlian cosmic ray resulting in increase of cloud cover especially in the Inter-Tropical Convergence Zone (ITCZ). This effect could trigger a mini-Ice Age on Earth with increasing of precipitation in the tropical area. An increase of flooding may cause the increase of sediment transport from the river. TCE should solve these challenges of coastal and estuary problems in Indonesia. This paper summarizes these effects in Indonesian costs and perspectives of TCE.

Keywords: Tropical coastal engineering, climate changes, lunar nodal tide, PDO, ENSO.

INTRODUCTION

The Research Centre for Water Resources, Ministry of Public Works, Republic of Indonesia opened the new Experimental Station for Coastal Engineering in Bali, September, 2012 to enhance the skill and research in the field of Coastal Engineering in Indonesia.

Since Indonesia's coastal engineering has been developed by directly introducing the technology that had been developed in Japan, Europe and the United States, there is still plenty of room for improvement in the technology that considers the special characteristics in Indonesia, such as siltation of volcanic sediment in the coast and estuary, tropical coastal environment and ecosystems, atmospheric and oceanic external forces in the inter-tropical convergence zone together with climate changes and anthropogenic coastal development.

With increasing the number of researchers and engineers who engages in the Coastal Engineering in Indonesia, an establishment of “Tropical Coastal Engineering” (TCE) has become increasingly necessary. Having been recognized the need of TCE, the Bali Experimental Station for Coastal Engineering was established to conduct the researches on sustainable development in tropical coast, estuary and lowland peatlands.

This paper shows the near-term perspective of ocean-climate changes in Indonesia and summarizes the challenges in TCE.

CHARACTERISTICS OF TROPICAL COAST

Tropical Weather and Ocean Characteristics

The Indonesian archipelago is located the weak wind zone near the equator called the doldrums, which is sandwiched in the Southern Hemisphere and the southeast trade winds northeast trade winds in the Northern Hemisphere. Also referred to as the equatorial trough since the low pressure zone and strong updraft occurs because of the solar radiation, thunderstorms, and squall are likely to occur in this area. (see Fig.1)

The Indonesian archipelago is affected by ENSO (El Niño/La Niña–Southern Oscillation), which is a band of anomalously warm ocean water temperatures that occasionally develops off the western coast of South America and can cause climatic changes across the Pacific Ocean. The “Southern Oscillation” refers to variations in the temperature of the surface of the

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tropical eastern Pacific Ocean (warming and cooling known as El Nino and La Nina, respectively). The two variations are coupled. The warm oceanic phase is called El Nino, accompanies high air surface pressure in the western Pacific, while the cold phase is called La Nina, accompanies low air surface pressure in the western Pacific. Weather in Indonesia is strongly affected by this oscillation together with the Indian Ocean Dipole (IOD) that is also known as the Indian Nino is an irregular oscillation of sea-surface temperatures in which the western Indian Ocean becomes alternately warmer and then colder than the eastern part of the ocean.

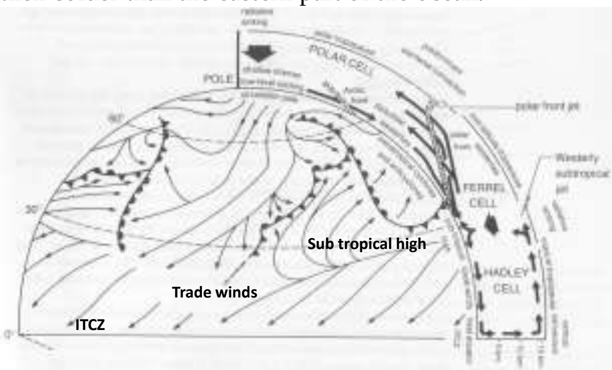


Fig.1 Weather map in Northern Hemisphere (Musk, 1988)

Tropical Cyclone and Ocean Winds

Most tropical cyclones are generated in the Pacific Ocean west of the International Date Line than any other ocean. There is almost no activity in the South Atlantic Ocean and near the Equator including the Indonesian archipelago due to weak Colioris force.

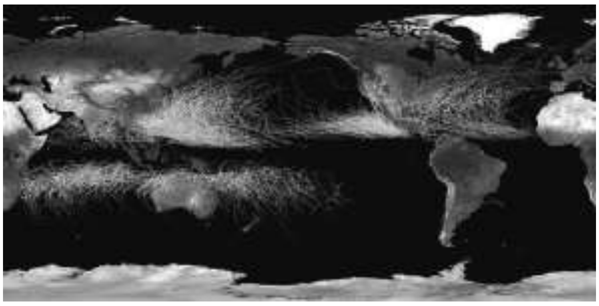


Fig.2 Map of the cumulative tracks of all tropical cyclones during the 1985–2005 time period. (http://en.wikipedia.org/wiki/Tropical_cyclone)

Wind Waves and Swells

Waves in Indonesian sea are largely generated by local winds. Even though being gentle in the equatorial zone, stronger waves on the northern and southern coasts subject to northeast and southeast trade winds, respectively. Ocean swell moves into the southern coast from the Indian Ocean and to the northern coast from the southwest Pacific, are creating particularly larger waves.

The KNMI/ERA-40 Wave Atlas available on this server is provided for research purposes. The atlas statistics are based on data averaged on a 1.5°x1.5° area or equivalently a period of about 3 hours, and could be exceeded at short time/space scales. The ERA-40 model does not account for shallow water effects and therefore the atlas statistics are only valid in deep water regions. Due to resolution, tropical cyclones are not resolved by the ERA-40 system. Therefore, the statistics for the regions of the tropical storms may be too low. From this database, global distributions of the significant wave heights in winter and summer are shown in the upper figure in Fig.3. Annual average of significant wave height in 1972-1981 is shown in the left lower figure, that in 1986-1995 is shown in the right lower figure in Fig.3 in which the increase in wave energy due to global warming can be recognized. The upper figure shows that major swells along the Indonesian southern coasts propagating the Indian Ocean are generated by the Antarctic circumpolar winds in summer (July, see the upper right figure in Fig.3).

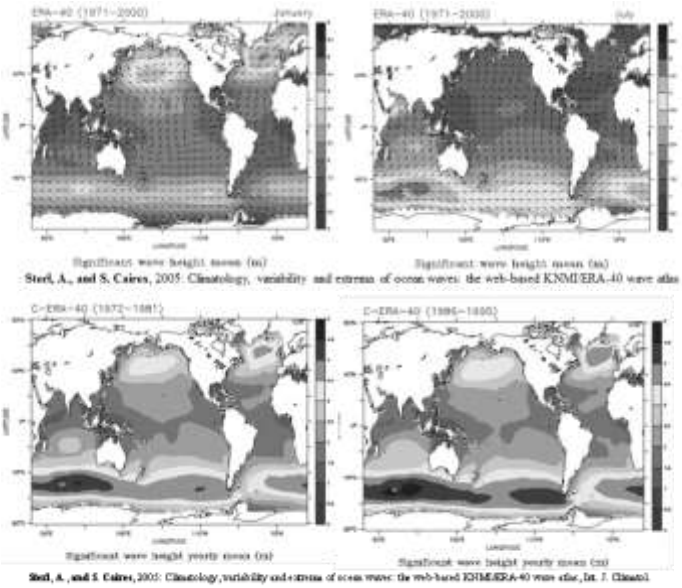


Fig.3 Global wave climate of KNMI/ERA-40 Wave Atlas. Upper: average wave height in January(left) and July(right). Lower: average wave height in 1972-1981 and 1986-1995.

Estuary, Tidal Flats and Lowland Peatlands

Fig.4 shows Indonesia's primary forest in green and peatland in red. White areas indicate forest and peatland that will remain unprotected by the moratorium where concessions have already been allocated. Lowland peatland protection in Sumatra, Kalimantan and Papua is one of key issues of Indonesia's forest management through the REDD+, in which estuary and tidal flat conservation should be considered together.

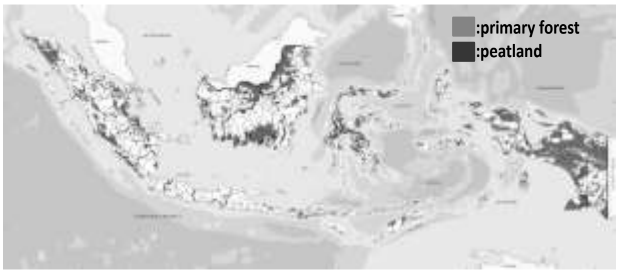


Fig.4 Indonesia's peatlands distribution along the coast. (http://www.redd-monitor.org/2011/05/26/is-indonesias-moratorium-worth-the-paper-its-written-on/)

Coral Reefs

The well-being of coastal communities in the tropics is linked to the condition of the coral reefs upon which they depend for both food and livelihoods. Indonesia has the reef area of 51,020 km^2 that is 17% of the world's total coral reef areas. 82% of that amount is at risk due to coral mining for construction material and blast fishing, which has been illegal since 1985 still goes on with cyanide fishing. Too much uses of coral reefs are destructive and unsustainable, causing the reef conditions deteriorate rapidly (see Fig.5). Both Coral reef preservation and coral beaches protection should be done comprehensive in a comprehensive management structure.

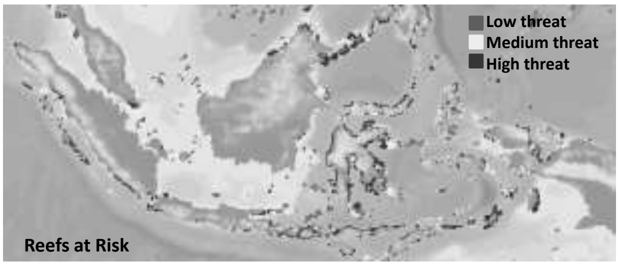


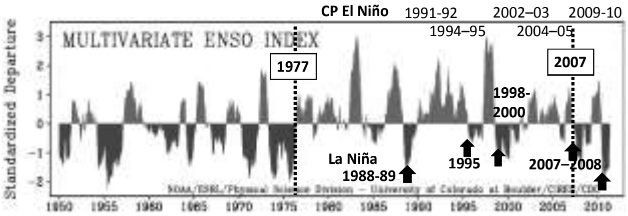
Fig.5 Coral reefs at risk in Indonesian water. (*ReefBase*: A global information system for coral reef, http://www.reefbase.org/main.aspx)

NEAR-TERM PERSPECTIVE OF OCEAN CLIMATE CHANGES

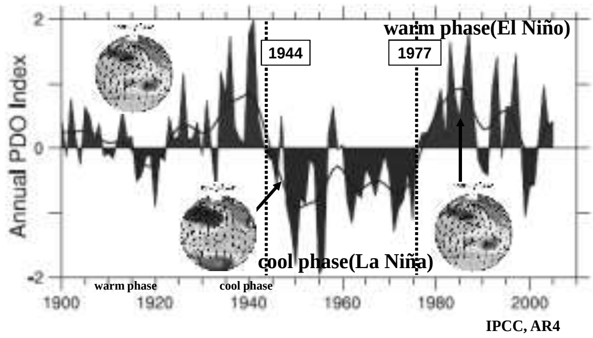
Atmosphere-Ocean Oscillation: ENSO, DMI and PDO

During the last several decades (1977-2005) the number of El Niño events increased, and the number of La Niña events decreased. It can be called the El Niño dominant phase. Before that phase, during the period of 1945-1977, the number of La Niña events were much more numbers of El Niño events. (See Fig.6 upper).

After subtracting the positive influence of decadal variation, shown to be possibly present in the ENSO trend, the amplitude of the ENSO variability in the observed data still increases, by as much as 60% in the last 50 years. This may be caused by the global climate changes towards global warming. However the cycle of La Niña events dominant phase and El Niño dominant phase may still exist in the future. Recent researches, Schneider and Cornuelle (2005), have indicated that the PDO (Pacific Decadal Oscillation) index can be reproduced with superimposing tropical forcing and extra-tropical processes.



http://www.esrl.noaa.gov/psd/enso/mei/



IPCC, AR4(2007)

Fig.6 Changes in MEI (upper) and PDO (lower) indexes

Unlike ENSO, the PDO is not a single physical mode of ocean variability, but the sum of several processes with different dynamics of

(1) ENSO induced variability in the Aleutian low on decadal timescales of ENSO teleconnections,

(2) stochastic atmospheric forcing,

(3) changes in the North Pacific ocean gyre circulation, and

(4) SST anomalies have some winter to winter persistence due to the reemergence mechanism.

ENSO influences the global circulation pattern through the "atmospheric bridge". During El Nino events a deep convection and heat transfer to the troposphere is enhanced by the warm SST resulting in the ENSO related tropical forcing generates Rossby wave that is observed as a large-scale meander of the jet stream that propagates poleward and eastward and subsequently refracted back to the tropics from the pole. This ENSO-driven pattern modifies surface temperature, humidity, wind and the distribution of cloud over the North Pacific that alter surface heat, momentum and freshwater fluxes in the atmosphere and finally change the sea surface temperature, salinity and mixed layer depth in the ocean. This is called the atmospheric bridge that is more effective during boreal winter. When the Aleutian low is deepened a northwesterly wind in the central Pacific becomes stronger and cold, moreover the warm and humid southerly winds blows along the North American's west coast. This large scale atmospheric circulation derives the changes in the surface heat fluxes that create negative sea surface temperature anomalies and a deepened mixed layer depth in the Central Pacific and warm the ocean water from the Hawaii to the Bering Sea. This is one of the mechanisms of PDO, that is the mechanism of ENSO induced variability in the Aleutian low on decadal timescales of ENSO teleconnections.

PDO has several regime shifts that are apparent both in the reconstructions and instrumental data. During the 20th century, its regime shifts associated with concurrent changes in SST, SLP, land precipitation and ocean cloud cover occurred in 1945-1946 and 1976-1977 as shown in Fig.6 (cited from IPCC, AR4, 2007).

Super Typhoon Close to the Equator: A case of Bopha in 2012

The circulation became exposed, and the JTWC noted that Bopha was unable to intensify significantly due to its low latitude and correspondingly low Coriolis effect. However, late on November 29, 2012, convection increased, aided by warm waters and low wind shear. As the system continued to intensify, organized bands of thunderstorms began to develop rapidly around the system. Typhoon Bopha was the strongest tropical cyclone that hit Mindanao, the southern Philippine island, making landfall as a Category 5 super typhoon with winds of 72 m/s. Bopha made landfall on Mindanao late on December 3, 2012, leaving thousands homeless and more than 600 fatalities. Bopha originated unusually close to the equator, reaching the minimum latitude of 7.4°N on December 3 as shown in Fig.7.

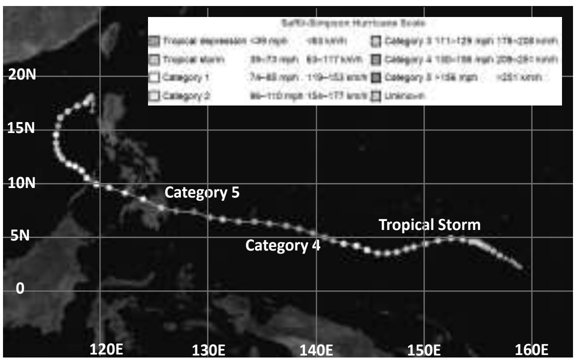


Fig.7 Track map of Typhoon Bopha in 2012.
(http://en.wikipedia.org/wiki/Typhoon_Bopha)

Only Typhoon Louise in1964 came closer to the equator at this strength, at 7.3°N. Even though in the low latitude, it is possible to generate the super typhoon under the condition of high temperature of sea surface water. The points in Fig.7 show the location of the storm at 6-hour intervals. The color represents the storm's maximum sustained wind speeds as classified in the Saffir-Simpson Hurricane.

RELATIVE SEA LEVEL CHANGES

Land Subsidence

The major causes of land subsidence are both ground water extraction and natural consolidation of alluvial soil. Land subsidence is continuing as long as groundwater is extracted. This has worsened the flood risks particularly in those specific areas in Jakarta.

The other land subsidence near the coast, former mangrove forest, becomes very seriously after the development in the western regions of Jakarta. In the process of rapid sprawling of Jakarta Metropolis around 1980-1995, the mangrove forests Cisadane river mouth has been developed resulting in sever land subsidence of over 12cm/year. Fig.8 shows the land subsidence contour map measured by satellite and GPS data. H. Z. Abidin et al(2008) investigated the spatial and temporal variations of subsidence in the Jakarta over the period of 1982 to 2007 and made clear the subsidence rates of about 1 to 15cm/year. Several locations of once mangrove forest had the subsidence rates about 20-25 cm/year.

Fig. 8 Satellite (ALOS/PALSAR) measurement of land subsidence in Jakarta.

Sea Level Rise

Fig.9, the image created with sea surface height data from the Topex/Poseidon and Jason-1 satellites, shows how ocean surface heights have changed from 1993 to 2013. The order of sea level rise in the Indonesian Archipelago is less than 5mm/yr except the Pacific Ocean of Papua State.

During the fist half of the next century, the choice of emission scenario has relatively little effect on the projected sea level rise due to the large thermal inertia of the ocean-ice-atmosphere climate system, but has increasingly larger effects in the later part of the next century. In addition, because of the thermal inertia of the oceans, sea level would continue to rise for many centuries beyond 2100 even if concentrations of greenhouse gases were stabilized at that time (see Fig.10, UNEP).

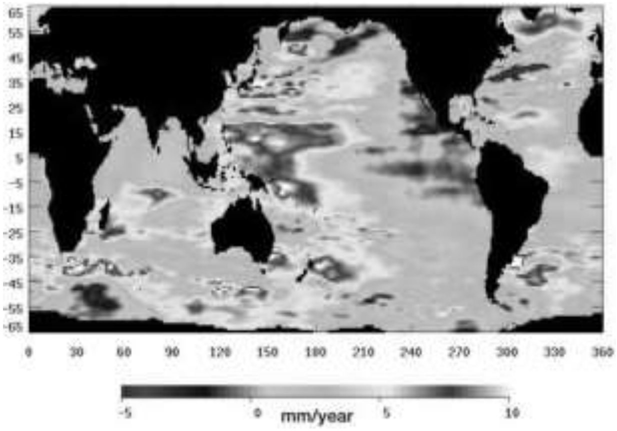


Fig. 9 A new map pinpoints areas of sea level increase (http://climate.nasa.gov/news/16)

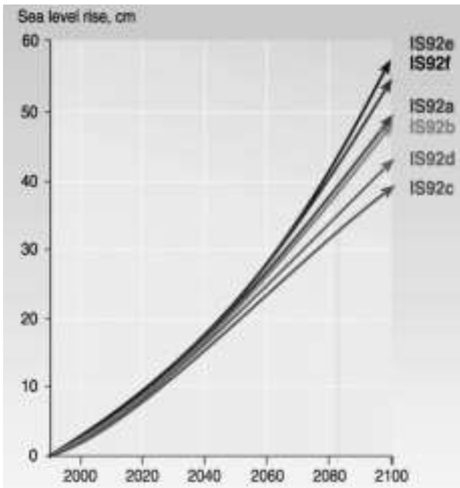


Fig. 10 A new map pinpoints areas of sea level increase (http://climate.nasa.gov/news/16)

18.61-year Luna Nodal Tide

The high astronomical tides contribute to the occurrence of extreme sea level rise. Two precessions associated with the orbit of the Moon cause systematic variation of high tides. A global prediction of the enhanced risk of coastal flooding caused by interannual astronomical tide is effective for coastal disaster prevention. The influence of the 18.61 year lunar nodal cycle is greatest in diurnal regions with tidal ranges of over 4 m. Indonesian coastal cities, such as Jakarta and Semarang suffered with ocean flooding enhanced by the 18.61 year lunar nodal tide in February, 2007. It was a result of heavy rain, deforestation in the areas south of the city, waterways clogged with debris, and the 18.61 year lunar nodal tide. This flood was the worst in the last three centuries including 1996 and 2002.

The maximum spring tide levels in Fig.11 clearly show a periodicity between 18.61years.

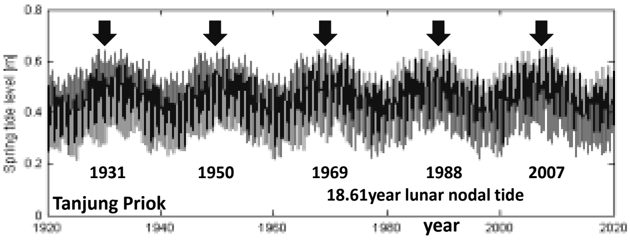


Fig. 11 Maximum spring tide levels at Tanjung Priok from 1920 to 2020 based on water level predictions. (from Jakarta Flood Hazard Mapping Framework)

TROPICAL COASTAL ENGINEERING

The Bali Experimental Station for Coastal Engineering will be the center of researches on TCE. This chapter summarizes research activities and introducing models/methods for establishing TCE in Indonesia.

Database and Information Necessary

1) Database of tropical weather and coastal climate
・Create a database of surface meteorological information: temperature, wind velocity vector, pressure, precipitation, humidity, solar radiation, soil moisture and temperature, carbon dioxide concentration, and ENSO.
・Create a database of coastal climate: waves, ocean currents, sea surface temperature, sea surface wind speed vector, ENSO and PDO.
2) Database of tropical swamp and lowland peatlands
・Tropical lowland peatlands: coastal region (see Fig.5), peat thickness, groundwater level, forest form, terrain slope, rainfall, evapotranspiration etc.
・Development processes and conservation measures of tropical lowland peatlands with REDD+ scheme
・Fire information of tropical lowland peatlands: spontaneous and anthropogenic ignition, size of the fire.
・Physical, chemical characteristics, amount of biomass.
・Surrounding vegetation and biodiversity.
3) Basic information of tropical coastal ecosystems
・Coral reefs (see Fig.5)
・Fishing and aquaculture activities
・Swamp and mangrove forests
・Estuaries, tidal flat and lowland peatlands
4) Sediment database
・Sandy beaches: sediment characteristics, sediment cell system, beach topography

・Coral reef beaches: coral sediment characteristics, currents and waves inside coral pool.
・Cohesive sediment coasts: mud/sand characteristics in the tidal flats, source of sediment, flocculation properties, organic matter distribution.
・Estuary, swamp and lowland peatlands: sediment input from the river, underground water flow, salt water intrusion, organic matter distribution

Coastal Preservation Technology

1) Beach stabilization by headlands: formation of series of stable pocket beaches (see Fig.12) to prevent beach erosion and/or create a new sandy beach.

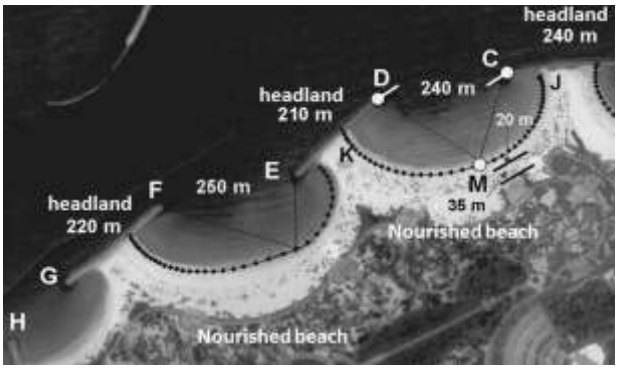


Fig.12 A sample of beach stabilization by headlands

2) Beach nourishment: coastal protection by sandy fill
3) Coral transplant: coral reef system recovery
4) Mangrove forestation on muddy tidal flat: beach protection and nursery of ecosystem
5) Siltation measures: navigation channel maintenance

Hydraulic Experiments and Numerical Models

1) Technology enhancement of hydraulic experiments: Physical and numerical hybrid experimental methods.
2) Enhancement of numerical Simulation capacity by introducing the Regional Environment Simulator of which framework is shown in Fig.13 (Yamashita et al., 2005).
・Coastal current simulation : MIKE21, POM (Princeton Ocean Model), MITgcm.
・Coastal weather simulation: WRF (meso-scale meteorological model).
・Beach change simulation: three dimensional beach change model.
・Cohesive sediment transport: ECOMSED-COSINUS model developed by Fitri & Yamashita(2005).
・Tsunami simulation: earthquake fault model, tsunami propagation and inundation.
・Ecosystem models: coastal ecosystem, coral reef ecosystem, estuary ecosystem, swamp and lowland peatlands ecosystem.
・Hydrology and hydraulics model for lowland peatland.

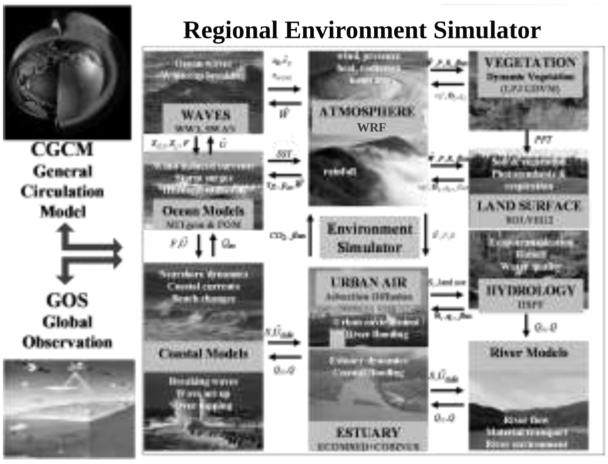


Fig.13 Regional Environment Simulator

Coastal and Lowland Peatland Monitoring

・Analysis of indices of Indian Ocean Dipole (IOD), ENSO and PDO.
・GPS monitoring of swamp and lowland peatland subsidence.
・Depth sounding by the multibeam echosounder.
・Carbon emission monitoring in lowland peatlands.
・Tsunami warning system.
・Satellite remote sensing data collection and analysis: Landsat, TRMM, ALOS, GCOM-C, GCOM -W1.

REFERENCES

Abidin H.Z., H. Andeas, M. Gamal, P. Susanti, L. Hutasoit, Y.Fukuda, T. Deguchi, Y. Maruyama: Land Subsidence Characteristics of the Jakarta Basin (Indonesia) as estimated from Leveling, GPS and InSAR and its Relation with Groundwater Extraction, Proceedings of 36th IAH Congress, October, 2008.

Fitri R. and T. Yamashita(2005), Cohesive Sediment Transport Model and Application of Advection-Diffusion Type Consolidation Equation in ECOMSED, Annual Journal of Coastal Engineering, JSCE, Vol.52, pp.991-995.

IPCC, AR4 (2007), Chapter 3 Observations: Surface and Atmospheric Climate Change, WG1, p.289, 2007.

Musk, L.F.(1988), Weather Systems, Cambridge University Press.

Schneider, Niklas and Bruce D. Cornuelle (2005). “The Forcing of the Pacific Decadal Oscillation”, *Journal of Climate* 18 (8): 4355–4372.

Yamashita T., K. Kim, H. Lee, H. Mohhamed(2007), Environment Simulator: Contribution to Coastal Engineering Problems, Annual Journal of Coastal Engineering, JSCE, Vol.54, pp.1301-1305.