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Original Article

Effect of global warming in Thailand

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Abstract

The earth absorbs much radiation from the sun to warm the atmosphere, the land, and the oceans. This energy is re-radiated back into space. In the past, the thermal budget of the earth is more or less balanced, with radiation from the sun on par with thermal radiation from the earth. With increasing greenhouse gases in the atmosphere, some of the thermal radiation is absorbed by these gases resulting in an increase of global mean surface temperature, melting of polar ices and thus contributing to a rising of sea level. However, sea-level changes depend upon four main processes: 1) Glacio-eustasy, 2) Emergence/subsidence of land, 3) Man-made activities, and 4) Ocean-atmosphere effects. The assessment report of the Inter-governmental Panel on Climate Change (IPCC, 1990), which was based on past data in Europe and the USA, including the North Atlantic Ocean, published a mean temperature of 14°C and an actual increase of 1°C in the last century, plus an increase of CO_2 from 370 ppmv to 550 ppmv, and a three-fold temperature increase of 3°C in this century. All these changes are projecting a sea level rise (SLR) of 31-110 cm per century on global scale, which was in fact applicable to the North Atlantic. The assessment report of the IPCC Working Group I (1996) has realized that differential SLR occurs due to different geographical conditions. It identified ten regions on earth and compared the actual climate change to what it was postulated to be, and came up with SLR of 15-95 cm per century. The assessment report of the IPCC Working Group II (2001) employed improved data obtained from tide gauges and satellite images as well as mathematical model results with the most convincing evidence in the North Atlantic, and it concluded an SLR of 9-88 cm per century. But it had, however, noted a lack of data in the Pacific and Indian Ocean. The assessment report of the IPCC Summary for Policy Makers (SPM, 2007) that included six different arctic and antarctic climate science scenarios reported relatively lower value of 18-59 cm per century. The North Atlantic that is surrounded by glaciers might see a SLR due to ice melting related to an increase of the temperature in the Atlantic Ocean. Nevertheless, the lack of data on global warming in the tropics especially in the Pacific and the Indian Oceans, which have no glaciers, might put a different view on the conclusions derived from temperature and arctic data. Six decades of comprehensive information from the Gulf of Thailand regarding oceanographical and meteorological data is revealing a much lower SLR. The mean monthly sea levels in six decades at Sattahip and Ko Lak showed no increasing trend, while those rises at Samut Prakan and Samut Sakhon are due to land subsidence from excessive groundwater pumping.

Keywords: coastal erosion, greenhouse effect, groundwater abstraction, ocean-atmospheric interaction, sea-level change.

1. Introduction

Due to extreme differences of meteorological and glacial conditions between the North Atlantic Ocean and the South Pacific Ocean, it will be shown that sea-level rises in these two regions are extremely different in terms of global warming due to greenhouse effects on temperature increase and glacial melting by using six decades of meteorological and oceanographical data from the Gulf of Thailand. The main factor affecting the global warming is the increase in greenhouse gases, which results in an increase of the mean

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surface temperature. However, sea-level changes depend upon four main processes: 1) glacio-eustasy, 2) emergence/ subsidence of land, 3) man-made activities, and 4) ocean-atmospheric interactions. The first process is pronounced in the North Atlantic Ocean but it is negligible in the Gulf of Thailand. The second and third processes are applicable to both regions. The fourth process is pronounced in the North Atlantic Ocean due to very strong winds in the rowing latitudes, 40°-50°, while the strong equatorial winds are weakened when they are blocked by the Thai-Malaysian Peninsula. Therefore this effect is negligible. Detailed discussion on these four processes will be presented in this paper. Coastal erosion along the shorelines of the Gulf of Thailand is an important topic related to the sea level rise (SLR).

2. Literature Review

Vongvisessomjai (2006) reported on impacts of global warming on sea-level rises in the Gulf of Thailand and Warrick *et al.* (1993) on the four processes of the sea-level rise (see also Table 1).

2.1 Glacio-eustasy

Clark *et al.* (1978) proposed a number of numerical models to divide six sea-level zones for realistic melting cases as shown in Figure 1:

1) Europe, USA, and Canada along the Atlantic Ocean and with glacial and high mountains face a significant sea level rise in Zone III.

2) The Gulf of Thailand, Indochina, Korea, China, and Japan along the South China Sea and the Pacific Ocean will experience less SLR in Zone IV due to no-existence of glaciers, as the Himalayan Mountain and Tibet are located thousands of kilometers from the sea shores.

2.2 Emergence/subsidence of land

Yanagi and Akaki (1993) studied sea-level variation rates from 1950 to 1991 in the East Asian region, which showed that the sea-level has fallen for the past 40 years in an area including the southern part of the Sea of Japan, the Korean Peninsula, Indochina, and the Malay Peninsula. Note that these areas are the most active area along the Java Trench that generated the 2004 Indian Ocean Tsunami resulting in high damages and casualties (Vongvisessomjai and Suppataratarn, 2005). However, Michel *et al.* (2000) reported on crustal motion in East and Southeast Asia from GPS measurements that Sundaland i.e. Indonesia as well as the western and central part of Indonesia, together with South-China, constitute an apparent stable tectonic block that was decoupled from Eurasia, and this block moved to the south horizontally but much less vertically.

Table 1. Summary of processes affecting sea-level changes.

Process	Rate (mm/yr)	Period (yr)
1 Glacio-eustasy	up to 10	Around 7,000 years following deglaciation
	~1	Last 100
2 Vertical Land Movements		
2.1 Long-wavelength processes 100-1000 km		
a Glacio-isostatic changes	±1-10	10^4
b Shelf subsidence due to oceanic lithosphere cooling and sediment/ water loading	0.03	10^7-10^8
c Shelf sediment accumulation, global	0.02-0.05	10-10^6
2.2 Short-wavelength processes <100 km		
a Neo-tectonic uplift/subsidence	±1-5	10^2-10^4
b Shelf sediment accumulation, local-large river deltas	1-5	10-10^4
3 Anthropogenic activity		
3.1 Water impoundment in dams, reservoirs	-0.75	<100
3.2 Groundwater mining (to river runoff)	0.7(?)	<100
3.3 Subsidence due groundwater/oil/gas withdrawal (local)	3-5	<100
	Amplitude (cm)	Period (yr)
4 Ocean-atmosphere effects		
4.1 Geostrophic currents	1-100	1-10
4.2 Low-frequency atmospheric forcing	1-4	1-10
4.3 El Nino	10-50	1-3

* Source: Warrick *et al.* (1993)

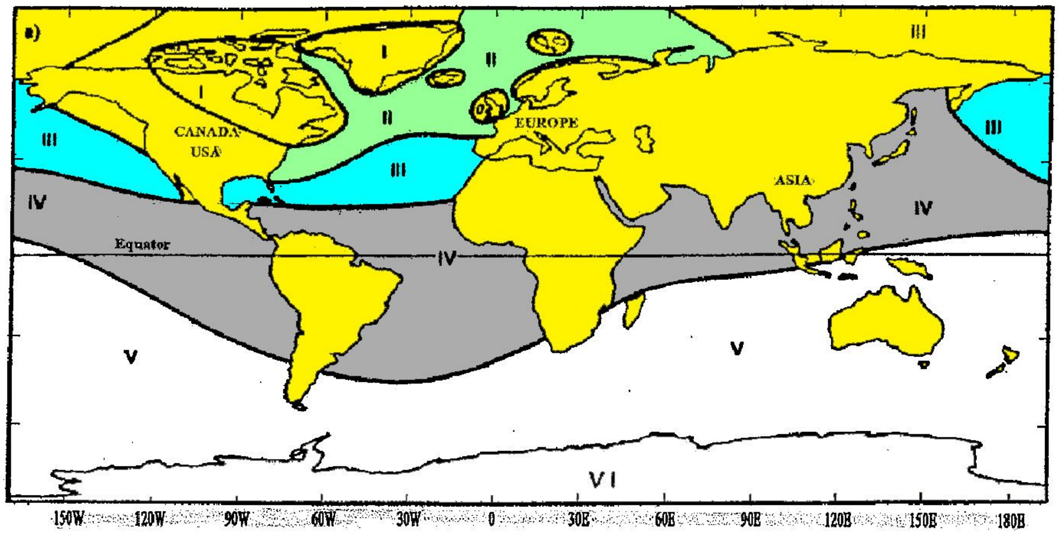

Figure 1. Six sea-level zones for realistic melting (Clark *et al.*, 1978).

2.3 Man-made activities

1) Groundwater abstraction in Bangkok and nearby areas was investigated by the Asian Institute of Technology (AIT) jointly with the Department of Mineral Resources (DMR), Thailand, for a project 'Groundwater Resources in Bangkok Area: Development and Management Study for the National Environment Board (NEB)'. The results showed areas identified by the DMR (1998) as being at greatest risk of future subsidence and areas where groundwater abstractions is being actively discouraged, like Bangkok, Samut Prakan, and Samut Sakhon. Critical zone 1 is where land subsidence is more than 3 cm/year and groundwater level drops more than 3 m/year, Critical zone 2 is where land subsidence is 1-3 cm/year and groundwater level drops 2-3 m/year and Critical zone 3 is where land subsidence is less the 1 cm/year and groundwater level drops less than 2 m/year. DMR (2007) reported some success in the remediation of the land subsidence by reducing the groundwater abstraction rate from 2.4 to 1.2 million cubic meters/day, by ending the abstraction of groundwater by the Metropolitan Waterworks, and by increasing the costs of groundwater for the end users, namely, 1 Baht/m^3 in 1984, 3.5 Baht/m^3 in 1994, 8.5 Baht/m^3 in 2000, and 17 Baht/m^3 in 2006. A satisfactory situation in terms of a reduced rate of subsidence and a rise of the groundwater levels in various areas are shown as following. Figure 2 at Ramkamhang University experienced previously a land subsidence rate of 10 cm/year (1978-1985); however,

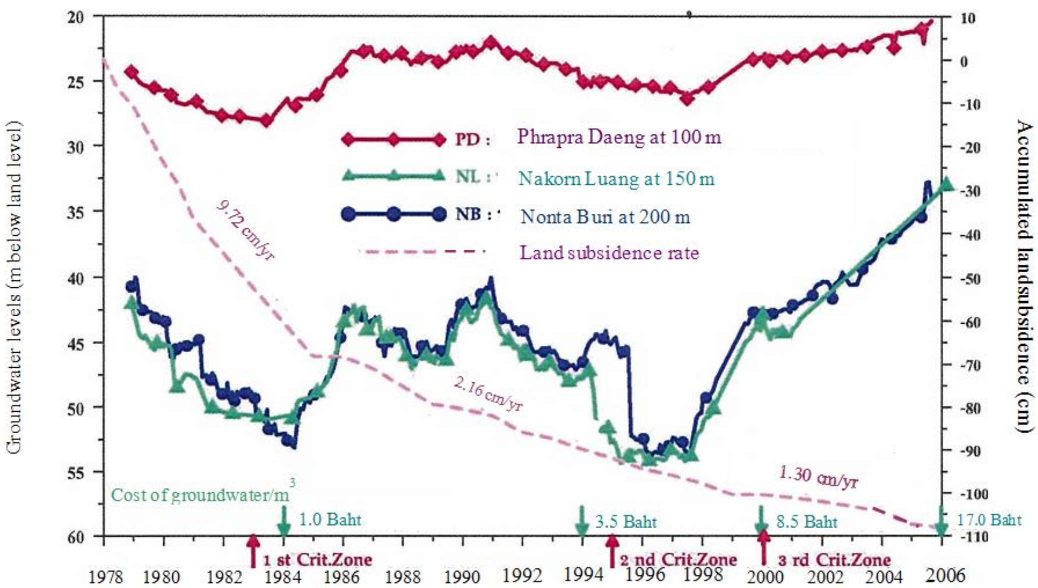

Figure 2. Groundwater levels in 3 aquifers (PD, NL and NB) and accumulated landsubsidence at Ramkamhang University, Bangkok.

the present rate is 1.3 cm/year (2005). The previous groundwater level was -57 m (1996), and the present level is -33 m (2006). Figure 3 at Bang Pli District, Samut Prakan Province, shows a previous land subsidence rate of 5.7 cm/year (1986-1998); however, the present rate is 2.3 cm/year (2006). The previous groundwater level was -50 m (1997), and the present level is -34 m (2006). Figure 4 at Muang District, Samut Sakhon Province, shows a land subsidence rate of 0.9 cm/year for 1979-1989 and 2.6 cm/year for 1990-1997; however, the present rate is 2.3 cm/year (2006). The previous groundwater level was -51 m (1997), and the present level is -33 m (2006). Note that the strict control of groundwater abstraction at Mueang District, Samut Sakhon Province need be continued.

2) Coastal erosion in Thailand is an important topic, which is related to SLR. The most severe coastal erosions along the muddy coastlines of Samut Prakan and Samut Sakhon are related mainly to land subsidence due to pumping of groundwater. IPPC (1990) listed the following physical impacts of a sea level rise on coastal zones: (i) inundation of lowlands and wetlands, (ii) coastal erosion, (iii) coastal storm flooding, (iv) increase in salinity of estuaries, (v) change of tide in rivers and bays, (vi) change of sediment deposition patterns, and (vii) a decrease in the amount of light reaching the sea bottom. UNESCO (1993) reported on sea level changes and their consequences for hydrology and water management. Not only higher water levels related to SLR cause negative effects, but also morphological changes of the shoreline resulting in a backward shift of the coastlines can have negative impacts that are greater than the loss due to direct inundation. There are various methods to determine the retreat of shorelines due to sea level rise (Brunn, 1964, Leasherman, 1984; and Dean *et al.*, 1987).

2.4 Ocean-atmosphere effects (El Nino)

Gregory (1993) calculated the regional distribution of changes of mean sea level with a version of the U.K. Meteorological Office's 'Coupled Ocean-atmosphere General Circulation Model' (CGCMs), in which the CO_2 concentration increases at 1% per year over 75 years. This study showed that there was considerable regional variation in the changes of mean sea level showing that the global figure by itself gave only a rough idea of the local rise in sea level. Figure 5 shows the relative changes in the sea surface topography and that the Gulf of Thailand is in a zone where the sea level falls of 0-50 mm, whereas between latitude 30° S and 60° S the sea levels falls 50-100 mm.

3. Methodology

3.1 Natural greenhouse effect

The earth absorbs radiation from the sun, including ultraviolet, visible, and other rays. After warming the atmosphere and the land and the oceans, this energy is re-radiated

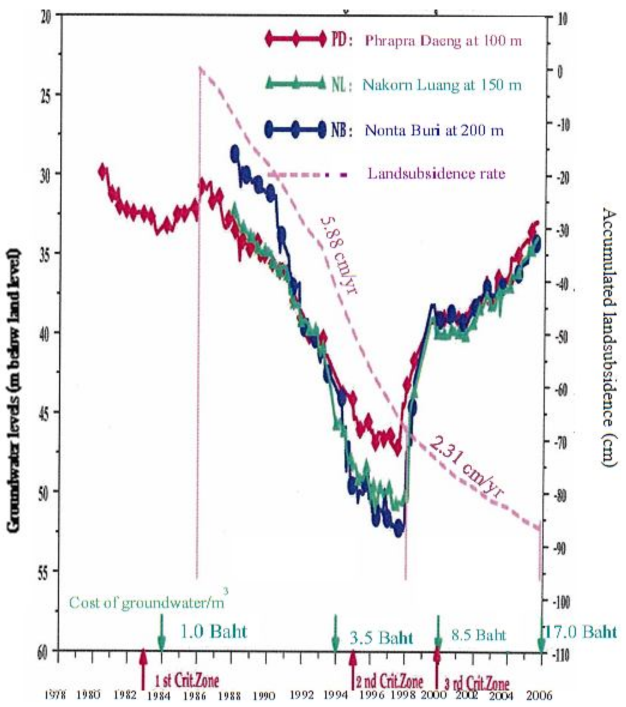

Figure 3. Groundwater levels in 3 aquifers (PD, NL and NB) and accumulated landsubsidence at Bang Pli, Samut Prakan.

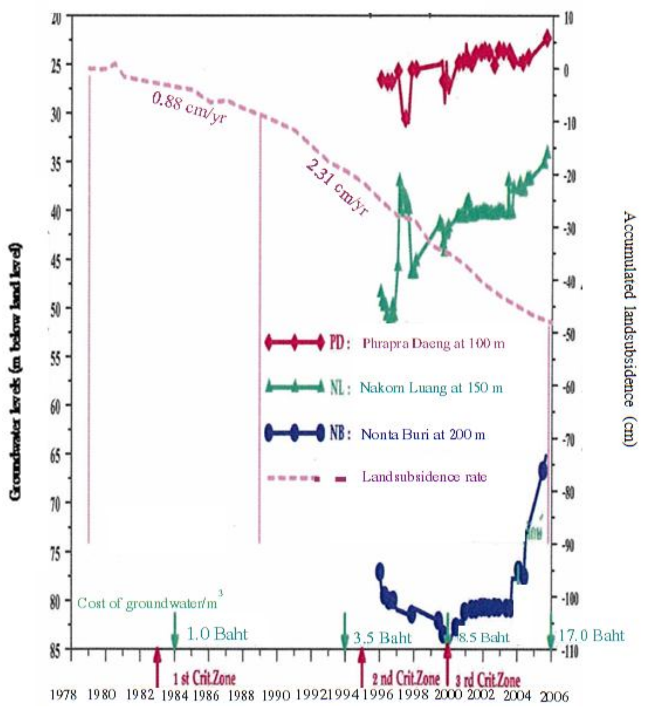

Figure 4. Groundwater levels in 3 aquifers (PD, NL and NB) and accumulated landsubsidence at Mueang District, Samut Sakhon.

to space at longer wavelengths (infrared rays). Normally the thermal budget of the earth is balanced, with the radiation from the sun equal to the thermal radiation from the earth. However, when greenhouse gases (GHGs) exist in the atmosphere, some of the thermal radiation is absorbed by these gases. The absorbed energy is eventually radiated to space from higher, colder levels in the atmosphere, after repeated absorption and re-radiation by GHGs between the atmosphere and the surface of the earth. In brief, the atmosphere is easily penetrated by the radiation from the sun but prevents some thermal radiation from the earth from flowing out to space, and keeps the thermal energy near the surface. As a result of the natural greenhouse effect, the global mean surface temperature is already approximately 33°C warmer than the earth would be without GHGs. Natural GHGs include water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), and nitrous oxide, as well as man-made chlorofluorocarbons (CFCs 11 and 12), which all have different global warming potentials, 1, 11, 270, 3400, and 7100, respectively.

3.2 Man-made global warming/climate change

The changes in the radiative balance of the earth, including those due to an increase in GHGs, will tend to alter atmospheric and oceanic temperatures and circulations (the jet stream and ocean currents, etc.), and weather patterns. Global warming and climate change are the general terms for these changes. Since the industrial revolution, the atmospheric concentrations of GHGs have been increased significantly, mainly caused by accelerated consumption of fossil fuels and changes in land-use and land-cover change (Table 2). The Inter-governmental Panel on Climate Change (IPCC) reported that the best global estimate of annual average concentrations of CO_2 in 1991 was approximately 355 ppmv, given the recent observed rate of increase of 1.8 ppmv/year, and that global mean surface temperature has increased by 0.3 to 0.6°C over the last 100 years (IPCC, 1992).

3.3 Factors of sea-level rise

It is generally accepted that the mean sea level will gradually rise as a result of global warming over a period of decades to hundred years. There are four major factors related to global warming:

1) Thermal expansion of the oceans: The volume of seawater in the mixing layer of the oceans (from the surface to about 200 m in depth) expands, causing the sea level to rise as a result of an increase in the temperature of seawater. The sea level rise due to the thermal expansion has recently been examined by several types of models, box-upwelling-diffusion, subduction, and coupled ocean general circulation model.

2) Mountain glaciers and small ice caps: The amount of ice stored in mountain glaciers and small ice caps is only a fraction of the total amount of land ice. However, because they have shorter response times than the large ice sheets of Greenland and Antarctica, they are thought to be important for sea level rise on a lime scale of 10 to 100 years. Oerlemans and Fortuin (1992) reported that the rate of rise in sea level due to the melting of mountain glaciers and small ice caps would be 0.58 mm/year for a temperature increase of 1°K.

3) Greenland ice sheet: A significant summer melting of the Greenland ice sheet, induced by the warmer climate of Greenland, is likely to contribute to a rise in sea level. IPCC (1990) reported that the rate of rise in sea level due to melting of the Greenland ice sheet was 0.3±0.2mm/year/°C.

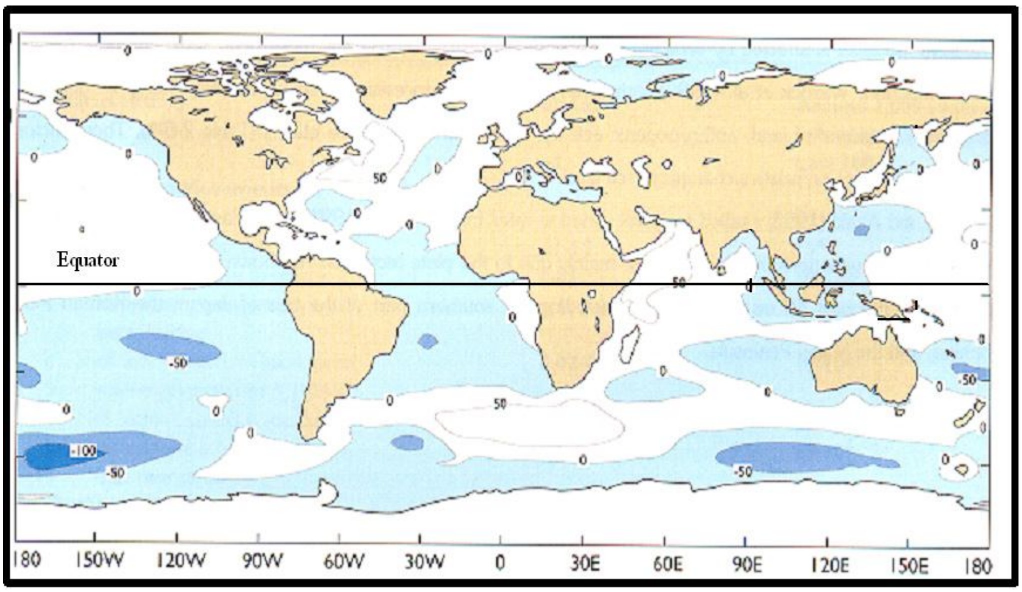

Figure 5. Relative changes in surface topography, years 66-75 (Gregory, 1993).

4) Antarctic ice sheet: IPCC (1990) assumed that the global warming would not diminish the size of the Antarctic ice sheet. The IPCC (1990) reported that snowfall and accumulation rates in Antarctica would increase because of increasing atmospheric moisture caused by global warming and that at least for the next half century the most likely contribution of Antarctica to the impacts of global warming would be an effective decrease in sea level. The IPCC (1990) reported on the best estimated values of sea level rise due to the above major factors of 4, 4, 2.5, and 0 cm respectively over the last century for a sum of 10.5 cm, while the observed value is 15 cm.

4. Analysis of Meteorological Data

Six decades of meteorological data are obtained from the Thai Meteorological Department (TMD, 2007). Six decades of rainfall data are shown in Figure 6a, while variations of the annual rainfall over Thailand, over the northern part, northeastern part, central part, eastern part, southern east coast, and southern west coast are shown in Figure 6b. The analysis of rainfall data show that for all parts of Thailand the rainfall has a decreasing trend for the whole period of observation. A prominent decreasing trend is observed in the eastern part. However, the annual rainfall trend increases in the last decade, so it can be concluded that the overall rainfall patterns in Thailand showed little changes.

The annual mean minimum surface temperatures over Thailand in six decades as presented in Figure 7a show some increase especially in the last decade, while the variation of the annual minimum surface temperatures over Thailand, over the northern part, northeastern part, central part, eastern part, southern east coast, and southern west coast are shown in Figure 7b. From the data it can be concluded that the annual mean minimum surface temperatures have little increased over the six decades.

The annual mean maximum surface temperatures over Thailand in six decades as shown in Figure 8a shows a small increasing trend, while the variation of the annual maximum surface temperatures over Thailand, over the northern part, northeastern part, central part, eastern part, southern east coast, and southern west coast are shown in Figure 8b.From the data it can be also concluded that the annual mean maximum surface temperatures have little increased over the time.

The numbers of tropical cyclones passing Thailand and the South China Sea in six decades as shown in Figure 9 are three and 13 per year, respectively, and their severity are the same over time. Note that the tropical cyclones in the Gulf of Thailand in the cooler months of October, November and December are the weaker ones having lower values of maximum wind velocity and pressure drop (Vongvisessomjai, 2009).

5. Analysis of Sea-Level Data

There are 22 tide gauge stations operated by the Hydrographic Department (HD, 1998) of Royal Thai Navy, which have recorded data in six decades. An example of hourly sea level data at Sattahip and Ko Lak station in 1993 are shown in Figure 10. These hourly sea level data in each month at Bangkok Bar, Sattahip, Ko Lak, and Songkhla are used to calculate monthly sea levels from January to December. The lowest monthly sea level is in the middle of the year at about -0.20 m MSL and highest monthly sea level is at the beginning and the end of the year at about +0.20 m MSL, which are then used to calculate the yearly sea level having a value of near to zero or near to MSL. Figure 10 shows monthly sea levels at Ko Lak and Sattahip over 56 years from 1940-1996, which indicates that the sea level in the Gulf of Thailand is falling 0.36 mm/yr or 36 mm/century, which is a negligible change of sea level.

The analysis of sea level data shows that the sea level rise projection by the IPCC (1990) is valid only for the Atlantic Ocean due to significant increase of temperature and melting of glacial ice. But the Gulf of Thailand and nearby regions faces only an increase of temperature of less than 1°C/century and there is no glacial ice, so therefore, no increase of the sea level might occur, which agrees with data of Yanagi and Akaki (1993) and Gregory (1993).

Table 2. Trace Gas Concentrations from 1765 to 1990.

Year	GAS				
	CO_2 (ppmv)	CH_4 (ppbv)	N_2O (ppbv)	CFC-11 (ppbv)	CFC-12 (ppbv)
1765	179.00	790.0	285.00	0	0
1900	295.72	974.1	292.02	0	0
1960	316.24	1272.0	296.62	0.0175	0.0303
1970	324.76	1420.9	298.82	0.0700	0.1211
1980	337.32	1569.0	302.62	0.1575	0.2725
1990	353.93	1717.0	309.68	0.2800	0.4844

* Source: IPCC (1992)

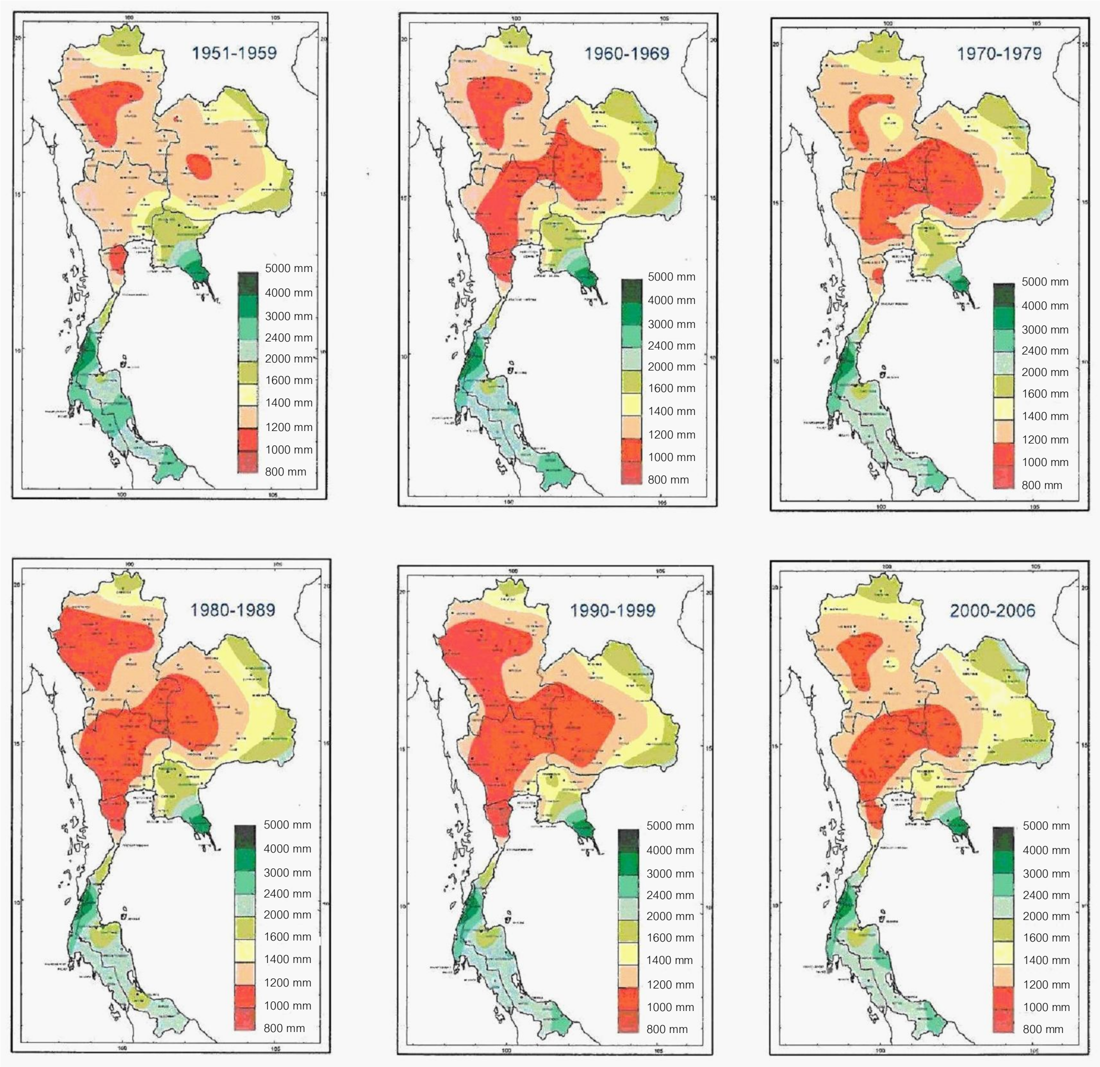

Figure 6. a) Annual rainfall over Thailand in decade.

6. Coastal Erosion in the Gulf of Thailand

The National Research Council of Thailand (NRCT, 1989) used satellite images and aerial photographs in studying coastal erosions is the Gulf of Thailand and they found severe erosion rates of about 500 m in 20 years on the west of the Chao Phraya river mouth, 200 m at Petchaburi, and 100 m at Hua Hin due to a decreases of the sediment supplies from rivers to the sea. JICA (2001) reported on erosion rate of 1,000 m in 30 years at Bang Khun Thiean, which could be restored by plantation of mangroves. The Office of Natural Resources and Environment Policy and Planning (ONEP, 2003) has commissioned a master plan study to AIT and SEATEC in order to determine suitable remedial measures for coastal erosion and to systematically and continuously rehabilitate and restore the coastal areas from Phetchaburi River mouth to Pranburi River mouth to their original natural beauty using aerial photographs for two periods of 23 and 20 years. These shorelines are important tourist destinations in Thailand. The Marine Department is responsible to protect the shorelines from erosion and prevent navigation channels for fishery and deep sea ports from sedimentation in order to increase the economy of fishery and tourist communities as described in the following paragraphs.

6.1 Tourism and fisheries development

In the past, the Rayong river mouth had severe sedimentation due to littoral drifts obstructing the passage of fishing boats. In 1984 the Marine Department constructed breakwaters, 400 m long on the west and 100 m long on the east of the Rayong river mouth, enabling a fishing boat passage all year round and by this boosting the income of the fishermen. Further, another offshore breakwater was constructed at Ban Pae in 1992 for tourist ferries to Ko Samet and it is also used as a refuge harbor for fishermen. In addi-

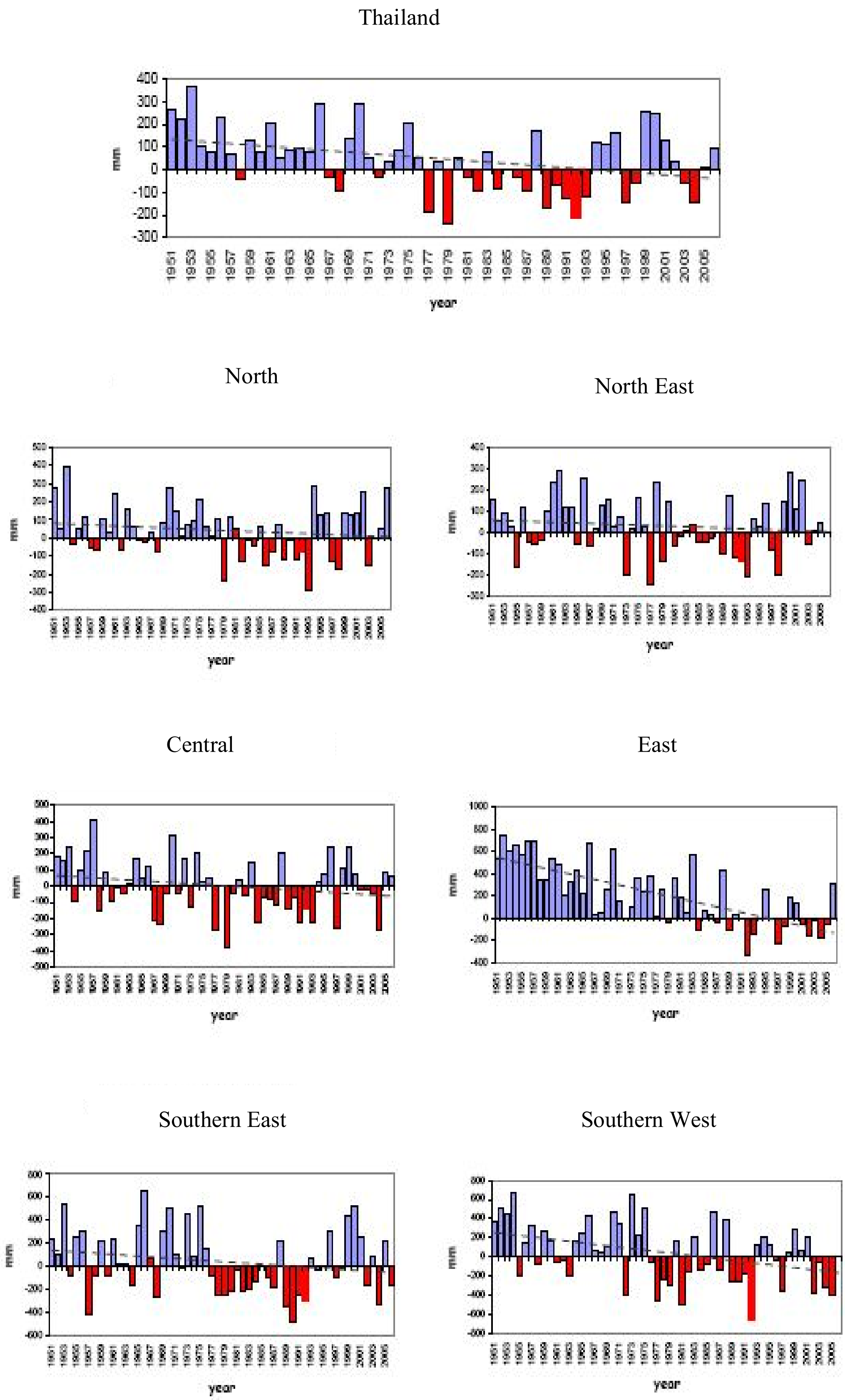

Figure 6. b) Variation of annual rainfall over Thailand, Northern part, Northeastern part, Central part, Eastern part, Southern East coast and Southern West coast. The variation is expressed by deviation from normal (1971-2000). Bar graph is rainfall anomaly; line graph is regression equation.

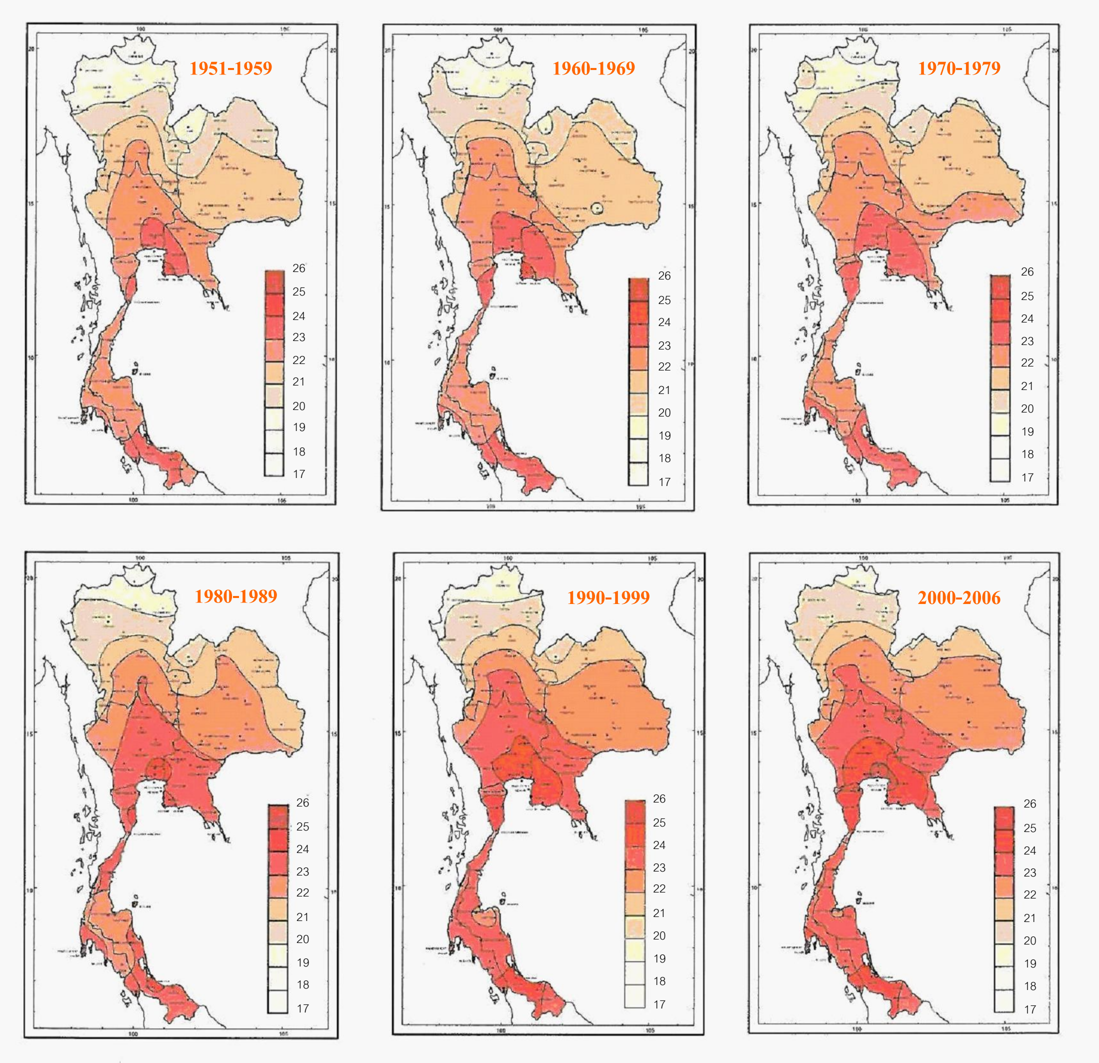

Figure 7. a) Mean minimum temperature over Thailand in decade.

tion, detached offshore breakwaters were built from Had Saeng Chan at the Map Ta Phut Industrial Estate to the Rayong river mouth to stop coastal erosion on this shoreline.

6.2 Fisheries and deep sea port development

In the past, the inlet of the Lower Songkhla Lake had severe sedimentation due to littoral drift from the south obstructing the fishing boat passage. In 1968, the Marine Department constructed a jetty, 700 m long on the south and extended another 300 m in 1987, enabling fishing boats passage all year round and boosted by this the economy and tourism of Songkhla. In 2004, a deep sea port was constructed on the north of the inlet of the Songkhla Lake for export and import.

6.3 Coastal erosion mitigation of muddy shorelines in the Upper Gulf of Thailand

The Marine Department has mitigated coastal erosion of muddy shorelines at Klong Daen, Samut Prakan Province using 82 Geo-tubes, each 200 m long with a gap of 50 m, for a shoreline length of about 20 km. In 2007 the same Geo-tubes were used to mitigate shorelines of the Tha Chin river mouth, Samut Sakhon Province at Kalong, Bangkachao, and Puntay Norasing District for a shoreline length of 9 km. These areas have SLR/land subsidence due to the excessive pumping of groundwater.

The Department of Marine and Coastal Resources had developed a strategy to prevent and mitigate coastal erosion and submitted it to the National Environment Board, which accepted it on October 24, 2007, and approved two projects on ‘Preliminary Study on Coastal Erosion in the Upper Gulf’, which has SLR due to pumping of groundwater and a ‘Master Plan Study of Coastal Erosion of Lower Gulf from Laem Talumpuk to Songkhla Lake Inlet’, which is an area of the Royal Project at the Pak Panang River Basin where SLR is less but where more utilization of coastal areas can be observed.

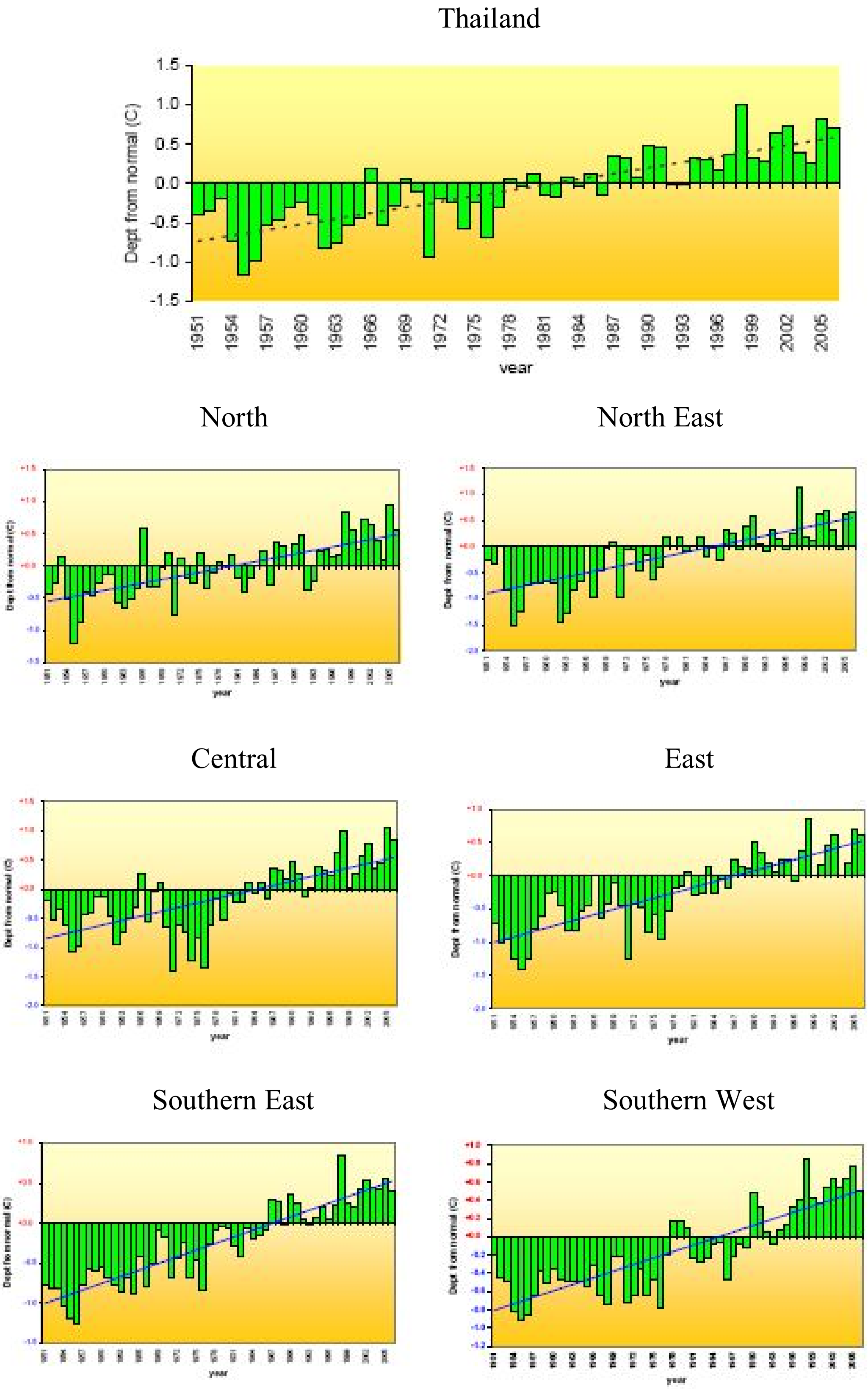

Figure 7. b) Variation of annual minimum surface temperature over Thailand, Northern part, Northeastern part, Eastern part, Southern East coast and Southern West coast. The variation is expressed by deviation from normal (1971-2000). Bar graph is minimum surface temperature anomaly; line graph is regression equation.

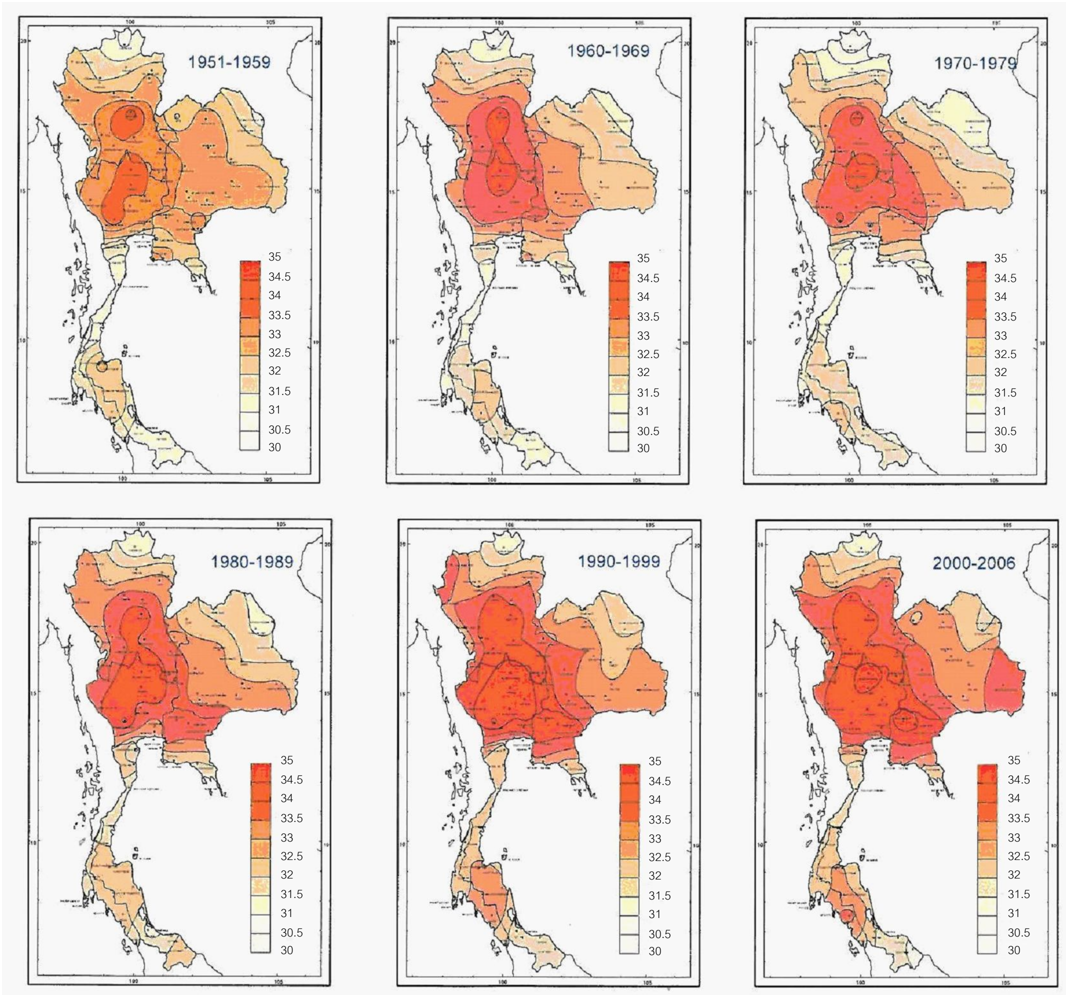

Figure 8. a) Mean maximum temperature over Thailand in decade.

7. Conclusions

The analysis of the meteorological data of the Thai Meteorological Department in six decades showed that rainfall data in all parts over Thailand showed decreasing trends, with the eastern part having a maximum decrease and the northern part having an increasing trend. It can be concluded that rainfall in Thailand showed little changes while the annual mean minimum and maximum surface temperatures showed some increase and the numbers of tropical cyclones passing Thailand and the South China Sea were about three and 13, respectively, with their severity almost the same over six decades.

The analysis of sea level data of the Hydrographic Department in six decades showed that the monthly water levels at Bangkok Bar, Sattahip, Ko Lak and Songkhla showed cyclic variations having a maximum level of 0.2 m MSL at the beginning and the end of the year and minimum level of -0.2 m MSL at the middle of the year, while the yearly average was zero. The mean monthly water levels over six decades at Sattahip and Ko Lak (Figure 10) showed no increasing trend. The sea levels at Samut Prakan and Samut Sakhon showed some rising trends due to land subsidence from pumping of groundwater.

Coastal erosion in Thailand is mainly attributed to a decrease in the sediment supplied from rivers to the sea. The land subsidence due to pumping of groundwater in Samut Prakan and Samut Sakhon, however not global warming, was the cause in the rise of the sea level. The Department of Marine and Coastal Resources had mitigated coastal erosion problems with an integrated approach and participation of coastal communities.

References

Brunn, P. 1973. Port Engineering. Gulf Publishing Company, Houston, Texas, pp. 1-436.

Clark, J.A., Farrel, W.E. and Petter, W.R. 1978. Global changes in Post-glacial sea level: A numerical calculation. Quaternary Research. 9, 265-287.

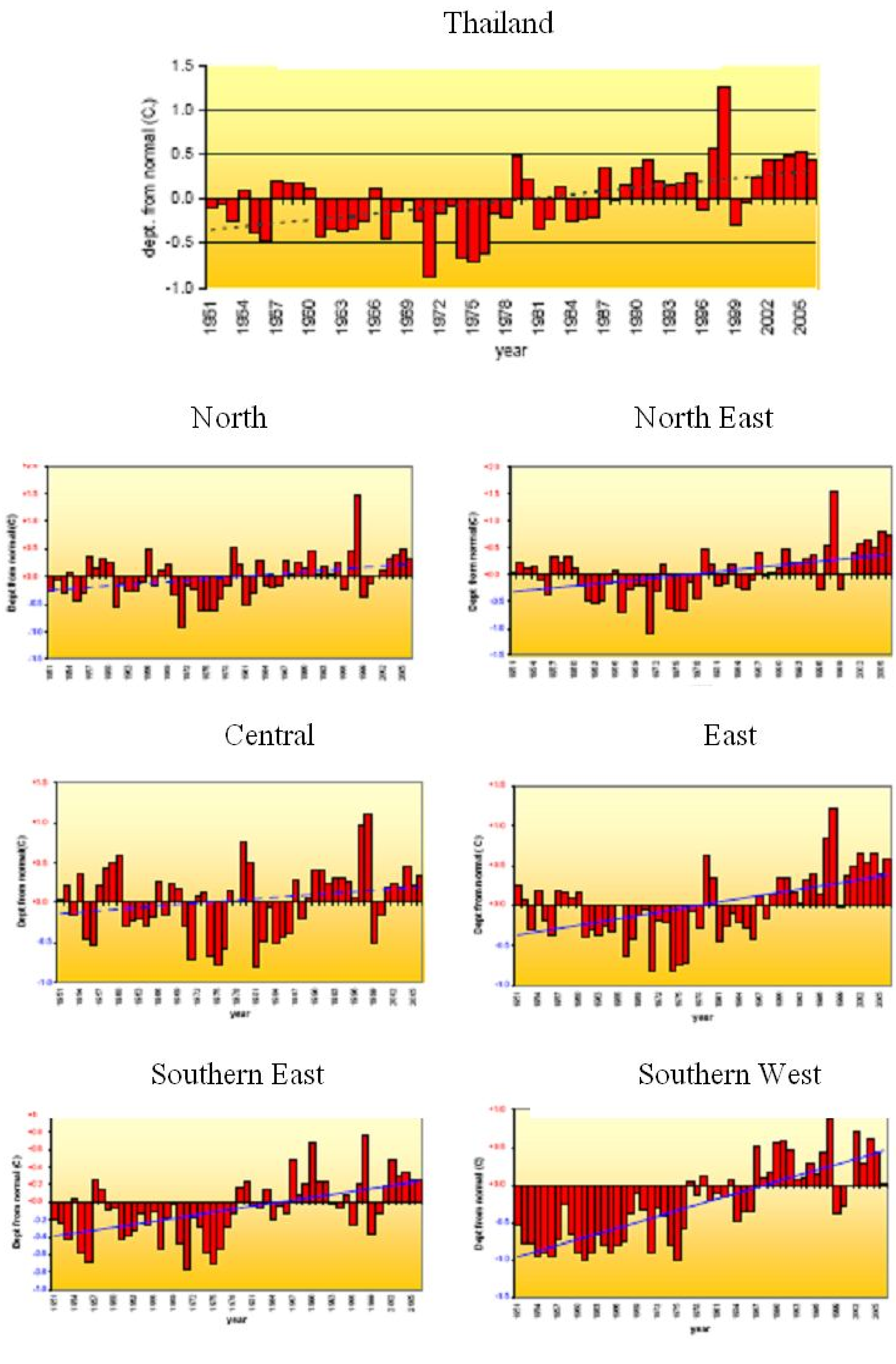

Figure 8. b) Variation of annual maximum surface temperature over Thailand, Northern part, Northeastern part, Central part, Eastern part, Southern East coast and Southern West coast The variation is expressed by deviation from normal (1971-2000). Bar graph is maximum surface temperature anomaly; line graph is regression equation.

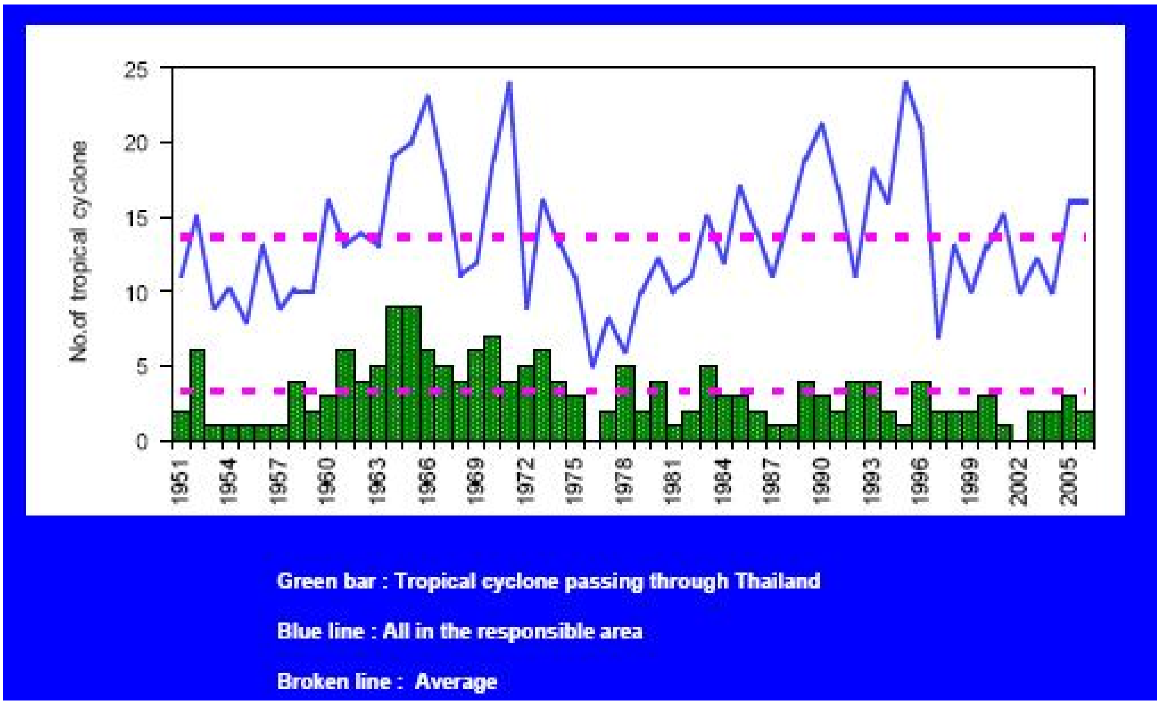

Figure 9. Numbers of tropical cyclone passing Thailand and the South China Sea.

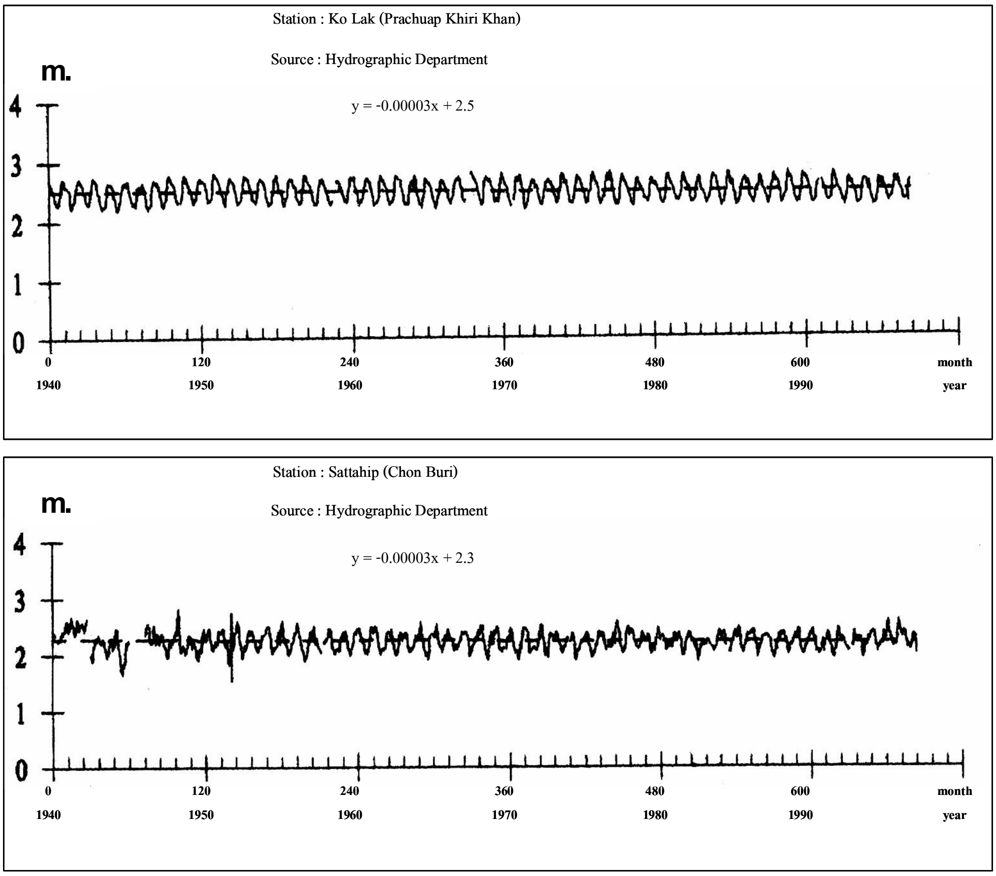

Figure 10. Monthly mean water levels at Ko Lak and Sattahip from 1940-1996 (HD,1998).

Dean, R.G., Webster, W.C. *et al.* 1987. Responding to change in sea level, Engineering implications. National Research Council. National Academy Press, Washington, D.C.

DMR. 1998. Groundwater and land subsidence crisis in Bangkok metropolitan and vicinity, Technical Report, Vol.3/1998. Department of Mineral Resources.

DMR. 2007. Land subsidence crisis in Bangkok metropolitan and vicinity, Technical Report, Vol.1/2007 Department of Mineral Resources.

Gregory, J.M. 1993. Sea Level Changes under Increasing Atmospheric CO_2 in a Transient Coupled Ocean-Atmosphere GCM Experiment. Journal Climate 6, 2247-2262.

HD. 1998. Tide Tables. Hydrographic Department, Thailand.

IPCC. 1990. Climate Change. The IPCC Scientific Assessment, Cambridge University Press. Intergovernmental Panel on Climate Charge.

IPCC. 1992.Climate Change. The Supplementary Report to The IPCC Scientific Assessment, Cambridge University Press, pp. 1-200.

IPCC. 1996. Climate Change 1995. The Science of Climate Change. Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change.

IPCC. 2007. The IPCC sea level numbers. The Fourth Assessment Report of Arctic and Antarctic Climate Science. Intergovernmental Panel on Climate Change.

JICA. 2001. The Feasibility Study on Mangrove Revival and Extension Project in the Kingdom of Thailand. Japan International Cooperation Agency.

Leatherman, S.P. 1984. Coastal geomorphic responses to sea level rise: Galveston Bay, Texas. In: Greenhouse Effect and Sea Level Rise: A Challenge for this Generation. M.C. Barth and J.G. Titus, editors. Van Nostrand Reinhold Co., New York. pp. 151-178.

Michel, G.W., Becker, M., Angermann, D. Reigber, C. and Rainhart, E. 2000. Crustal Motion in E- and SE-Asia from GPS Measurements. Earth Planets Space. 52, 713-720.

NEB. 1982. Groundwater Resources in Bangkok Area: Development and Management Study, Publication No. 001. National Environment Board of Thailand.

NRCT. 1989. Coastal Morphology with Emphasis on Coastal Erosion and Coastal Deposition, Research Report (in Thai). National Research Council of Thailand.

Oerlemans, J. and Fortuin, J.P.F. 1992. Sensitivity of Glacier and Small Ice Caps to Greenhouse Warming. Science. 258, 115-117.

ONEP. 2003. Master Plan Study of Remedial Measures for Coastal Erosion from Phetchburi River-Mouth, Phetchburi Province to Pranburi River-Mouth, Prachuab Khiri Khan Province. Office of Natural Resources and Environmental Policy and Planning, Ministry of Natural Resources and Environment. Thailand.

TMD. 2007. Thai Meteorological Department. Thailand.

UNESCO. 1993. Sea Level Changes and Their Consequences for Hydrology and Water Management, State of the Art Report, International Workshop, 19-23 April 1993, Noordwijkerhout, The Netherlands.

Vongvisessomjai, S. and Suppataratarn, P. 2005. 2004. Sumatra Tsunami. Songklanakarin Journal of Science and Technolology. 27(5), 929-942.

Vongvisessomjai, S. 2006. Will sea-level really fall in the Gulf of Thailand? Songklanakarin Journal of Science and Technolology. 28(2), 227-248.

Vongvisessomjai, S. 2009. Tropical cyclone disasters in the Gulf of Thailand, Songklanakarin Journal of Science and Technolology. 31(2), 213-227.

Warrick, R.A., Barrow, E.M. and Wigley, T.M.L. (eds.) 1993. Climate and Sea Level Change: Observation, Projections, and Implications, Cambridge University Press, 39p.

Yanagi, T. and Akaki, T. 1993. Sea Level Variation in the East Asia; in Opening Remarks: IPCC and IGBP. In Vulnerability Assessment to Sea-level rise and Coastal Zone Management. R. McLean and N. Mimura, editors. Proceedings of the IPCC Eastern Hemisphere Workshop, pp. 11-14.