Modelling of coastal flooding due to the dissolved CO_2 in the ocean emitted from oil refinery

By

LEOW YENN SHERN

15926

Dissertation submitted in partial fulfilment of

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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Approved by,

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DR. Nurul Izma Binti Mohammed

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JANUARY 2016

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

LEOW YENN SHERN

Abstract

Objective of this research paper is to study the carbon dioxide emission emitted from oil and gas activity which will affect the rising of sea level. This thesis focuses on the rising of sea level in Malaysia and the impact of global mean sea level rise. There are two objectives that govern the flow of this research which, to determine amount of emitted carbon dioxide from oil refinery. Then specific heat capacity equation is used to determine the relationship of the emitted carbon dioxide to the rising of sea level and also coastal flooding which will impact the coastal community. One of the problem of dissolved carbon dioxide in the ocean is that as sea level rise, the carbon sink of the ocean will decrease, therefore resulting in the reduction of carbon uptake in the ocean. Another factor that affects the ocean is as dissolved carbon dioxide in the ocean increases, the process of ocean acidification also increases where carbon dioxide dissolved in the ocean produces carbonic acids where the pH of the ocean is reduced and also causing the reduction of carbonate ions where shelled marine creatures such as phytoplankton, and pteropods struggles to build their exoskeleton as they require calcium carbonate which ocean acidification reduces the carbonate ion in the sea.The total CO_2 emission annually is 4,006,057,500 kgCO_2e/ year from Malacca refinery plant. With the specific heat capacity formula which equates the heat transfer of carbon dioxide in the atmosphere into the ocean. Results are tabulated and projected that in order to reach 1 °C temperature raise which is 0.09 m in sea level rise, it would take 23454 years alone from Melaka oil refinery plant. The projected impact of population for coastal flooding in the coastal area of Malaysia and Indonesia is 0 for the 0.09 m sea level rise. Significant impact is only seen when sea level rise to 1 m, which is a total of 11 °C temperature raise in ocean. This will affect approximately 19877 of people staying along the coastal area, however if coastal flooding includes Sabah and Sarawak the 1 m sea level rise will impact about 455024 people. With the Sea level rising up to 10 m, the model projected a total of affected population of 560304 for peninsular Malaysia and Indonesia.

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I have done my best and gave fully commitment to complete this report. However, it would not have been possible without support and help of many Individuals. I cannot express enough thanks to all those who provided me the Possibility to complete this report. My deepest gratitude and immeasurable appreciation also goes to my supervisor, DR Nurul Izma Binti Mohammed which is the senior lecturer who taught me most of the important points in managing a final year project and to maintain its workflow with minimal obstruction. DR Izma also enlighten me and gave me idea on what to proceed or research on this. I would like to further extend my gratitude to DR Izma for sacrificing her precious time and effort to conduct the assessment and proper guidance.

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1.1: Background of study

For the past decades, the main cause of global warming is by the contribution of greenhouse gasses (GHGs) from natural activities such as volcanic eruptions where the large amount of suspended dust and ash emitted in the atmosphere will reflect the solar radiation and keeping the earth temperature down. The Sun also contributes to climate change as solar activity emits an average of 1.4 watts per square meter annually. The trend of natural cycles and events that are known who contributed to warming that's been recorded cannot be explained by these events alone. However, global warming can be explained by human activities which they are responsible for the effect of greenhouse gases (GHGs) emission. Greenhouse gasses consist of carbon dioxide, nitrous oxide, methane, fluorinated gasses. Most of the greenhouse gases are responsible for global warming, and human activities are emitting them in many ways ("*Global Warming Causes, Climate Change Causes"*, 2015).

These anthropogenic emissions can be explained by the combustion of fossil fuels in vehicles and factories, and electricity production. The dominant gas responsible for global warming in all greenhouse gasses is known as carbon dioxide, also called CO_2, takes up to 82 % of the GHGs components. These greenhouse gasses contain heat trapping ability, some even more than CO_2. For example, methane and nitrous oxide which is 20 times and 300 times more powerful the heat trapping ability of CO_2. when compared, and also chlorofluorocarbons which have thousands times the heat trapping potential but was banned due to its ability to degrade the ozone layer. Although these gasses contribute to global warming such as methane from landfills and agricultural activities, nitrous oxide from fertilizers, gases used for refrigeration and industrial processes and the loss of forest due to human development and forest fires. But CO_2 still contribute the most in climate change as these gasses are much lower in concentrations when compared with CO_2 ("*Global Warming Causes, Climate Change Causes"*, 2015).

These GHGs contain heat trapping ability where they are released into the atmosphere and ultimately causing the temperature to rise. These are then absorbed into the ocean where the heat causes the warming of the ocean will ultimately lead to the rising of the sea level. Over the years, core samples are used, tide gauge readings and the latest technology, satellite measurements to measure the Global Mean Sea Level (GMSL). Data acquired was it has risen by 10 to 20 centimetres. However, readings recorded over 20 years has been 3.2 millimetres a year, twice the rate of the past 80 years. The rising of sea level is related to 3 primary factors ("*Sea Level Rise"*, 2015).

The sea level rise is contributed mainly by the thermal expansion of the sea, when water heats up, it will expand, rising sea level is attributed to warmer ocean which is expanding to occupy more space. The melting of large ice formations like glacier during summer will keep increasing as the high temperature caused by global warming far outweighed the rate of ice formation during snowfall, this is another contributing factor of rising sea level. Furthermore, ice loss from Greenland and west Antarctica is accelerating where the meltwater seeps beneath the ice sheets which lubricates the ice streams and causes them to move into the sea at a faster rate. The warming of our earth also melts the ice shelves that is extended outwards which they eventually breakoff into the ocean ("*Sea Level Rise"*, 2015).

Sea level rise will lead to severe effects on coastal habitats, as they rise and reaches farther inland, it will cause erosion, contamination, loss of habitat for land flora and fauna and also the flooding of wetlands. Human will also be expose to the risk of flooding and will be forced to relocate. Global warming will likely accelerate where the ocean level will also continue to rise. A recent study proved that we can expect the ocean to rise between 0.8 and 2 meter by 2100, which is adequate to flood many of the cities in the world. While direr predictions mentioned that including a complete meltdown of the Greenland ice sheet, it is enough to submerge London with a sea level rise of 7 meters ("*Sea Level Rise"*, 2015).

Global atmospheric CO_2 reached an all-time high of 400 parts per million (ppm) recorded on November 2015 (NASA, 2015). The ocean plays an important part in removing anthropogenic CO_2 emission by utilizing its carbon sink. The amount of net ocean-atmosphere exchange of CO_2 is estimated at 2 GtC (Gigatonnes of carbon) while terrestrial carbon sinks takes up an additional 1.5 GtC annually (Peng & Takahashi, 1993).

Ocean have the harshest condition and it is also less habitable, therefore there is lesser study conducted on climate change. However, due to the rising problem which created awareness for the past decades, Carbon monitoring system has been establish all over the world by environmental organizations such as Carbon Monitoring for Action (CARMA), NASA's Carbon Monitoring System (CMS), World Meteorological Organization (WMO) and also National Oceanic and Atmospheric Administration (NOAA). Severe climate change by the emission of greenhouse gasses especially carbon dioxide will affect the oceans carbon sink due to the rise of sea level and also by warming of ocean which causes carbon sequestration to decline over the past decade.

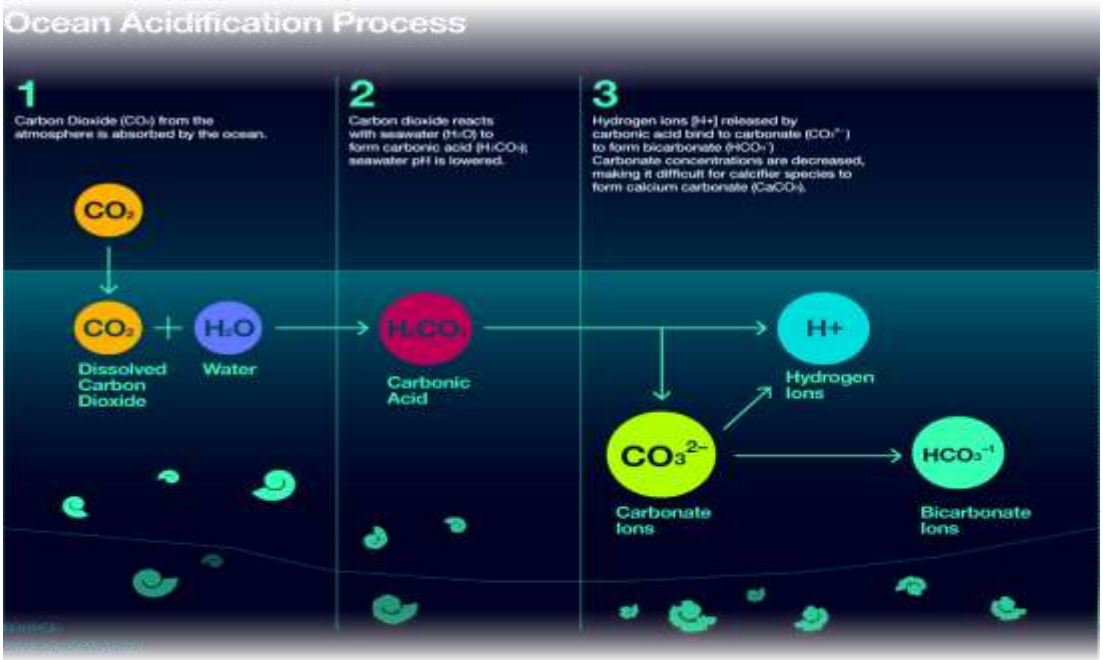
1.2 Problem statement

The ocean is the largest non-geological reservoir of carbon, which is also called as the ocean carbon sink, it exchanges CO_2 with the atmosphere and will also accumulate and store some carbon- containing chemical compound for an indefinite period. This also includes the natural carbon dioxide cycle as well as the uptake of CO_2 from fossil fuel burning and other human activities. CO_2 exchange between the atmosphere and the ocean happen as some of the area act as carbon sink and other as carbon source, net exchange of CO_2 is a different of 2% gross flux, which can be deduce that the ocean is a sink for $CO_{2.}$ The exchange is executed in many ways, one of the main methods is by the different in partial pressure of carbon dioxide of ocean surface waters and the atmosphere. The lower the temperature of the water, the higher the solubility of $CO_{2.}$ The transfer of CO_2 from the surface of the ocean to deep ocean is known as the net oceanic uptake of ocean. Biological activities are the transportation of carbon in the dead marine plants and animals allows it to travel downwards into the deep ocean, while planktons and plant organisms are taking up CO_2 through photosynthesis and releasing CO_2 through respirations. Calcifying organism also effect the carbon uptake by releasing CO_2 into the atmosphere as they form calcium carbonate ($CaCO_3$) structure, these shell are much denser and heavier causing the acceleration of carbon uptake by increasing the rate of sinking into deep ocean (Hardman-Mountford et al., 2009). Climate change will definitely make an impact towards the ocean carbon sink which will eventually effect the marine life. Therefore, it is very important that we understand the problem we are facing currently.

Ocean is the dominant role in earth major processes by covering 71% of the globe. They are the host to thousands of species of organism in different variety of habitats. Carbon dioxide emitted by natural activity such as volcano eruption and by solar flares, and human activities which consists of burning of fossil fuels which releases large amount of CO_2 to the atmosphere that is dissolved in the ocean, making them more acidic. This process is known as ocean acidification. For the past century, global warming and climate change has garnered enough attention that increasing atmospheric levels of CO_2 is causing global mean surface temperatures to rise. About 30 % to 40 % of the carbon dioxide from human activities are dissolved into the ocean. In order to achieve chemical equilibrium, some of it reacts to give a bicarbonate ion and hydronium ion, thus increasing ocean acidity.

This process that will cause harmful consequences which will change the water chemistry that affects life cycles of many marine organisms such as the lowest end of food chain such as coral and plankton is called as ocean acidification.

Figure 1: Ocean Acidification Process (Ocean Health Index, 2015)



When the carbon dioxide from the atmosphere dissolve into the ocean, it transforms into carbonic acids where it releases hydrogen ions (H+) and bicarbonate ions (HCO_3-), chemical equation is shown in Eqn (1).

$CO_2 + H_2O => H^+ + HCO_3$- Eqn (1)

The pH of the ocean is reduced causing ocean acidification where the carbonic acid binds with carbonate ions ($CO_3{}^{2-}$) to form HCO_3 – at Eqn (2).

$H^+ + CO_3{}^{2-} => HCO_3$ – Eqn (2)

At Eqn (3), the concentration of $CO_3{}^{2-}$ is then reduced resulting in the consequences that marine creatures is having a hard time to build their exoskeletons from calcium carbonate.

$Ca^{2+} + CO_3^{2-} => CaCO_3$ Eqn (3)

The decreasing carbonate ion in the ocean endangers the life of marine habitat such as algae, phytoplankton, corals and pteropods. The shelled creatures use calcium carbonate to build their exoskeletons. As phytoplankton and zooplankton are the basis of the food chain in the ocean. They as face extinction, our entire ocean food chain will be affected effecting our economics and coastal community as we highly depend on fisheries and food from the ocean.

The baseline temperature of the ocean has risen so much that coral reefs no longer able to cope during the normal El Nino years which it occurs every 3 to 5 years (NOAA, 2007) which they are able to previously. The corals turned into white coral as they cannot support the algae that sustain them, this is known as “Coral Bleaching”. More than 500 million peoples will lose their stand on storm surge and also the economic system that support agriculture, aquaculture and also tourism. Most of us think that the ocean doesn’t not affect us in anyway, however according to Natalie (2012), “we are relying heavily on ocean for natural resources and protein such as salt and kelp, foods as a source of protein as one- fifth of the world’s population relies on seafood”. Furthermore, revenue from fisheries are also mildly affecting the country’s economic sector.

Global average sea level rise has been about 200 mm since the industrial revolution, and it continues to rise, at an accelerating rate. Sea level rise has caused many catastrophic damages such as coastal property and infrastructure, degradation of our shorelines and also loss of life (“*Causes of Sea Level Rise: What the Science Tells Us”, 2013).*

The rising temperature of our atmosphere are also warming of our ocean. As the ocean gets warmer, it expands and will ultimately lead to rising of the sea level. Since the industrial revolution, the most critical factor that contributes the most on global sea level rise is thermal expansion. The activities caused by human and natural processes has led to the rising temperature which accelerates the land ice melting, as temperature rises, the ice formation during winter cannot keep up with the rate of ice melts during summer and therefore results in sea level rise. Amplified storm surge is one of the consequences of sea level rise as our dynamics of coast is constantly changing. Storm surge will also damage buildings and infrastructure along the coastal level. Sea level rise means that storm surges could reach further inland. The rising of sea level will also cause coastal problems such as coastal retreat, the rising of sea level allow waves to penetrate further inland and erode the area it infiltrates. A rise in 600 mm of today's sea level will definitely cause critical damages to properties and structures, the risen sea water level will also penetrate into coastal groundwater system, increasing the salinity of the freshwater used for our daily consumption and also agriculture or aquaculture ("*Causes of Sea Level Rise: What the Science Tells Us", 2013).* Oil and gas activities in offshore that releases effluent to the ocean mainly focusing on carbon dioxide which definitely contain heat which leads to climate change due to sea level rise, warming of ocean that will definitely contribute to the acidification of ocean.

The performance of ocean carbon sink will definitely be affected due to the rigorous oil and gas activity in the ocean. Anthropogenic CO_2 emission is definitely a huge and critical factor that contributes to climate change and the global mean sea level rise. Further research should be conducted to further understand on how big an impact the dissolved carbon dioxide in the ocean emitted from the oil and gas industry where they contribute to the rising of sea level.

1.3 Scope of work and Objective

1.3.1 Scope of work

Scope of work for this thesis project will be covered from Introduction to Literature Review, Methodology, data and results and lastly discussion and conclusion. For this research thesis project. This thesis will be focusing on the impact of climate change on sea level due to the dissolved CO_2 in the ocean from oil and gas activities. Which would be covering the parameter of carbon particle that is emitted by ongoing oil and gas works and how these CO_2 particles impact the sea level and finally climate change.

The area of study that this research focuses on is to simulate modelling on is the South China Sea. It is because that for this moment, there is little research done at the South China Sea. Furthermore, an oil and gas plant will be chosen for the case study due to the time limit of this final year project which is a duration of 8 months. The effluent characteristic data of the plant will be obtained and analysed with proper modelling software to assess the magnitude of impact on the environment at the respective area.

1.3.2 Objectives

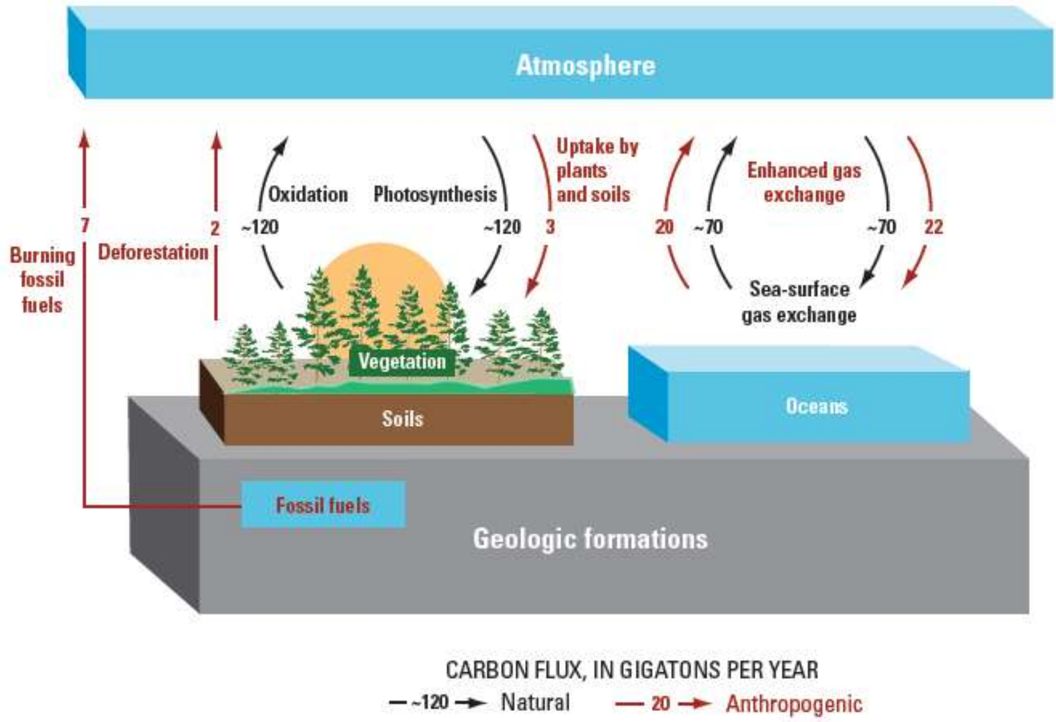
1. To determine the total emission of carbon dioxide for a barrel of crude oil from refinery plant.
2. To calculate the temperature and sea level rise of ocean.
3. To model the impact of sea level rise on the coastal area of Malaysia.

Chapter 2: Literature Review

Sea level rise, which has been a critical issue now in our world as we are developing. There are basically two causes of carbon emission which are natural carbon emission and also anthropogenic causes which where human activity increases that compromise of the burning of fossil fuel, gas, oil and coal since the industrial revolution. This will affect the population living near the coastal area, the economics of the country due to the loss of land for the agriculture and aquaculture industry. These burning of fossil fuels and industrial emission results in mass release of carbon dioxide to the atmosphere which will cause our global temperature to rise and ultimately effecting the sea level rise by ocean warming.

The definition of carbon sequestration is whereby CO_2 is removed from the atmosphere which was emitted by either natural or anthropogenic sources which is stored in the ocean, forests or even geologic formation. A carbon cycle is a process where they maintain a balance in between the CO_2 uptake to the carbon uptake mechanism which is called as CO_2 sink and release it back to the atmosphere. The increasing rate of carbon emission caused by human activity are disrupting the balance of the carbon cycle where the carbon uptake by the carbon sinks cannot keep up with the rate of anthropogenic carbon emission (USGS, 2015).

Figure 2: The carbon cycle (USGS, 2008)



Ocean possess the largest carbon sink in the world when compared to the forest carbon sink. They are the main carbon uptake mechanism which are responsible for absorbing the net uptake of 2 Giga-tons of carbon yearly. This increasing carbon uptake by the ocean due to the anthropogenic emission causes a process named as ocean acidification.

As the atmosphere carbon dioxide dissolved into the ocean. The dissolved carbon dioxide reacts with reacts with water to form Carbonic Acid (H_2CO_3). The H_2CO_3 then releases hydrogen ions (H+) to bind with the Carbonate ions which will form bicarbonate (HCO_3^{-1}). This process causes the concentration of carbonate ions to decrease as more carbon dioxide is dissolved into the ocean which results in the endangerment of calcifying species such as oysters, clams, corals and calcareous plankton which will ultimately effect the entire food chain.

The contributing factor which leads to sea level rise are by thermal expansion and also the melting of glaciers and ice sheets where thermal expansion is the dominant forces in causing sea level rise (Warrick et. Al, n.d.).

The melting of ice sheets and ice glaciers is increasing due to the rise in temperature. The formation of these ice glaciers during winter cannot keep up with the rate of it melting in the summer which also a contributing factor in global mean sea level rise. The ocean is so important to us because it covers 71 % of our earth and it absorbs 80 % of the excess heat trapped by the atmosphere since 1880. How sea level rises are that as the water absorbs the heat emitted by natural and anthropogenic causes by fossil fuel burning and industrial air emission. As the water temperature rises, it warms up and therefore expand which results in the sea level rise ("*Sea Level Rise"*, 2015).

Modelling are made for the Global mean sea level rise for the 21st century. The figure below shows the sum of the modelled contributions for the coming global mean sea level rise.

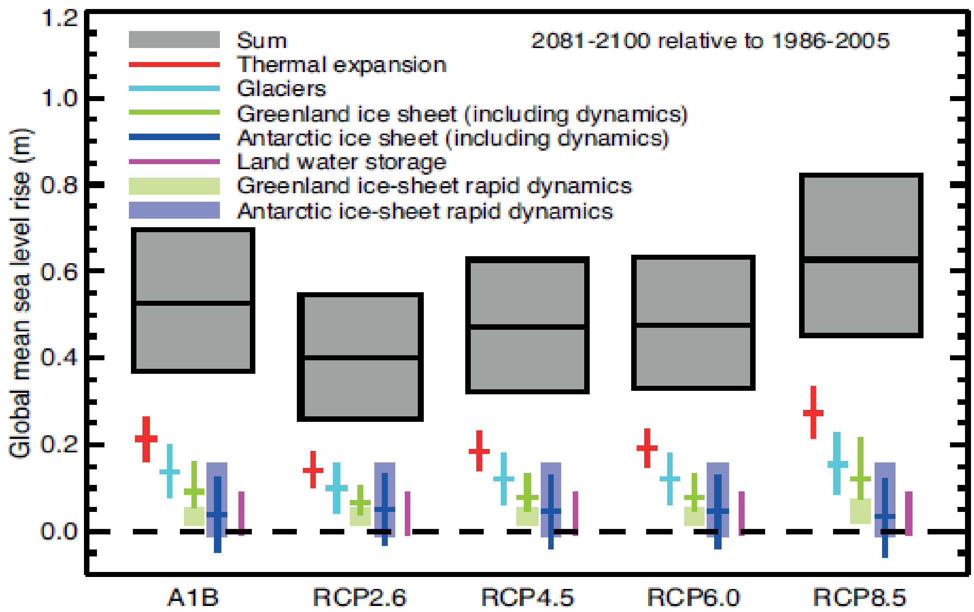


Figure 3:Projections from process-based models with likely ranges and median values for global mean sea level rise and its contributions (Church, J.A. Et Al, 2013).

Based on the results tabulated above, it is proved that thermal expansion is the dominant force in causing the sea level rise which they took about 30 % to 55 % of the projections, followed by glaciers and Greenland ice-sheet. Based on this evidence provided, it is logical for a research to focus on the rising of sea level due to the thermal expansion based on the heat that carbon dioxide has which is emitted from oil and gas activity.

Many methods are used to measure the global sea level rise. Few of the methods are by using tide gauges, land benchmarks and also by spatial satellite analysis to determine the sea level rise. It is known that the global rate of has risen from 2.79 mm to 3.30 mm per year for the past 20 ("*Sea Level Rise"*, 2015). These heat trapping emission has caused the sea level rise which even when our global emission reduced to zero which will still result in another 366 mm to 487 mm of rise by year 2100 because the ocean and ice glaciers are still adapting to the difference inflicted by the atmosphere. Scientist have made research based on few scenario ranging from the lowest sea level rise of 200 mm and to the highest rate which is a 6.6 feet rise (2 meter) reflects the minimum and maximum plausible contribution where the highest rate scenario is considered where there is little tolerance for risk (Parris. A Et Al., 2012)

The projection of global mean sea level rise is varied based on the Representative Concentration Pathways (RCPs). RCPs is defined as the total anthropogenic emission of Greenhouse gasses (GHGs) measure by the units of Watts per square meter (W/m^2). There are three different RCP scenarios which are picked ranging from low, medium and high. Low scenarios which is RCP 2.6 which the GHG concentration do not exceed the values of 500 ppm CO_2, they are modelled with a range of 0.5 % to 2 % increase in CO_2 up to 450 ppm where there is no emission after that. For medium scenarios, RCP 4.5 with CO_2 range of 500 ppm to 700 ppm, they are increasing the CO_2 by 1 % up to 560 ppm and lastly, high scenarios which includes RCP 8.5 which are above 700 ppm of CO_2 are modelled to stop at 1120 ppm of carbon dioxide. The following scenario is then projected to the year 2500 and tabulated in the Assessment Report 5 of (IPCC) Intergovernmental Panel on Climate Change (R.K. Pachauri Et Al., 2014).

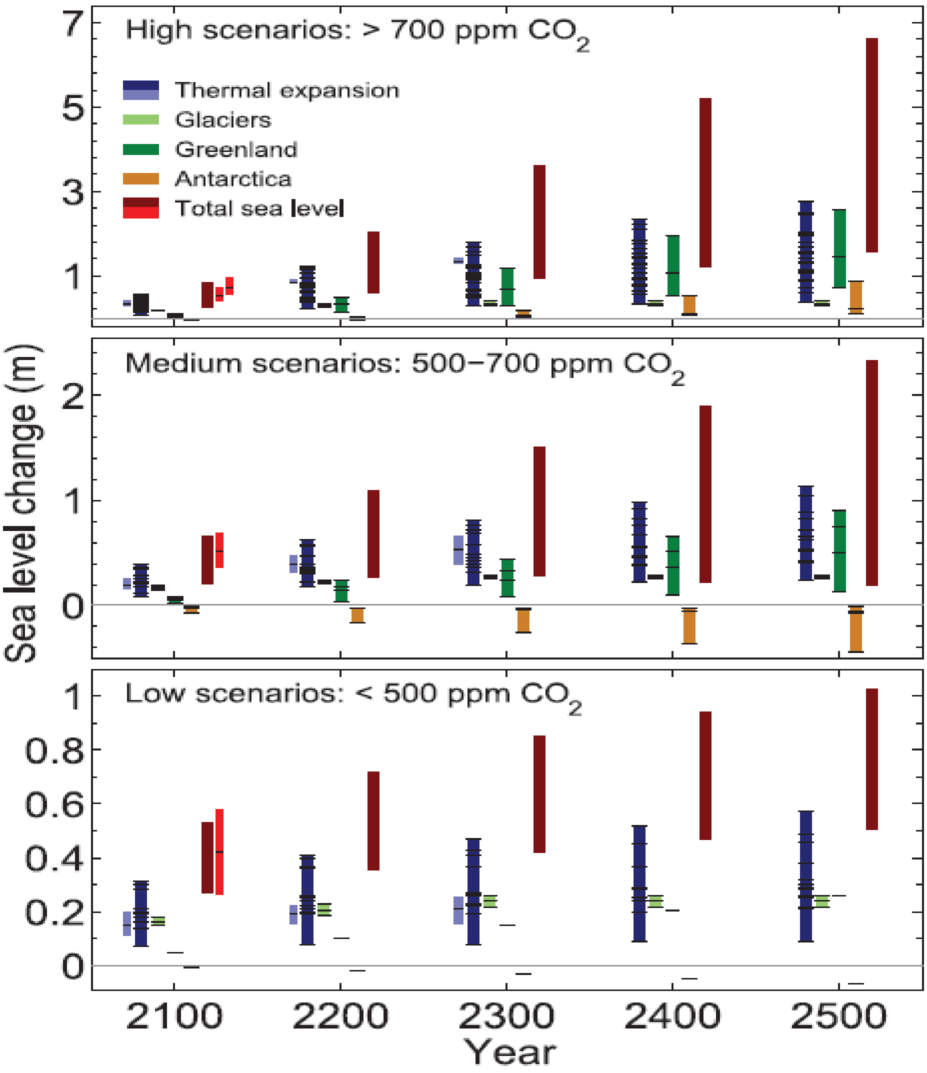


Figure 4:Sea level projection on different scenarios of CO2 concentration (R.K. Pachauri Et Al., 2014)

Figure above illustrates the sea level rise projected based on low, medium and high scenario up to the year 2500. The projection made beyond year 2100 shows positives contribution from thermal expansion, glacier and changes in Greenland ice sheet whereas observed above, the worst case scenario that our global mean sea level can rise up to 6.8 m (R.K. Pachauri Et Al., 2014).

It is very important to understand why in this research paper we focus on carbon dioxide out of so many greenhouse gases (GHGs). Greenhouse gasses contains a combinations of heat emitting gasses. 82 % of it are carbon dioxide from the burning of fossil fuels, 10 % are methane which are emitted from the production and transport of coal, natural gas, oil and natural decay of organic waste, 5 % is taken by Nitrous Oxide which are contributed from agricultural and industrial activities and lastly 3 % are from Fluorinated Gases from a range of industrial processes (EPA, 2013).

Ocean thermal expansion is mainly contributed by the dissolved carbon dioxide in the ocean which contains heat as shown in the list below, it is known that CO_2 is the dominant force in heat emission due to the volume it takes in the greenhouse gasses composition. As seen in the figure is the radiative forcing of the gasses, RF (Radiative Forcing) is defined as the measure of the how the energy balance of the earth-atmosphere system is influenced when factors that affects climate change which they are measured in terms of watts per square meter. As shown below, a positive radiative forcing reading will cause the warming of the earth while negative reading means that energy will decrease and this will cause the cooling of the system.

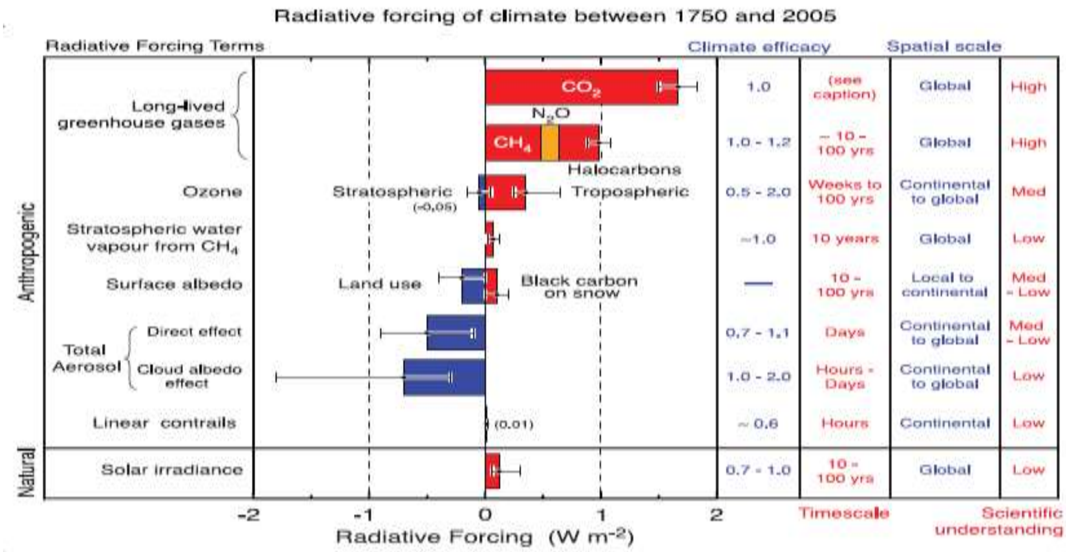


Figure 5: Radiative forcing of climate change (Forster, P. Et Al, 2007)

The reason of focusing on the carbon dioxide emission on this oil and gas activities is justified by this table above which proved that carbon dioxide contains and contributes the most to warming of our system. CO_2 have a positive radiative forcing reading of 1.66 Wm^{-2} (Forster, P. Et Al, 2007).

It is clear that the radiative forcing of carbon dioxide emitted to the atmosphere is affecting our global mean sea level rise by causing thermal expansion of the ocean. Table 1 IS tabulated with the most likely value ranges and their average value of global mean sea level rise and its contributions in meters with different scenarios.

Table 1: Projection of Breakdown of contributing factor based on different scenario

	SRES A1B	RCP 2.6	RCP 4.5	RCP 6.0	RCP 8.5
Thermal expansion	0.21[0.16 to 0.26]	0.14[0.10 to 0.18]	0.19[0.14 to 0.23]	0.19[0.15 to 0.24]	0.27[0.21 to 0.33]
Glaciers[a]	0.14[0.08 to 0.21]	0.10[0.04 to 0.16]	0.12[0.06 to 0.19]	0.12[0.06 to 0.19]	0.16[0.09 to 0.23]
Greenland ice-sheet SMB[b]	0.05[0.02 to 0.12]	0.03[0.01 to 0.07]	0.04[0.01 to 0.09]	0.04 [0.01 to 0.09]	0.07[0.03 to 0.16]
Antartic ice- sheet SMB[c]	-0.03[-0.06 to -0.01]	-0.02[-0.04 to -0.00]	-0.02[-0.05 to -0.01]	-0.02[-0.05 to -0.01]	-0.04[-0.07 to -0.01]
Greenland ice-sheet rapid dynamics	0.04[0.01 to 0.06]	0.04[0.01 to 0.06]	0.04[0.01 to 0.06]	0.04[0.01 to 0.06]	0.05[0.02 to 0.07]
Antartic ice-sheet rapid dynamics	0.07[-0.01 to 0.06]	0.07 [-0.01 to 0.16]	0.07[-0.01 to 0.16]	0.07[-0.01 to 0.16]	0.07[-0.01 to 0.16]
Land water storage	0.04[0.01 to 0.06]	0.04[-0.01 to 0.09]	0.04[-0.01 to 0.09]	0.04[-0.01 to 0.09]	0.04[-0.01 to 0.09]
Global mean sea level rise in 2081-2100	0.52 [0.37 to 0.69]	0.40[0.26 to 0.55]	0.47[0.32 to 0.63]	0.48[0.33 to 0.63]	0.63[0.45 to 0.82]
Greenland ice sheet	0.09 [0.05 to 0.15]	0.06[0.04 to 0.10]	0.08[0.04 to 0.13]	0.08[0.04 to 0.13]	0.12 [0.07 to 0.21]
Antartic ice sheet	0.04[-0.05 to 0.13]	0.05[-0.03 to 0.14]	0.05[-0.04 to 0.13]	0.05[-0.04 to 0.13]	0.04[-0.06 to 0.12]
Ice-sheet rapid dynamics	0.10[0.03 to 0.19]	0.10[0.03 to 0.19]	0.10[0.03 to 0.19]	0.10 [0.03 to 0.19]	0.12[0.03 to 0.20]
Rate of global mean sea level rise	8.1 [5.1 to 11.4]	4.4[2.0 to 6.8]	6.1[3.5 to 8.8]	7.4[4.7 to 10.3]	11.2 [7.5 to 15.7]
Global mean sea level rise in 2046- 2065	0.27 [0.19 to 0.34]	0.24[0.17 to 0.32]	0.26[0.9 to 0.33]	0.25[0.18 to 0.32]	0.30 [0.22 to 0.38]
Global mean sea level rise in 2100	0.60[0.42 to 0.80]	0.44[0.28 to 0.61]	0.53[0.36 to 0.71]	0.55[0.38 to 0.73]	0.74 [0.52 to0.98]

***Notes:**

[a] Excluding glacier on Antartica but including glaciers peripheral to the Greenland ice sheet

[b] Including the height-SMB feedback

[c] Including the interaction between SMB change and outflow

Thermal expansion dominates in contributing towards global mean sea level rise and it is proved in the different scenarios modelled as above as value of 0.21 m to 0.27 m (Forster, P. Et Al, 2007).

The physical properties of carbon dioxide is tabulated in the figure below:

Table 2:Physical properties of carbon dioxide (Airproducts, 2015)

Carbon dioxide	
Formula	CO_2
Molecular Weight (lb/mol)	44.01
Critical Temp. (°F)	87.9
Critical Pressure (psia)	1071
Boiling Point (°F)	-109.2
Melting point (°F)	-69.9
Psat @ 70°F (psia)	852.8
Liquid Density @ 70°F (lb/ft3)	47.64
Gas Density @70°F 1 atm (lb/ft3)	0.1144
Specific Volume @70°F 1 atm (ft3/lb)	8.74
Specific Gravity	1.555
Specific Heat @ 70°F (Btu/lbmol-°F)	8.92

With all these researches done ranging from global scale considering all radiative forcing gasses. It can be concluded where the largest contributing factor to sea level rise is by the thermal expansion of the ocean where natural and anthropogenic carbon dioxide emission which dissolve into the ocean causing the warming and finally expansion of the ocean which ultimately lead to sea level rise.

Oil and gas activities are the ones that causes the global mean sea level rise due to the harvesting and processing of fossil fuel. Therefore, proper modelling for coastal flooding have to be done on the carbon dioxide emitted from oil and gas activity so that we can have a better understanding on the impact that is caused on the sea level rise due to these activities.

Steric sea level rise

The increasing radiative forcing cause by anthropogenic carbon dioxide enhances the steric sea level rise proportionally. To further understand the relationship in between steric sea level rise and carbon dioxide in the ocean, data such as temperature, heat capacity and thermal expansion coefficient.

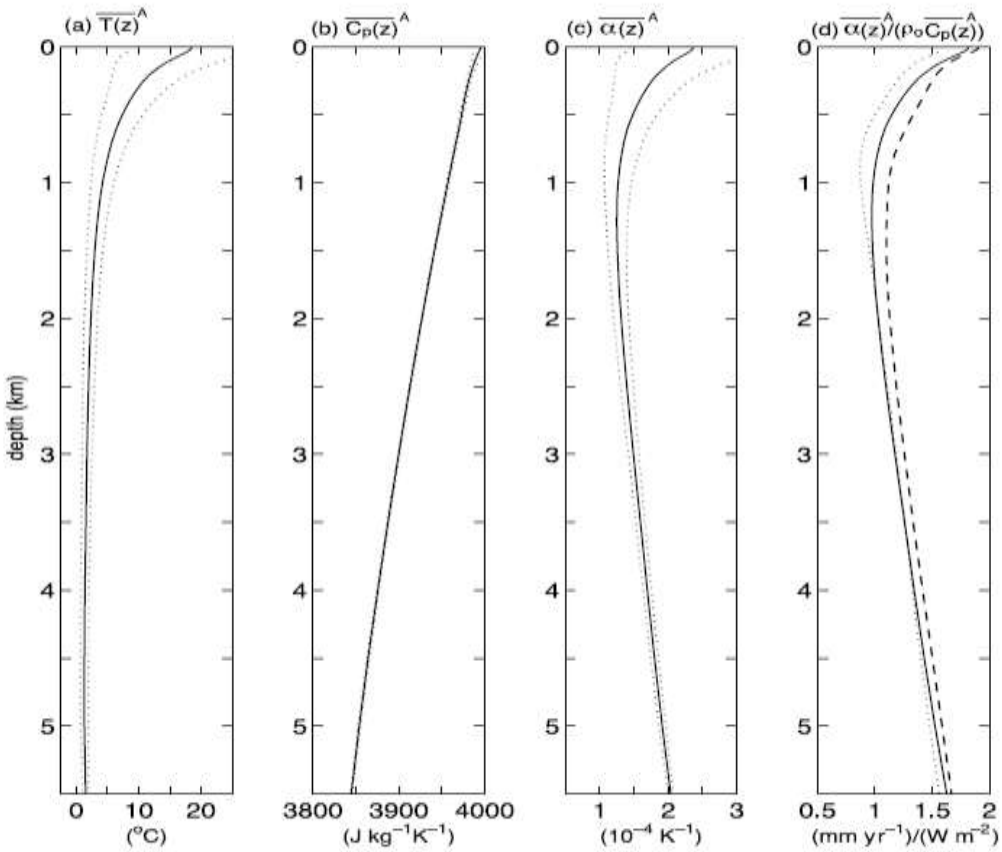


Figure 6: Global Mean area-averaged profiles for (a) temperature, (b) heat capacity, (c) thermal expansion coefficient and (d) factor of conversion from surface heat flux to steric sea level rise (Williams Et Al, 2012)

Data from figure 6 (b) is the heat capacity of global - mean ocean, $\overline{\boldsymbol{C_p^v}}$ = 3.910 ± 0.001 x 10^3 J kg^{-1}K^{-1}, while 8 (c) is the coefficient of thermal expansion which is $\overline{\boldsymbol{\alpha^v}}$ = 1.572 ± 0.147 x 10^{-4} K^{-1} and (d) the conversion factor of steric sea level rise by multiplying surface heat flux $\overline{\boldsymbol{\alpha^v}}$ / ($\overline{\boldsymbol{C_p^v}}$ ρ_0) = 1:236 _ 0:116 mm yr^{-1} (W m^{-2})$^{-1}$ (Williams, Goodwin, Ridgwell, & Woodworth, 2012). These data are used for the modelling of steric sea level rise from cumulative carbon dioxide emitted from oil and gas activity.

Ocean data view of scope of work is gathered where the physical properties of seawater is determined in the straits of Malacca where water temperature, salinity and dissolved oxygen over the monsoon season. It is observed that the straits are more stratified in warmer condition especially the southern section which are more homogenous which concludes that it undergoes better mixing (Amiruddin, Ibrahim, & Ismail, 2011)

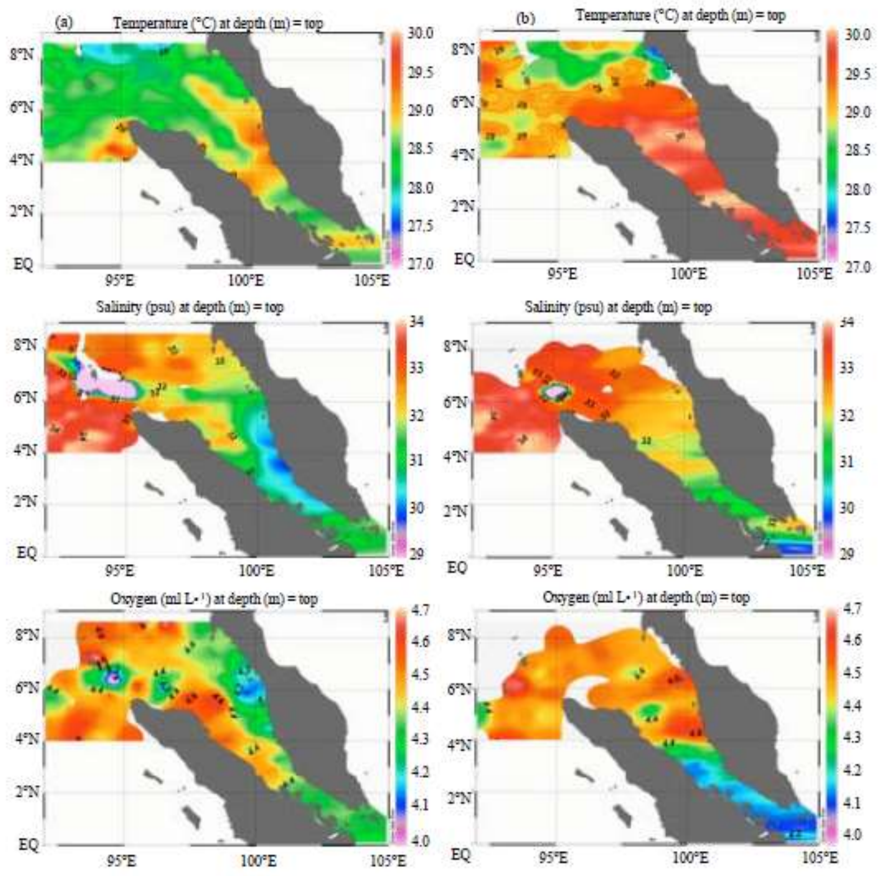


Figure 7:Seasonal surface water temperature and salinity in the Malacca Strait (a) Northeast Monsoon season (b) Southwest Monsoon season (Amiruddin, Ibrahim, & Ismail, 2011)

Temperature in Northeast Monsoon ranged from 28 and 29 °C where during Southwest Monsoon it increases to 30 °C. Similarly, the salinity is observed at 30.5 psu from west coast and the movement of high saline water from Andaman Sea during the Southwest Monsoon is around 32 to 33 psu intruding the straits from the northern strait. Dissolved oxygen is recorded at a range of 4.4 ml L^{-1} to 4.6 ml L^{-1}, however values are higher at the middle and northern straits when compared to the eastern part which is 4.3 ml L^{-1}.

Dissolved oxygen values were lower in Southern part of the Straits which are about 4.1 ml L^{-1} compared to a range at the Northern Straits of 4.4 to 4.6 ml L^{-1} (Amiruddin, Ibrahim, & Ismail, 2011).

Physical properties of CO_2 vary with depth and pressure. CO_2 is at gaseous state up to the depth of 500 m, below 500 m, CO_2 is liquid. Density of CO_2 also varies with depth as shown in figure 10. Figure 11 shows that CO_2 is denser at 3000 m and below and lighter than sea at the depth of 500 m to 2700 m.

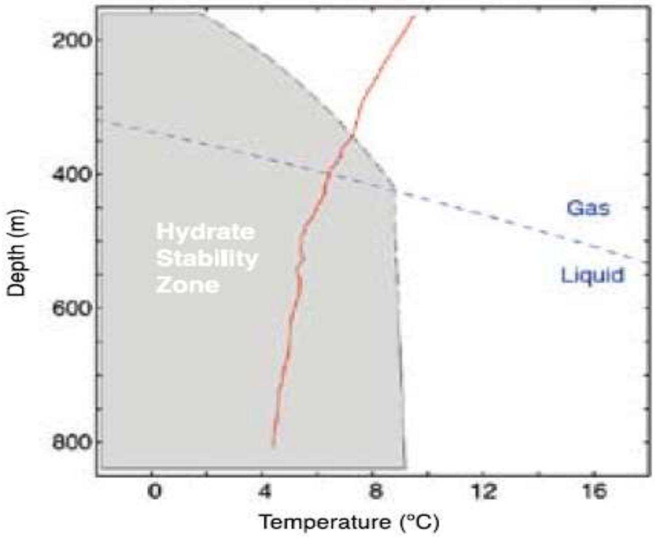


Figure 8:CO2 sea water phase diagram (Caldeira. Et. Al., 2005).

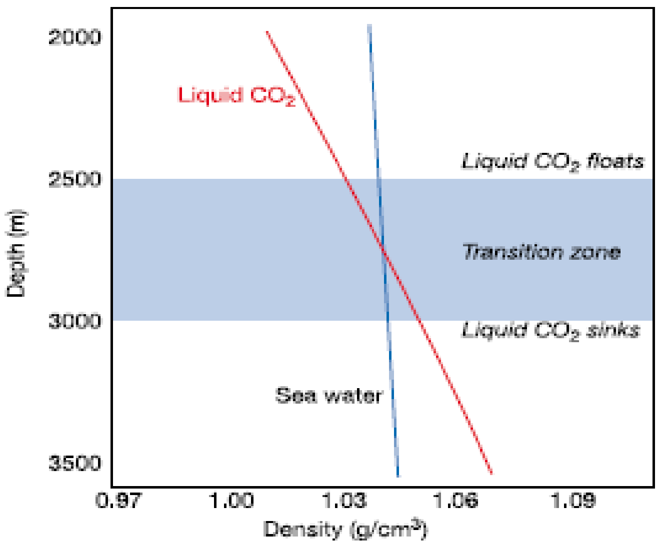


Figure 9: Range of liquid CO_2 float and sink (Caldeira. Et. Al., 2005).

Greenhouse Gases

Anthropogenic emission results in emissions of four primary gasses which are carbon dioxide, methane, nitrous oxide and also halocarbons.

- Halocarbon gases

Principle halocarbon gas is chlorofluorocarbons used extensively as refrigeration agents and in other industrial processes before its harm founded that it would has the depletion of stratospheric ozone.

- Nitrous oxide

Emitted by human activities of fertilizer use and fossil fuel burning also the natural processes in soil and ocean also releases N_2O.

- Methane

Emission increased for methane as the agriculture, natural gas distribution and landfills increases. However, the growth rate for methane in the atmosphere decreased over the last 2 decades.

- Carbon dioxide

CO_2 emission is contributed largely from combustion of fossil fuel used in transportation, factories and also emission from oil refinery processing.

Thermal Expansion

Coefficient of thermal expansion can be quantified by a constant particular to a material. Thermal expansion is also defined as the tendency of matter to increase in volume when heated. The ocean is susceptible to temperature induced expansion because salt water is densest at its temperature just below zero degree Celsius (Sommer, 2007).

Radiative Forcing

Definition of RF (Radiative Forcing) is explained by the change in net irradiance at the tropopause after allowing for the stratospheric temperatures to readjust to the radiative equilibrium with the value of tropospheric and surface temperature which they are constant at the unperturbed values. Natural and anthropogenic causes and drivers are compared and evaluated from radiative forcing. It is also related with a linear relationship to the global mean equilibrium change at the surface. Figure 10 shows how RF is linked to other aspects of climate change.

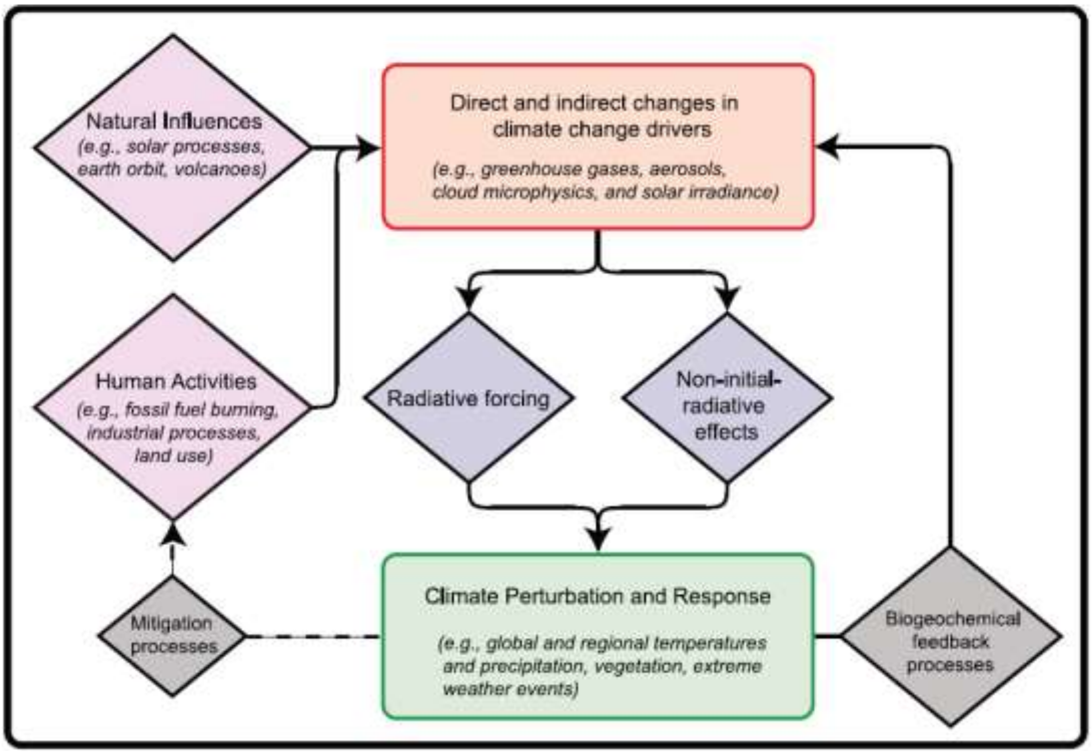


Figure 10: Component of climate change process (Forster, P. Et Al, 2007).

The most important stratospheric adjusted RF are displayed in figure 11 as climate change agents that require changes in the tropospheric state either temperature or water vapour amounts causes a radiative perturbation are aerosol-cloud lifetime and semi direct effects.

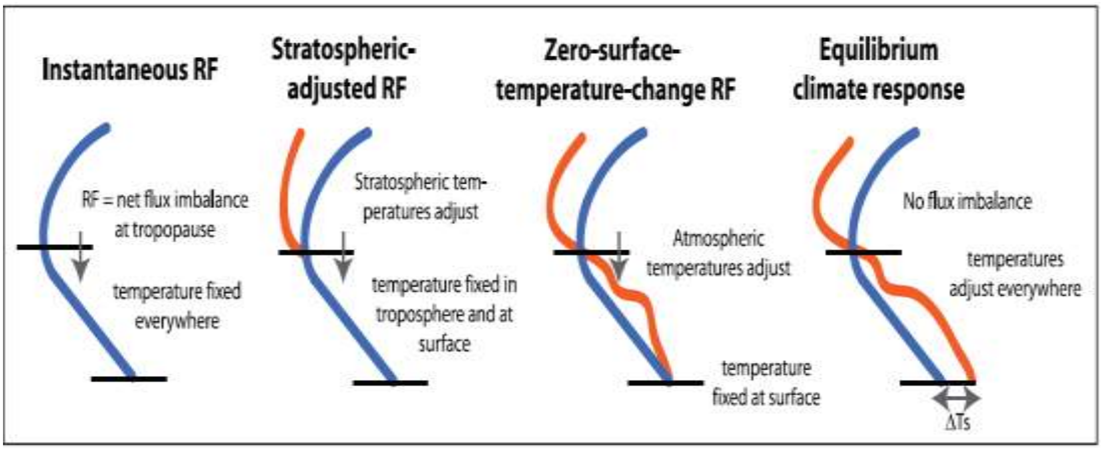


Figure 11: Schematic comparing RF calculation methodologies. Radiative forcing, defined as the net flux imbalance at the tropopause, is shown by an arrow. The horizontal lines represent the surface (lower line) and tropopause (upper line). The unperturbed temperature profile is shown as the blue line and the perturbed temperature profile as the orange line. From left to right: Instantaneous RF: atmospheric temperatures are fixed everywhere; stratospheric-adjusted RF: allows stratospheric temperatures to adjust; zero-surface-temperature-change RF: allows atmospheric temperatures to adjust everywhere with surface temperatures fixed; and equilibrium climate response: allows the atmospheric and surface temperatures to adjust to reach equilibrium (no tropopause flux imbalance), giving a surface temperature change (ΔTs) *(Forster, P. Et Al, 2007)*.

Chapter 3: Methodology

3.1 Research flow

To determine the concentration of carbon dioxide from oil and gas activities

- Gather amount of carbon dioxide from Melaka oil refinery plant.
- Calculate amount of CO_2 emitted per barrel of crude oil refined.

Utilize obtained data for Calculation of heat transfer to determine the rise of ocean temperature from oil and gas emission

- Specific heat capacity formula : $Q = m\,c\,\Delta T$
  $Q_{atmosphere} = Q_{ocean}$
- Q = Heat that flows into the system
- m = Mass of carbon dioxide
- c = Specific heat of carbon dioxide and ocean
- $\triangle T$ = Change in temperature

To model the sea level rise caused by thermal expansion from the temperature rise and tabulate a graph of temperature against sea level rise.

- $\triangle D = (\beta)(D_i)(\triangle T)$
- β = Coefficient of expansion (constant)
- Vi = initial volume
- $\triangle T$ = Change in temperature from oil and gas emission

Modelling of coastal flooding along the coastline of Malaysia and Indonesia

- ArcGIS spatial analyst tool is used for the modelling of sea level rise.
- Cells affected from the projected sea level rise are then calculated to assess on the population that is affected in coastal flooding

Research methodology

3.2 Introduction

The research method this research uses is by using the fundamental of physics where heat transfer is utilized in modelling the rise of sea level by the emission of anthropogenic carbon dioxide from oil and gas activity. By using the heat transfer concept, specific heat capacity formula is used for the heat transfer of carbon dioxide and ocean. This formula is further defined as the amount of heat emitted by anthropogenic carbon dioxide which will raise a gram of ocean by one degree Celsius in this research paper.

In order to verify the credibility of the amount of carbon dioxide emitted by the oil and gas industry, Petronas Technical Standard (PTS) is used for reliability check. Various amount of carbon dioxide is also used to model the rise of sea level rise in order to make projections of different concentrations.

3.3 Study area

Petronas Melaka refinery plant is our study area whereby it is location about 15 km from the town. They are built on a site of 926 acre. The plant also possess a capacity of 200,000 bpsd (barrels per stream day). Carbon emission concentration is obtained from the Petronas Melaka Refinery plant. The carbon dioxide concentration is verified with the PTS standard of emission in oil and gas activity to avoid any inaccuracy.

The average data collected at the straits of Malacca such as the average temperature is 29.60 ± 0.68 °C, the biochemical oxygen demand (BOD) and total suspended solid (TSS) concentration is 0.604 ± 0.077 (0.23-1.08) mg O_2 L^{-1} and 7.19 ± 0.49 (3.93-13.57) mg L^{-1} . Values of salinity, dissolved oxygen are 31.22±1.01 ppt and 5.28±0.42 mg O2 L-1 respectively, the average water depth is also recorded at 53.38m (Hii et al., 2006).

3.4 Mathematical Model

The data obtained is used to compute the sea level rise of the ocean where the fundamentals of heat transfer is utilized in order to achieve the result. Heat capacity is defined as when an object is heated, the temperatures increases. Temperature change is linear in the amount of heat added. Eqn (4) are as follows:

$$Q = mc \vartriangle T \qquad \text{Eqn (4)}$$

Q = Heat that flows into the system

m = Mass of carbon dioxide and ocean

c = Specific heat of carbon dioxide and ocean

$\vartriangle$T = Change in temperature

In this research, we assume that there is no heat lost in heat transfer of carbon dioxide from the atmosphere to the ocean. The specific equation that we are using is by utilizing Eqn (4).

Assuming there is no heat lost:

$Q_{\text{atmosphere}} = Q_{\text{ocean}}$ Eqn (5)

By substituting Eqn (4) into Eqn (5)

$(\mathbf{m}_{\text{carbon dioxide}})\,(\mathbf{c}_{\text{carbon dioxide}})\,(\mathbf{T}_{\text{carbon dioxide}} - \mathbf{T}_{f}) = (\mathbf{m}_{\text{ocean}})\,(\mathbf{c}_{\text{ocean}})\,(\mathbf{T}_{f} - \mathbf{T}_{\text{initial ocean}})$
-Eqn (6)

$m_{\text{carbon dioxide}}$ = Mass of carbon dioxide which will be dissolved into the ocean

m_{ocean} = Mass of ocean

$c_{\text{carbon dioxide}}$ = Heat capacity of carbon dioxide,

$C_{p,\text{ carbon dioxide}} = 0.844 \times 10^3$ J kg^{-1}K^{-}1 (Williams et al., 2012)

C_{ocean} = Heat capacity of global - mean ocean,

$\overline{C_p^v} = 3.910 \pm 0.001 \times 10^3$ J kg^{-1}K^{-1} (Williams et al., 2012)

$T_{carbon\ dioxide}$ = Temperature of carbon dioxide before dissolving into ocean

T_f = Final temperature of the ocean after heat transfer

$T_{initial\ ocean}$ = Initial temperature of ocean before heat transfer

By using Eqn (6) and solving for $m_{carbon\ dioxide}$, results is then obtained on the amount of carbon dioxide is required to raise the ocean temperature by 1 degree Celsius. Other value is then solved by varying the amount of anthropogenic carbon dioxide to observe the rise in temperature. A graph is then plotted of CO_2 against Temperature rise in the ocean.

By obtaining the temperature rise calculated and tabulated by the anthropogenic carbon dioxide. A formula is used to calculate the sea level rise from thermal expansion which is stated as:

$$\Delta V = \beta V_i \Delta T \quad \text{Eqn (7)}$$

$$\Delta V = (SA)(\Delta D) \quad \text{Eqn (8)}$$

<u>Description</u>

ΔV = Change in volume

β = Coefficient of expansion (constant) = $1.572 \pm 0.147 \times 10^{-4}\ K^{-1}$ (Sommer, 2007)

V_i = initial volume

ΔT = Obtained from Eqn (6)

SA = Surface area

ΔD = Change in depth

Assuming the initial surface area (SAi) = final surface area (SA)

By equating Eqn (7) and (8)

$(SA)(\Delta D) = (\beta)(D_i)(SA)(\Delta T)$

$\Delta D = (\beta)(D_i)(\Delta T)$ Eqn (9)

*Mean ocean depth (D_i) = 53.38 m

Upper 10% of ocean is most affected by initial mixing processes.

Therefore, Mean ocean depth (D_i) = 53.38 m x 0.10 = 5.38 m

After the sea level rise is calculated, a graph of temperature rise against sea level is plotted and analyse for its impact. From the results obtain, it can be determined that whether the emission from oil and gas activity have any impact or effect on sea level rise.

3.5 Software, ArcGIS

ArcGIS, which is also known as an geographical information system. ArcGIS utilize the maps and geographical information to project and analyse geographic data, mapped information, sharing and managing geographic information in database.

ArcMap

ArcMap is an extension tool which acts as a platform to create maps, carry out spatial analysis and manage geographic data. In our modelling analysis of studying the coastal flooding in Malaysia and Indonesia. This research uses the spatial analysis tool to conduct analysis to determine the total flooded cells if certain criteria is met.

Methodology:

Maps are downloaded in form of cell in 1 m x 1 m. In order to conduct spatial analysis, the map cell has to be combine. A tool is used for this in the ArcMap tool box. Steps are illustrated as following:

Arc Toolbox > Data Management Tools > Raster Dataset > Mosaic to New Raster.

Figure 10 below illustrates that that digital elevation map in Malaysia which are not combined into a new raster file to ease the handling of analysis.

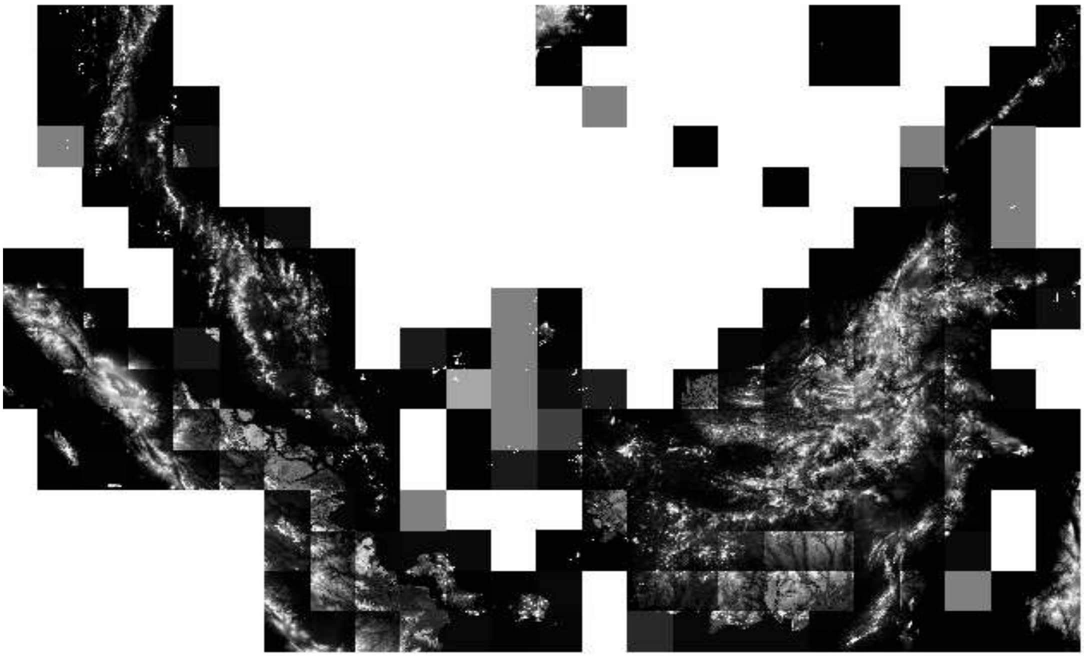


Figure 12:Malaysia Map without combination of raster

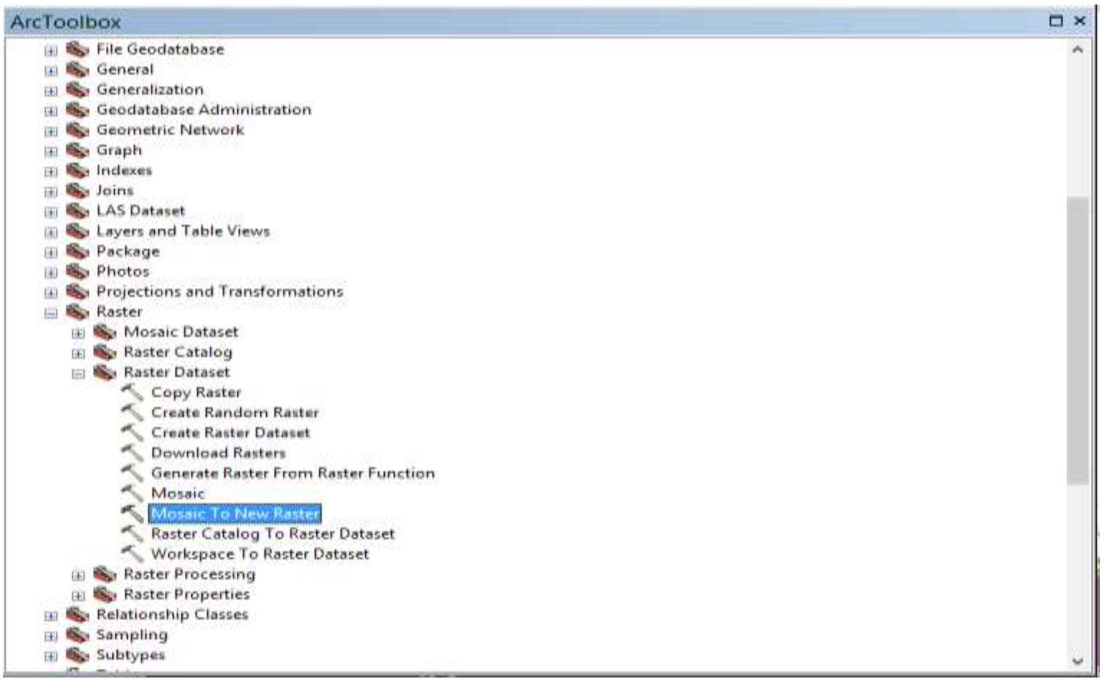


Figure 13: Arc Toolbox extension tool, Mosaic to New Raster

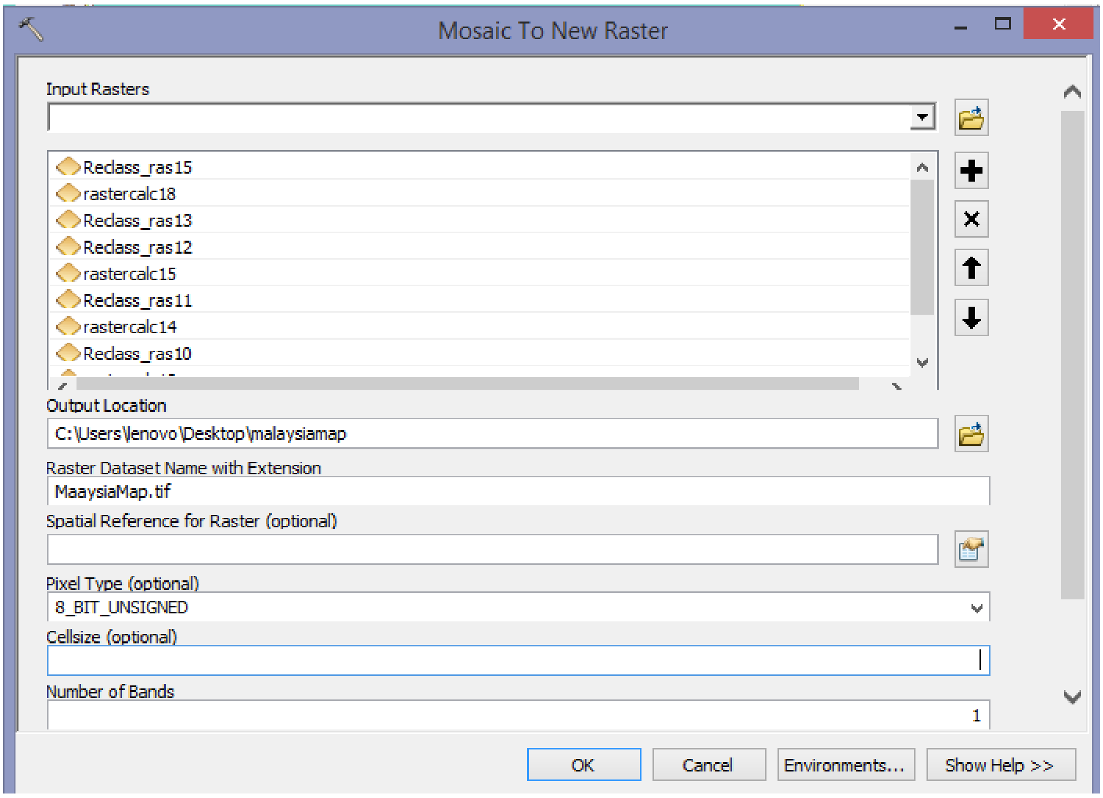


Figure 14: Select the Digital Elevation Map cells to combine into new raster

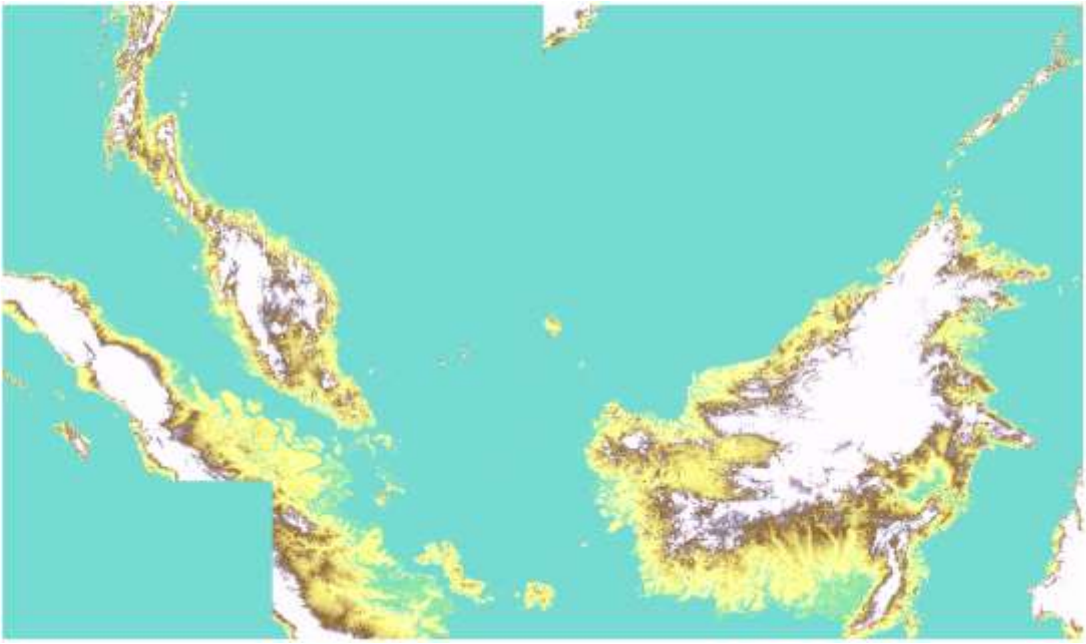


Figure 15:Combined new raster file

With this combined mosaic to new raster file allows the analysis of coastal flooding in Malaysia to be conducted.

Modelling of coastal flooding in ArcMap by using Spatial Analyst Tools

In order project the area affected from sea level rise due to dissolved carbon dioxide in the ocean.

Arc ToolBox > Spatial Analyst Tools > Map Algebra > Raster Calculator

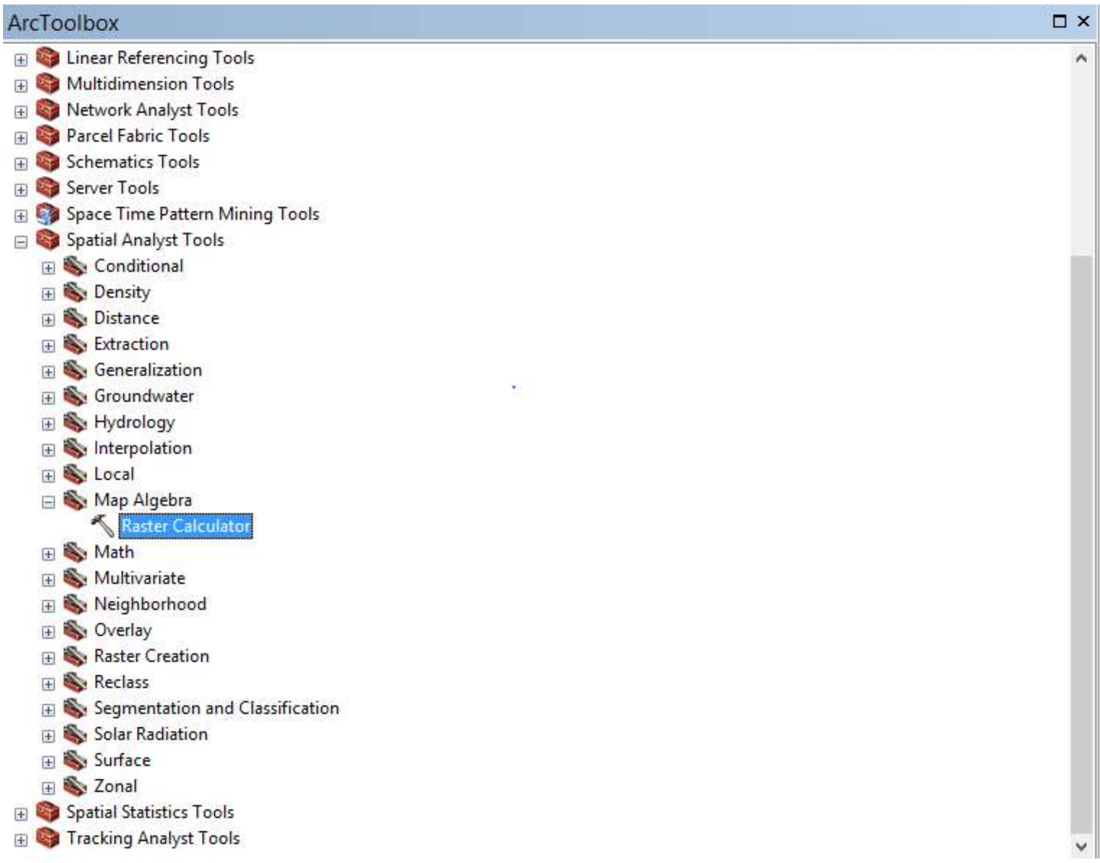


Figure 16:: Raster Calculator function

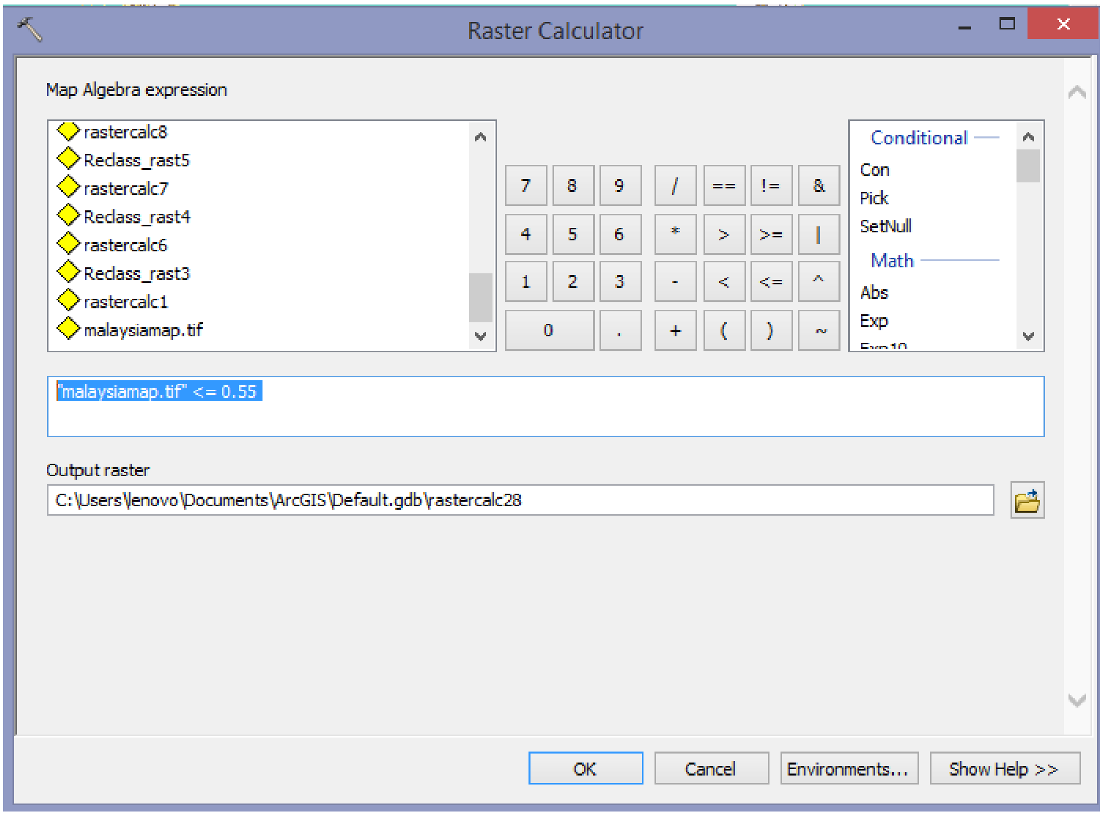


Figure 17: Modelling the projected data for analysis

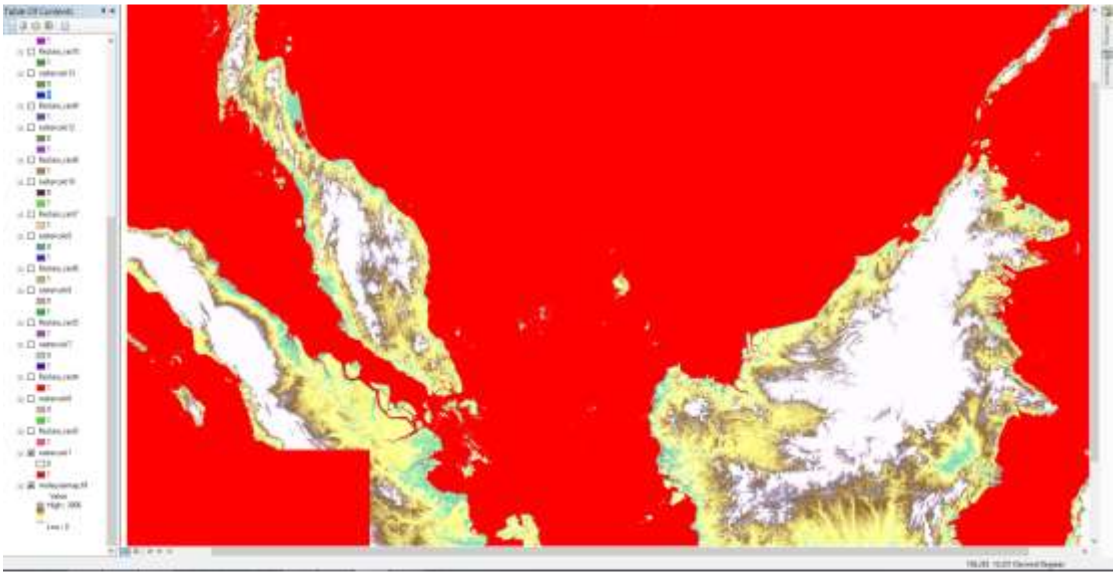


Figure 18: Modelled coastal flooding

Raster calculated is displayed of area that is below the sea level rise elevation with the colour of ocean changed to red for clearer view and it will display on the map as coastal flooding.

Another conversion is to be made which we reclassify the raster calculated so that the cells that are affected are only displayed and the total area of coastal flooding is obtained from ArcMap and therefore the population affected is calculated.

Reclassification of raster calculated from spatial analyst toolbox:

Spatial Analyst Tools > Reclass > Reclassify

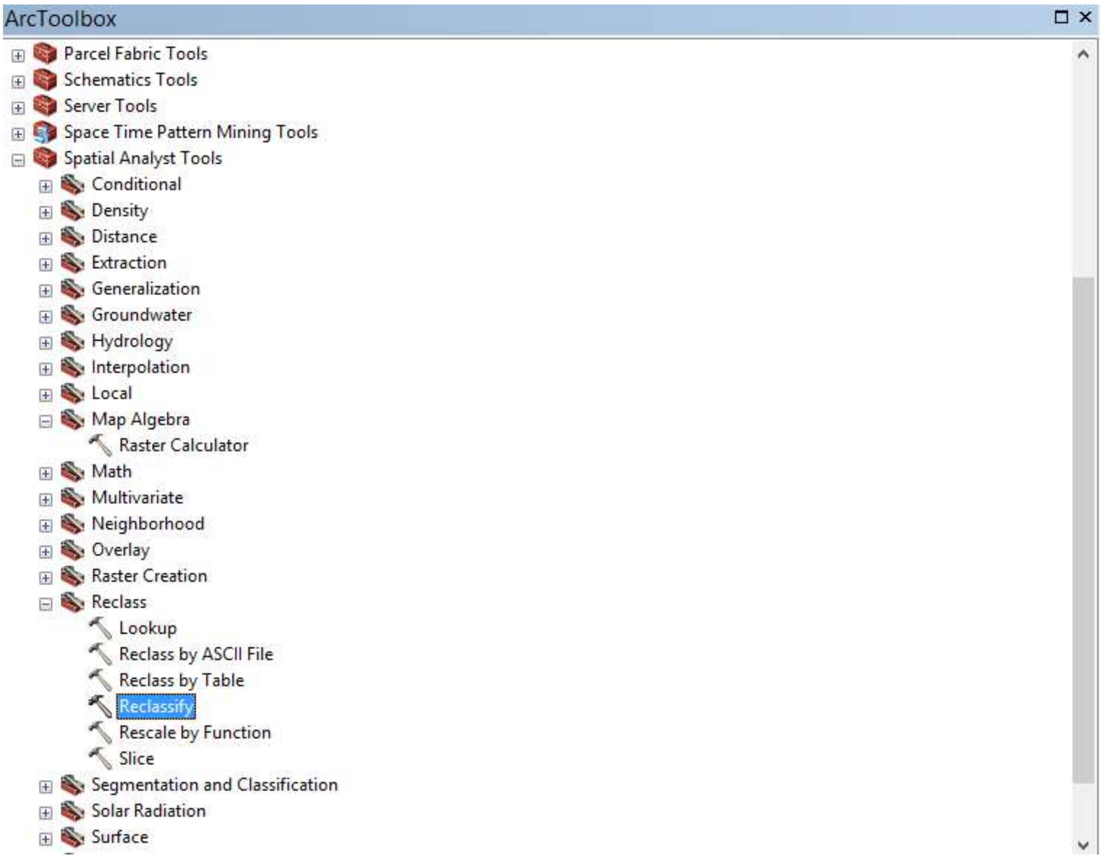


Figure 19:Reclassify function in ArcToolbox

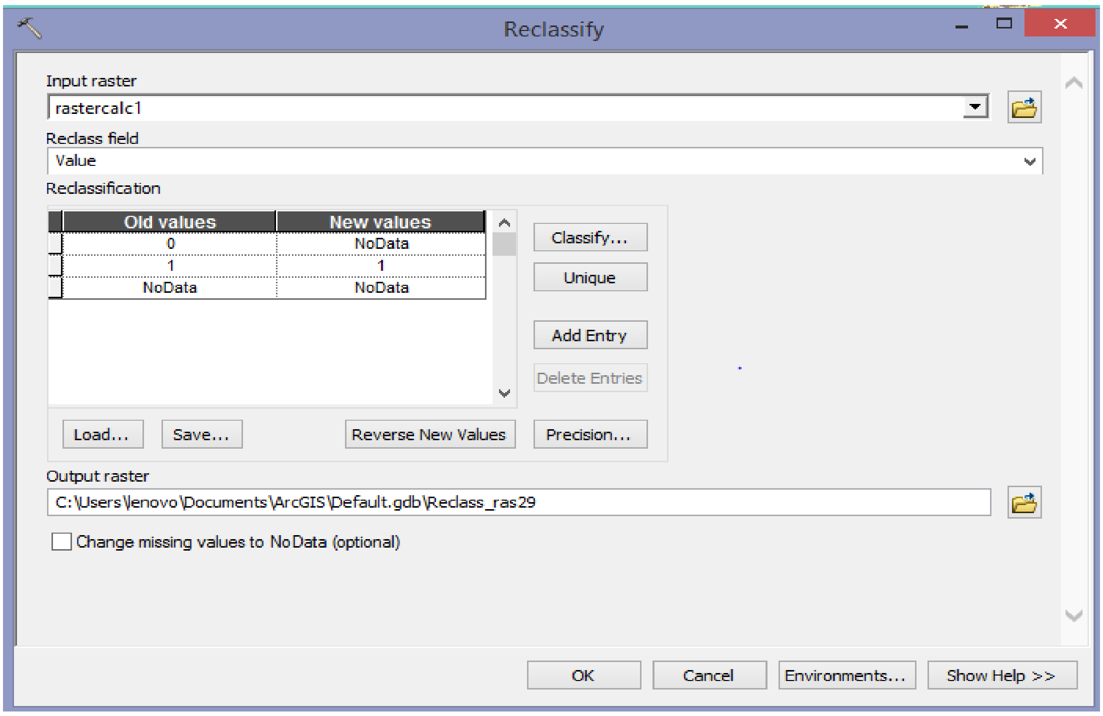


Figure 20:Reclassify editing table

Reclassification of data

Figure 21: Reclass option

By right clicking the Reclass_rast3 and opening the attribute table, total cells affected by flood is illustrated as figure 20 below:

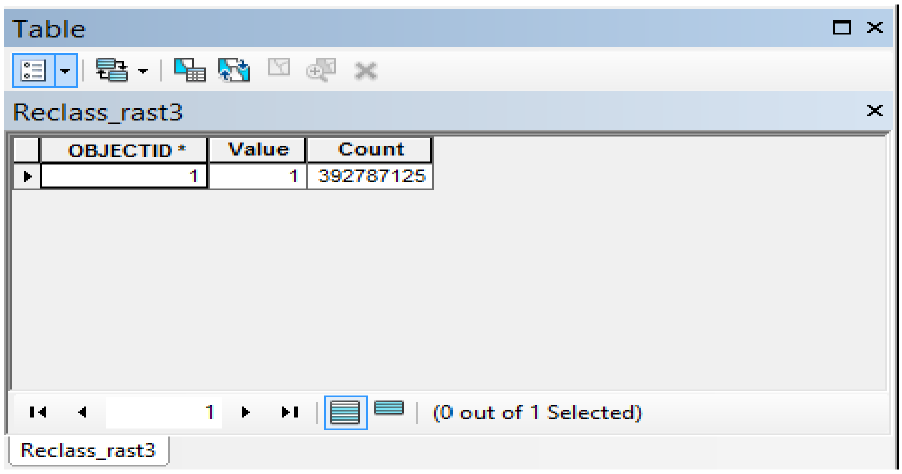


Figure 22:Attribute table

With this value obtained, the total population affected from the sea level rise from dissolved carbon dioxide into the ocean from oil refinery.

Gantt-chart and milestones

Key Milestone / Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Calculate the carbon emission of refinery	●													
Solve the specific heat capacity and sea level rise equation with graph plotted			●											
Discuss and prepare submission of progress report					●									
Modelling and analysing of results in ArcGIS							●							
Prepare poster and slides for pre-sedex and viva with final report and technical paper submission											●			
Submission of technical paper and completion of FYP														●

● Milestone

4.0 Results and discussion

The refinery capacity of Petronas's Melaka refinery (PSR-1) and (PSR-2) is at 100,000 and 170,000 barrels per day (Petronas, 2014).

The average carbon emission by refinery per barrel is calculated by averaging the data obtained at figure 21 (Forrest. J & Rocque. M, 2016).

	ARC Method						
kgCO2e/barrel	Data Source	Oil Production and Upgrading	Oil Transport	Refining	Refined Product Transport	Combustion	Total: Well-to-Combustion
China Conventional Heavy Oil (Bozhong)	1	262.9	8.7	68.8	2.3	390.4	**733.2**
Nigeria High Flaring (Obagi)	1	232.9	4.7	22.6	2.5	442.5	**705.2**
Canada Oil Sands Mining and Upgrading (Suncor Synthetic H)	1	148.1	7.4	96.5	2.6	441.2	**695.8**
US California Heavy Oil with Steam (Midway-Sunset)	1	202.2	0.3	84.9	2.4	404.2	**694.1**
Canada Oil Sands Mining and Upgrading (Syncrude Synthetic)	1	193.0	7.4	48.9	2.5	428.9	**680.7**
Indonesia Heavy Oil with Steam (Duri)	1	175.6	10.8	90.5	2.3	375.8	**655.0**
Nigeria High Flaring (Bonny)	1	164.5	4.6	22.6	2.5	442.5	**636.7**
Venezuela Orinoco Heavy Oil (Hamaca)	1	173.7	2.4	21.2	2.5	433.4	**633.2**
US California Heavy Oil with Steam (South Belridge)	1	109.8	0.4	101.5	2.4	409.2	**623.4**
Canada Oil Sands Mining and Upgrading (Suncor Synthetic A)	1	153.8	7.4	15.5	2.4	427.4	**606.5**
US California Conventional Heavy Oil (Wilmington-Duffy)	1	51.5	0.1	93.4	2.5	410.1	**557.5**
Canada Oil Sands Insitu (Cold Lake Dilbit)	1	112.9	7.3	66.8	2.1	355.5	**544.7**
UK Offshore (Brent)	1	111.3	3.6	17.9	2.3	408.6	**543.6**
US Conventional with High Gas (Alaska North Slope)	1	83.5	7.3	26.4	2.5	421.6	**541.3**
Brazil Deep Offshore (Lula)	1	42.8	3.7	48.3	2.6	431.0	**528.4**
Iraq Conventional (Zubair)	1	64.9	7.9	31.6	2.4	418.6	**525.4**
Brazil Conventional Heavy Oil (Frade)	1	27.4	4.5	87.5	2.4	394.0	**515.8**
Russia Deep Offshore (Chayvo)	1	68.4	7.2	18.3	2.4	417.8	**514.1**
Canada Conventional High Water (Midale)	1	55.4	5.4	34.4	2.4	411.8	**509.5**
Angola Conventional (Girassol)	1	35.9	5.4	29.6	2.5	430.5	**503.9**
US Average Crude Oil Refined (2005)	**2**	**50.3**	**4.7**	**33.8**	**2.4**	**409.9**	**501.1**
Angola Conventional Heavy Oil (Kuito)	1	33.5	5.8	27.9	2.4	425.7	**495.4**
UK Offshore (Forties)	1	42.4	3.3	36.3	2.4	406.5	**490.8**
US GOM Deep Offshore (Mars)	1	33.1	1.3	30.2	2.4	422.6	**489.8**
US Tight Oil (Bakken)	3	54.7	5.0	17.9	2.3	408.6	**488.5**
Canada Offshore (Hibernia)	1	24.6	2.0	26.1	2.4	421.9	**477.0**
Kuwait Conventional (Ratawi)	1	27.7	8.1	22.7	2.3	414.0	**474.9**
US GOM Deep Offshore (Thunder Horse)	1	30.1	1.3	24.9	2.4	413.6	**472.3**
Azerbaijan Conventional (Azeri)	1	26.5	6.8	14.5	2.4	419.5	**469.6**
Nigeria Conventional (Agbami)	1	47.1	4.3	15.3	2.2	388.7	**457.7**
US Tight Oil (Eagle Ford)	3	28.3	0.5	17.9	2.3	408.6	**457.7**
Norway Offshore (Ekofisk)	1	18.3	3.8	15.0	2.4	411.8	**451.2**
Kazakhstan Conventional (Tengiz)	1	19.6	10.3	31.9	2.3	382.1	**446.2**

Source: ARC Financial Corp. using input data from, (1) Global Oil Climate Index, (2) DOE/NETL and (3) IHS.

Figure 23:: Well to combustion GHG Emissions for a Benchmark Set of Crude Oils (Forrest. J & Rocque. M, 2016).

Average carbon dioxide emission rate calculated = 40.65 $kgCO_2e$/barrel.

Melaka total refinery production = 270,000 barrels per day.

Total daily CO_2 emission from Melaka refinery = 270,000 x 40.65 = 10975500 $kgCO_2e$

Assumption:
no heat lost occurs during the transfer process of carbon dioxide in the ocean

Based on the average temperature of the ocean in the straits of Malacca,

T = 29.60 ± 0.68 °C

C, carbon dioxide = Heat capacity of carbon dioxide,

$\mathbf{C}_{\mathbf{p,\ carbon\ dioxide}}$ = 0.844 x 10^3 J $kg^{-1}K^{-}1$ (Williams et al., 2012)

$\mathbf{C}_{\mathbf{ocean}}$ = Heat capacity of global - mean ocean,

$\overline{\boldsymbol{C_p^v}}$ = 3.910 ± 0.001 x 10^3 J $kg^{-1}K^{-1}$ (Williams et al., 2012)

By solving for the $\mathbf{T}_{\mathbf{carbon\ dioxide}}$:

$Q_{atmosphere} = Q_{ocean}$

$(m_{carbon\ dioxide})(c_{carbon\ dioxide})(T_{carbon\ dioxide} - T_f) = (m_{ocean})(c_{ocean})(T_f - T_{initial\ ocean})$

$$\mathbf{T}_{carbon\ dioxide} = \frac{(m\ ocean)(c\ ocean)\ (T\ f - T\ initial\ ocean)}{(m\ carbon\ dioxide\ )(c\ carbon\ dioxide)} + T\ f \qquad \text{Eqn (10)}$$

By solving the equation above, the change in sea temperature and temperature of carbon dioxide before it dissolved into the ocean is obtained in figure 13.

Mass of CO_2 production yearly =

(270,000 barrels per day x 40.65 $kgCO_2e$/barrel) x 365days

= 4006057500 kg CO_2/year Eqn (11)

$$M\ carbon\ dioxide = \frac{(Mocean)(Cocean)(T\ final - T\ initial\ ocean)}{(C\ carbon\ dioxide)(T\ carbon\ dioxide - Tfinal)}$$

T carbon dioxide = 205 °C

, average flue gas exit temperature (Garg & Nowakowski, 1987)

Table 3 displays the results for oil refinery projection of temperature rise due to the emission from Malacca refinery.

Table 3: Mass of carbon dioxide required to dissolved into the ocean in order to raise the temperature of the sea for oil refinery realistic projection

Years needed for CO2 to raise temperature	**Mass of CO2, kg**	**CO2 emission annual production, kg**	**∆T ocean, °C**
1	4.0E+09	4.0E+09	0.0000
2	8.0E+09	4.0E+09	0.0001
3	1.2E+10	4.0E+09	0.0001
4	1.6E+10	4.0E+09	0.0002
5	2.0E+10	4.0E+09	0.0002
6	2.4E+10	4.0E+09	0.0003
7	2.8E+10	4.0E+09	0.0003
8	3.2E+10	4.0E+09	0.0004
9	3.6E+10	4.0E+09	0.0004
10	4.0E+10	4.0E+09	0.0005

15	6.0E+10	4.0E+09	0.0007
20	8.0E+10	4.0E+09	0.0010
25	1.0E+11	4.0E+09	0.0012
30	1.2E+11	4.0E+09	0.0015
35	1.4E+11	4.0E+09	0.0017
40	1.6E+11	4.0E+09	0.0020
50	2.0E+11	4.0E+09	0.0025
60	2.4E+11	4.0E+09	0.0030
70	2.8E+11	4.0E+09	0.0035
80	3.2E+11	4.0E+09	0.0040
90	3.6E+11	4.0E+09	0.0045
100	4.0E+11	4.0E+09	0.0050

Table 4 is the projection of sea level rise for 100 years emitted from Melaka oil refinery. With this value obtained, figure

Table 4: Sea level rise projection (100 years) from temperature rise of dissolved CO_2

∆D,mm	**∆D,m**	**β**	**Di**	**∆T**
0.00004	3.9E-08	0.0001719	5.338	0.00004
0.00008	7.9E-08	0.0001719	5.338	0.00009
0.00012	1.2E-07	0.0001719	5.338	0.00013
0.00016	1.6E-07	0.0001719	5.338	0.00017
0.00023	2.3E-07	0.0001719	5.338	0.00025
0.00027	2.7E-07	0.0001719	5.338	0.00030
0.00032	3.2E-07	0.0001719	5.338	0.00035
0.00037	3.7E-07	0.0001719	5.338	0.00040
0.00041	4.1E-07	0.0001719	5.338	0.00045
0.00046	4.6E-07	0.0001719	5.338	0.00050
0.00069	6.9E-07	0.0001719	5.338	0.00075
0.00092	9.2E-07	0.0001719	5.338	0.00100
0.00115	1.1E-06	0.0001719	5.338	0.00125
0.00137	1.4E-06	0.0001719	5.338	0.00150

0.00160	1.6E-06	0.000171 9	5.338	0.00175
0.00183	1.8E-06	0.000171 9	5.338	0.00200
0.00229	2.3E-06	0.000171 9	5.338	0.00250
0.00275	2.7E-06	0.000171 9	5.338	0.00300
0.00321	3.2E-06	0.000171 9	5.338	0.00349
0.00366	3.7E-06	0.000171 9	5.338	0.00399
0.00412	4.1E-06	0.000171 9	5.338	0.00449
0.00458	4.6E-06	0.000171 9	5.338	0.00499

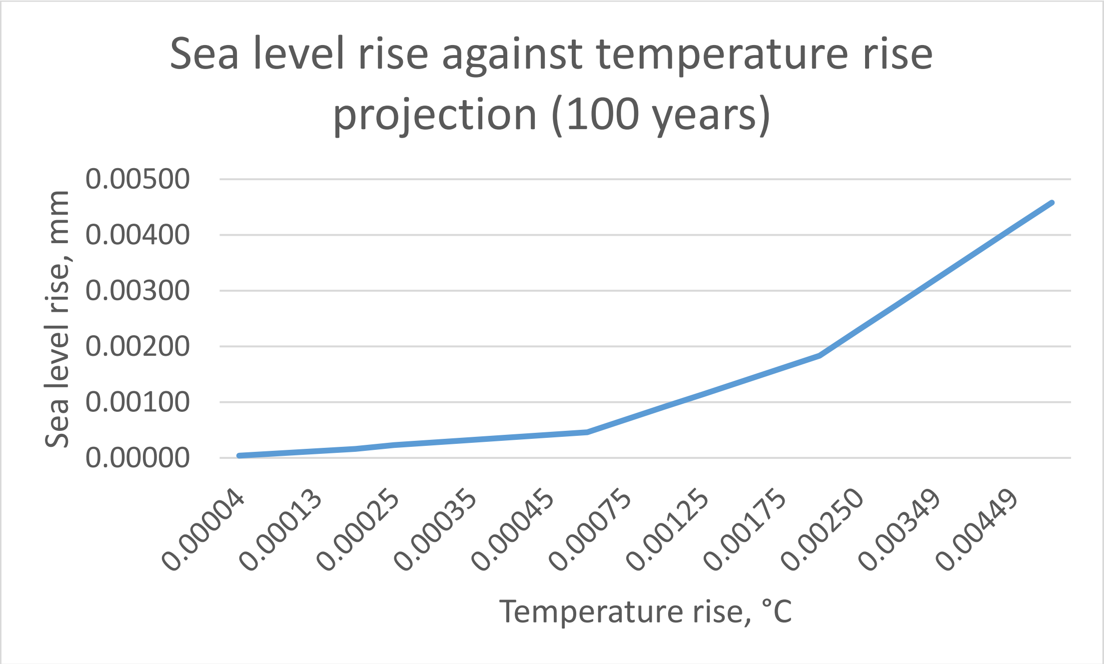


Figure 24: Sea level rise against temperature rise projection (100 years)

Table 5 Mass of carbon dioxide required to dissolved into the ocean in order to raise the temperature of the sea

Accumulated year of CO2	***Mass of CO2 production annually***	***Mass of CO2***	***T carbon dioxide***	***T f***	***T initial - ocean***	***T f– T initial ocean***	***C, carbon dioxide***	***C ocean***	***M ocean***
23454	*4006057500*	*93,958,740,053,295*	*205*	*29.92*	*28.92*	*1.00*	*844.00*	*3911.00*	*3550000000000000.00*
35282	*4006057500*	*141,341,759,152,229*	*205*	*30.42*	*28.92*	*1.50*	*844.00*	*3911.00*	*3550000000000000.00*
47178	*4006057500*	*188,996,969,307,569*	*205*	*30.92*	*28.92*	*2.00*	*844.00*	*3911.00*	*3550000000000000.00*
59142	*4006057500*	*236,926,722,671,546*	*205*	*31.42*	*28.92*	*2.50*	*844.00*	*3911.00*	*3550000000000000.00*
71176	*4006057500*	*285,133,398,576,337*	*205*	*31.92*	*28.92*	*3.00*	*844.00*	*3911.00*	*3550000000000000.00*
83279	*4006057500*	*333,619,403,927,789*	*205*	*32.42*	*28.92*	*3.50*	*844.00*	*3911.00*	*3550000000000000.00*
95452	*4006057500*	*382,387,173,606,016*	*205*	*32.92*	*28.92*	*4.00*	*844.00*	*3911.00*	*3550000000000000.00*
107697	*4006057500*	*431,439,170,872,996*	*205*	*33.42*	*28.92*	*4.50*	*844.00*	*3911.00*	*3550000000000000.00*
120013	*4006057500*	*480,777,887,787,316*	*205*	*33.92*	*28.92*	*5.00*	*844.00*	*3911.00*	*3550000000000000.00*
132401	*4006057500*	*530,405,845,626,213*	*205*	*34.42*	*28.92*	*5.50*	*844.00*	*3911.00*	*3550000000000000.00*
144862	*4006057500*	*580,325,595,315,057*	*205*	*34.92*	*28.92*	*6.00*	*844.00*	*3911.00*	*3550000000000000.00*
169504	*4006057500*	*679,042,773,084,772*	*205*	*35.42*	*28.92*	*7.00*	*844.00*	*3911.00*	*3550000000000000.00*
194292	*4006057500*	*778,343,799,788,541*	*205*	*35.92*	*28.92*	*8.00*	*844.00*	*3911.00*	*3550000000000000.00*
219226	*4006057500*	*878,233,870,428,148*	*205*	*36.42*	*28.92*	*9.00*	*844.00*	*3911.00*	*3550000000000000.00*

244310	*4006057500*	*978,718,241,821,205*	*205*	*36.92*	*28.92*	*10.00*	*844.00*	*3911.00*	*3550000000000000.00*
269542	*4006057500*	*1,079,802,233,523,330*	*205*	*37.42*	*28.92*	*11.00*	*844.00*	*3911.00*	*3550000000000000.00*
294926	*4006057500*	*1,181,491,228,766,880*	*205*	*37.92*	*28.92*	*12.00*	*844.00*	*3911.00*	*3550000000000000.00*
320462	*4006057500*	*1,283,790,675,416,620*	*205*	*38.42*	*28.92*	*13.00*	*844.00*	*3911.00*	*3550000000000000.00*
346152	*4006057500*	*1,386,706,086,942,630*	*205*	*38.92*	*28.92*	*14.00*	*844.00*	*3911.00*	*3550000000000000.00*
371997	*4006057500*	*1,490,243,043,410,810*	*205*	*39.42*	*28.92*	*15.00*	*844.00*	*3911.00*	*3550000000000000.00*
397999	*4006057500*	*1,594,407,192,491,480*	*205*	*39.92*	*28.92*	*16.00*	*844.00*	*3911.00*	*3550000000000000.00*
424159	*4006057500*	*1,699,204,250,486,230*	*205*	*40.42*	*28.92*	*17.00*	*844.00*	*3911.00*	*3550000000000000.00*
450478	*4006057500*	*1,804,640,003,373,690*	*205*	*40.92*	*28.92*	*18.00*	*844.00*	*3911.00*	*3550000000000000.00*
476958	*4006057500*	*1,910,720,307,874,340*	*205*	*41.42*	*28.92*	*19.00*	*844.00*	*3911.00*	*3550000000000000.00*
503600	*4006057500*	*2,017,451,092,535,050*	*205*	*41.92*	*28.92*	*20.00*	*844.00*	*3911.00*	*3550000000000000.00*

Table 6: Years required to raise certain temperature of the ocean

Accumulated year of CO2	**Mass of CO2, kg**	**CO2 emission annual production, kg**	**∆T ocean**
23454	93,958,740,053,295	4006057500	1.00
35282	141,341,759,152,229	4006057500	1.50
47178	188,996,969,307,569	4006057500	2.00
59142	236,926,722,671,546	4006057500	2.50
71176	285,133,398,576,337	4006057500	3.00
83279	333,619,403,927,789	4006057500	3.50
95452	382,387,173,606,016	4006057500	4.00
107697	431,439,170,872,996	4006057500	4.50

120013	480,777,887,787,316	4006057500	5.00
132401	530,405,845,626,213	4006057500	5.50
144862	580,325,595,315,057	4006057500	6.00
169504	679,042,773,084,772	4006057500	7.00
194292	778,343,799,788,541	4006057500	8.00
219226	878,233,870,428,148	4006057500	9.00
244310	978,718,241,821,205	4006057500	10.00
269542	1,079,802,233,523,330	4006057500	11.00
294926	1,181,491,228,766,880	4006057500	12.00
320462	1,283,790,675,416,620	4006057500	13.00
346152	1,386,706,086,942,630	4006057500	14.00
371997	1,490,243,043,410,810	4006057500	15.00
397999	1,594,407,192,491,480	4006057500	16.00
424159	1,699,204,250,486,230	4006057500	17.00
450478	1,804,640,003,373,690	4006057500	18.00
476958	1,910,720,307,874,340	4006057500	19.00
503600	2,017,451,092,535,050	4006057500	20.00

By utilizing the results obtained above, the sea level rise is modelled by using the equation as below:

$\Delta D = (\beta)(D_i)(\Delta T)$ Eqn (9)

*Mean ocean depth (D_i) = 53.38 m

Upper 10% of ocean is most affected by initial mixing processes.

Therefore, Mean ocean depth (D_i) = 53.38 m x 0.10 = 5.38 m

The data are then calculated and tabled as table 5 below.

Table 7: Sea level rise based on rise of temperature in ocean

∆D,cm	**∆D,m**	**β**	**Di**	**∆T**
0.09	0.0009	0.0001719	5.338	1.00
0.14	0.0014	0.0001719	5.338	1.50
0.18	0.0018	0.0001719	5.338	2.00
0.23	0.0023	0.0001719	5.338	2.50
0.28	0.0028	0.0001719	5.338	3.00
0.32	0.0032	0.0001719	5.338	3.50
0.37	0.0037	0.0001719	5.338	4.00
0.41	0.0041	0.0001719	5.338	4.50
0.46	0.0046	0.0001719	5.338	5.00
0.50	0.0050	0.0001719	5.338	5.50
0.55	0.0055	0.0001719	5.338	6.00
0.64	0.0064	0.0001719	5.338	7.00
0.73	0.0073	0.0001719	5.338	8.00
0.83	0.0083	0.0001719	5.338	9.00
0.92	0.0092	0.0001719	5.338	10.00
1.01	0.0101	0.0001719	5.338	11.00
1.10	0.0110	0.0001719	5.338	12.00
1.19	0.0119	0.0001719	5.338	13.00
1.28	0.0128	0.0001719	5.338	14.00
1.38	0.0138	0.0001719	5.338	15.00
1.47	0.0147	0.0001719	5.338	16.00
1.56	0.0156	0.0001719	5.338	17.00
1.65	0.0165	0.0001719	5.338	18.00
1.74	0.0174	0.0001719	5.338	19.00
1.84	0.0184	0.0001719	5.338	20.00

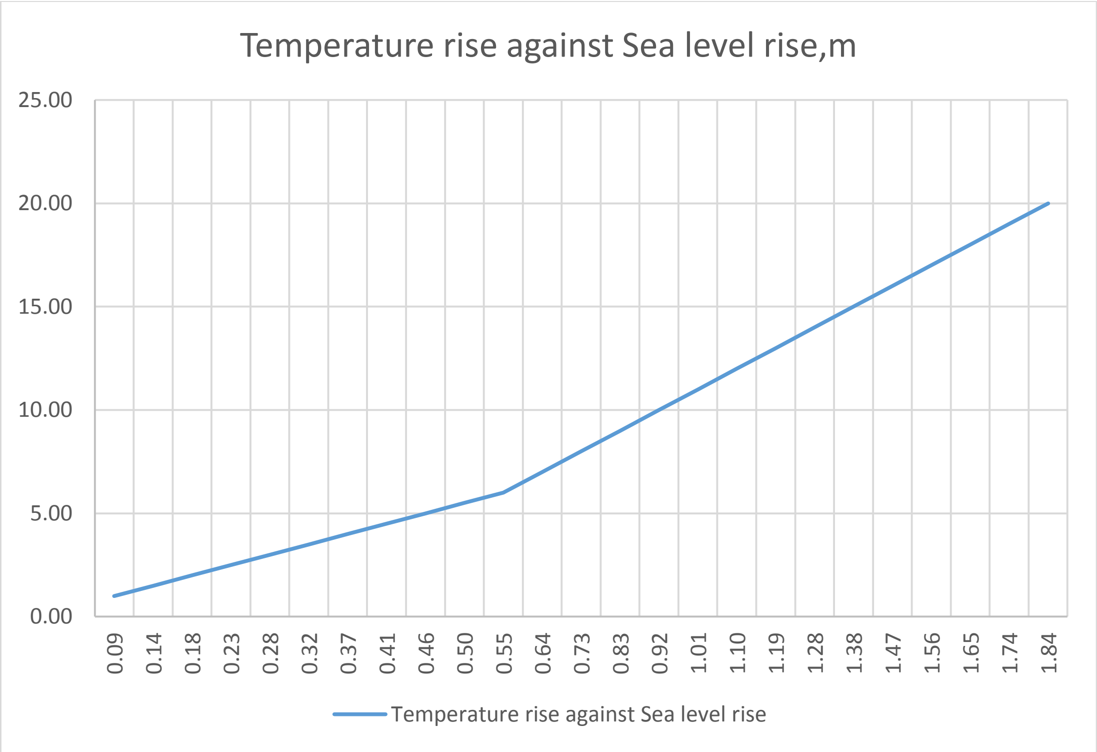


Figure 25: Temperature against sea level rise projection

Based on the model, a graph of temperature rise against sea level rise is plotted for analysis. The results calculated is then modelled in ArcGIS software to assess the impact of sea level rise to the coastal area in Malaysia.

Total population affected:

Indonesia = 140 per square km ("Population density (people per sq. km of land area) | Data | Table", 2016)

Malaysia = 91 per square km ("Population density (people per sq. km of land area) | Data | Table", 2016)

Average population of Malaysia and Indonesia = 116 per square km

Table 8: Population affected from projected Sea level rise

SLR	***Temperature rise***	***cell affected***	***Area flooded, m^2***	***Population affected***
0.04	*0.0000*	*0*	*0*	*0*
0.09	*0.0001*	*0*	*0*	*0*
0.13	*0.0001*	*0*	*0*	*0*
0.17	*0.0002*	*0*	*0*	*0*
0.25	*0.0002*	*0*	*0*	*0*
0.30	*0.0003*	*0*	*0*	*0*
0.35	*0.0003*	*0*	*0*	*0*
0.40	*0.0004*	*0*	*0*	*0*
0.45	*0.0004*	*0*	*0*	*0*
0.50	*0.0005*	*0*	*0*	*0*
0.75	*0.0007*	*0*	*0*	*0*
1.00	*0.0010*	*0*	*0*	*0*
1.25	*0.0012*	*0*	*0*	*0*
1.50	*0.0015*	*0*	*0*	*0*
1.75	*0.0017*	*0*	*0*	*0*
2.00	*0.0020*	*0*	*0*	*0*
2.50	*0.0025*	*0*	*0*	*0*
3.00	*0.0030*	*0*	*0*	*0*
3.49	*0.0035*	*0*	*0*	*0*
3.99	*0.0040*	*0*	*0*	*0*
4.49	*0.0045*	*0*	*0*	*0*
4.99	*0.0050*	*0*	*0*	*0*
0.5	*0.005*	*96340275*	*0*	*0*
0.6	*6*	*96340275*	*0*	*0*
1	*11*	*96511630*	*171355*	*19877*
1.5	*16*	*96511630*	*171355*	*19877*

2	*22*	*96798041*	*457766*	*53101*
3	*33*	*97184607*	*844332*	*97943*
4	*44*	*97655962*	*1315687*	*152620*
5	*54*	*98187430*	*1847155*	*214270*
6	*65*	*98767875*	*2427600*	*281602*
7	*76*	*99375364*	*3035089*	*352070*
8	*87*	*99991337*	*3651062*	*423523*
9	*98*	*10059860 8*	*4258333*	*493967*
10	*109*	*10117048 2*	*4830207*	*560304*

View of the coastal flooding is shown in figure 23 is converted to white for a clearer view.

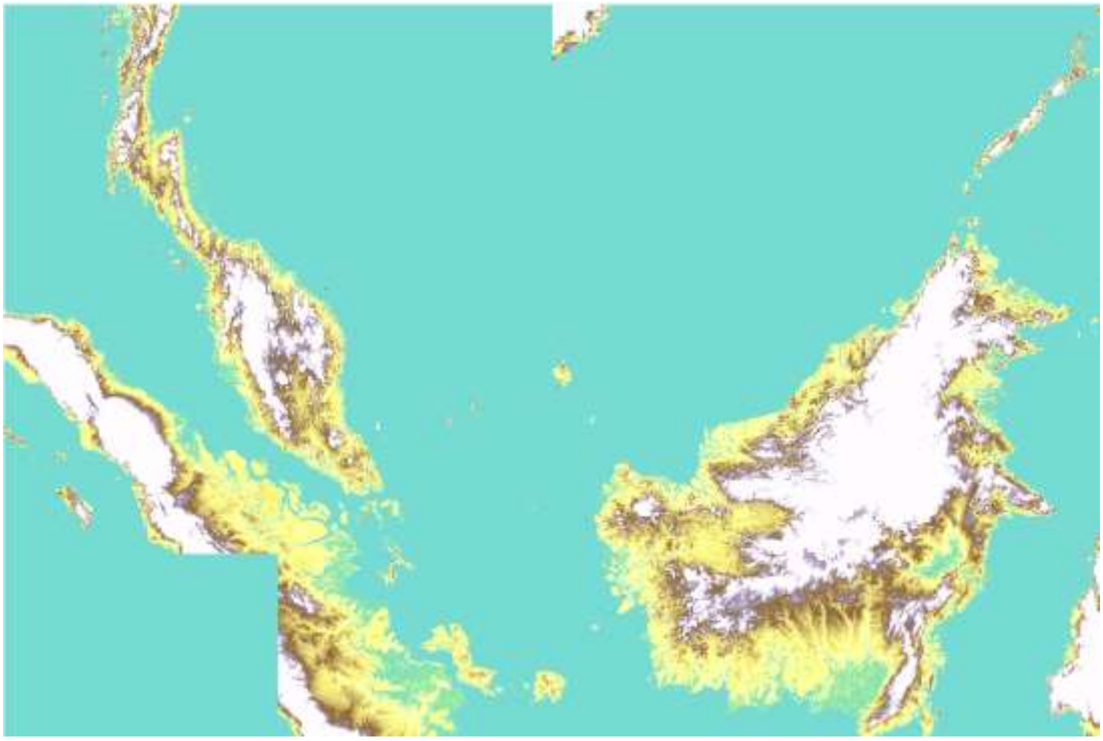


Figure 26: Malaysia Digital Elevation Map

Figure 27: Land in white view

In figure 25, is can be seen that certain area is affected from the sea level rise in Malaysia and Indonesia.

Figure 28:Projection of coastal flooding at 5 m.

Figure 29:Comparison of coastal flooding overview of 5 m Sea level rise

As seen in figure 26, the circled area are obviously displayed that Based on the cell affected, the total population affected are able to determine in this modelling. Table 7 below shows that the population affected in Peninsular Malaysia and Indonesia.

Table 9: Population affected from coastal flooding in west Malaysia and Indonesia

File name	**cell**	**Temp rise**	**SLR**	**Area flooded. m**	**Population affected**
rastercalc3/reclass16	96340275	0	0	0	0
rastercalc4/reclass17	96340275	6	0.55	0	0
rastercalc5/reclass18	96511630	11	1	171355	19877
rastercalc11 /reclass19	96511630	16	1.5	171355	19877
rastercalc19/reclass 20	96798041	22	2	457766	53101

rastercalc20 /reclass21	97184607	33	3	844332	97943
rastercalc 21/reclass22	97655962	44	4	1315687	152620
rastercalc22/reclass 23	98187430	54	5	1847155	214270
rastercalc23/reclass 24	98767875	65	6	2427600	281602
rastercalc24/reclass 25	99375364	76	7	3035089	352070
rastercalc25/reclass 26	99991337	87	8	3651062	423523
rastercalc26/reclass 27	100598608	98	9	4258333	493967
rastercalc27/reclass 28	101170482	109	10	4830207	560304

Table 10: Population affected from coastal flooding in Malaysia and Indonesia

File name	Temp rise	SLR	Area flooded	Population affected
raster 3	0	0	0	0
raster 6/ reclass4	1	0.09	0	0
raster 7/ reclass 5	2	0.18	0	0
raster 8/ reclass 6	3	0.28	0	0
raster9/reclass 7	4	0.37	0	0
raster10/reclass8	5	0.46	0	0
raster12/reclass9	6	0.55	0	0
raster13/reclass10	11	1.00	392448	45523.97
raster14/reclass11	16	1.50	392448	45523.97
raster15/reclass12	22	2.00	1128753	130935.35
raster16/reclass13	33	3.00	2343499	271845.88
raster17/reclass14	44	4.00	4166050	483261.80

raster18/reclass15	54	5.00	6484574	752210.58

Based on other research, it is projected that Peninsular Malaysia will have an estimated at 0.253 m to 0.517 m at the year 2100. Comparing with the results that we tabulated, it is projected at 0.5 m which it takes 132401 years to achieve. The percentage of impact that Melaka refinery is then calculated as following in table

Table 11: Comparison of years from overall and specific source

Source	Sea level rise	Projected	Years to reach projected year
Overall	0.5	2100	84
Melaka oil refinery	0.5	7,204,133	7202117

Contribution in sea level rise yearly = $\frac{84}{722117} \times 0.5$ = 5.83 × $^{10-6}$ mm

Percentage of contribution in sea level rise yearly = $\frac{84}{7202117} \times 0.5 \times 100\ \%$ = 0.0000583 %

Discussion

Sea level rise are occurring worldwide, and the main sources are from thermal expansion caused by CO_2. However, this research focuses on the carbon dioxide emission from oil refinery in Petronas Melaka oil refinery. Total carbon dioxide emission for a barrel of crude oil is at 40.65 $kgCO_2e$/barrel while the capacity of Melaka refinery production is 270,000 barrels daily. The total CO_2 emission annually is calculated at 4,006,057,500 $kgCO_2e$/ year.

By obtaining the total CO_2 emission yearly, the impact of sea level rise that this refinery plant imposed on can be modelled. By utilizing the specific heat capacity formula, the results are tabulated at its respective section. It would take approximately 23454 years in order to raise 1 °C of ocean in the straits of Malacca. This proved that the emission from oil refinery alone is not significant enough to cause a huge impact on coastal flooding. By taking 23454 years to reach 1 °C temperature raise which is 0.09 m in sea level rise. The projected impact of population for coastal flooding in the coastal area of Malaysia and Indonesia is 0 for the 0.09 m sea level rise. Significant impact is only seen when sea level rise to 1 m, which is a total of 11 °C temperature raise in ocean. This will affect approximately 19877 of people staying along the coastal area, however if coastal flooding includes Sabah and Sarawak the 1 m sea level rise will impact about 455024 people. With the Sea level rising up to 10 m, the model projected a total of affected population of 560304 for peninsular Malaysia and Indonesia. Contribution of sea level rise yearly compared in table 9 is 0.000322m and percentage of contribution is 0.0000583 % in the sea level rise, this value is not significant enough to cause an impact in future years.

This research focuses on only the carbon emission from oil refinery in one refinery plant to study the impact that it will cause. However, the rising temperature of the ocean is not only from this source but many other sources such as the manufacturing industry, combustion of cars and factories. GHGs emission such as methane and other components is also a source in contributing to the sea level rise. Future recommendation for this research is that to expand the scope from oil refinery to the combustion of cars and maybe including another greenhouse gas such as methane so that it can be comparable with CO_2. Furthermore, additional recommendation is that we can include other operational plant in the oil and gas industry.

5.0 Conclusion and recommendation

5.1 Conclusion

Thermal expansion of the ocean caused by anthropogenic emission especially CO_2. In this research from an oil refinery area. Based on the emission per barrel recorded at 40.65 kgCO_2e/barrel. With all the data acquired, the temperature and sea level rise of the ocean is tabulated. With the production of 270,000 barrels daily, total CO_2 emission annually is at 4,006,057,500 kgCO_2e/ year. With this a series of data is presented at the data sheet and assessment is made.

It would take approximately 23454 years in order to raise 1 °C of ocean in the straits of Malacca. This proved that the emission from oil refinery alone is not significant enough to cause a huge impact on coastal flooding. By taking 23454 years to reach 1 °C temperature raise which is 0.09 m in sea level rise. However, after modelling of coastal flooding in the coastline of Malaysia, impact is only seen at 1 m height of sea level rise.

With the rise of 1 m in sea level, population affected by coastal flooding is approximately 19877 people for peninsular Malaysia and Indonesia. In addition, the Modelling of coastal flooding which includes additional Sabah and Sarawak will impact about 4555024 people. But all of it will only happen in 269542 years based on figure 11. This result proved that the long year that it requires to impact the population in Malaysia and Indonesia is not viable and therefore it does not contribute largely to the current sea level rise issue that is happening globally. This is further proved by calculation that the contribution of sea level rise yearly compared in table 2 is 0.000322m and percentage of contribution is 0.0322 % in the sea level rise, this value is not significant enough to cause an impact in the near future years.

With concrete results, this research concludes that the impact of dissolved CO_2 in the ocean emitted from Melaka oil refinery does not contributes significant to the sea level rise problem we are currently facing as all it only takes is 0.0322 % in the sea level rise.

5.2 Future recommendation

Future recommendations for this thesis is that it can be considered other greenhouse gases such as methane and other factor which will affect the diffusivity of carbon dioxide such as the air -sea flux interaction. Another recommendation would also be to consider all refinery plant in Malaysia so study the impact of coastal flooding in Malaysia. Future research can also include other limiting factor such as the diffusivity of carbon dioxide in ocean, EL Nino and La Nina, wind factor, the effect of thermocline globally and also the mixing of ocean when carbon dioxide is dissolved into the ocean.

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Appendices

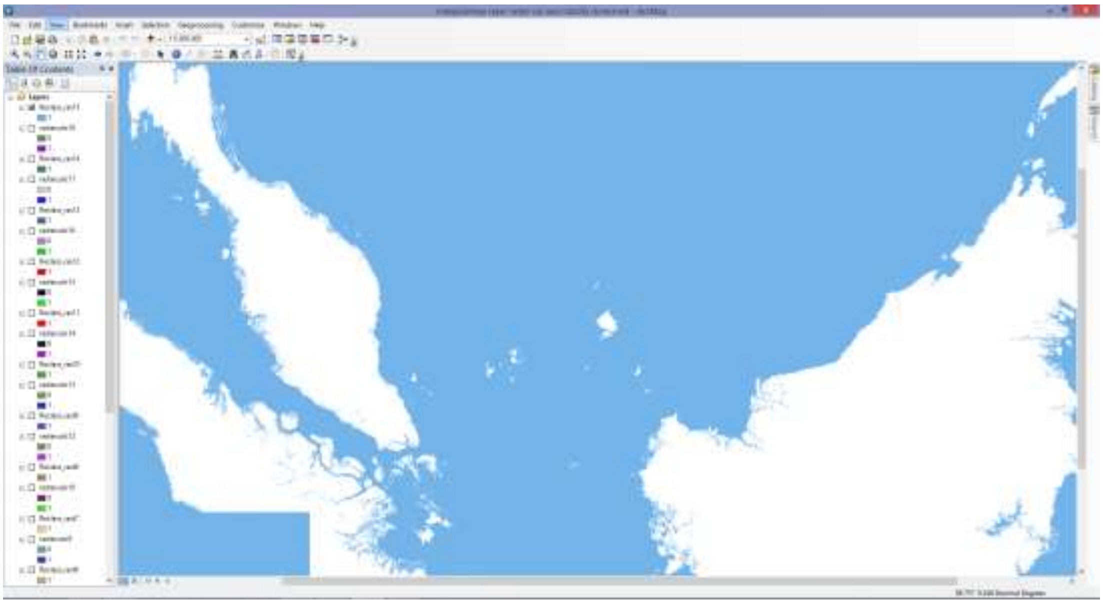

Figure 30: ArcGIS software spatial analyst simulation for Malaysia and Indonesia

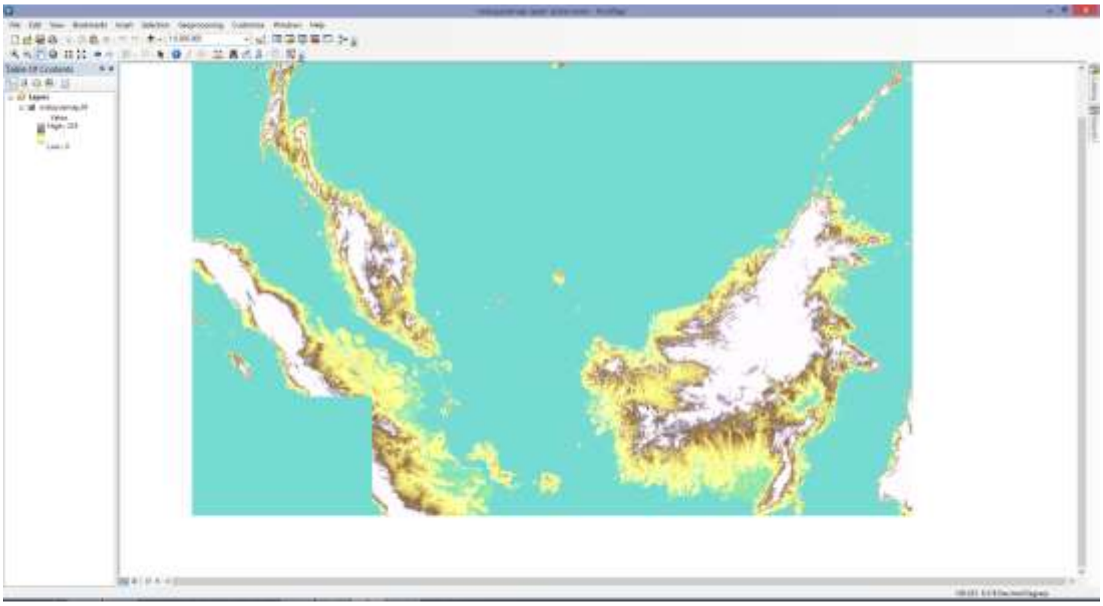

Figure 31: Digital Elevation Map of Malaysia and Indonesia

Table 12: Temperature needed of carbon dioxide to be emitted in order to raise certain temperature

ΔT	**T carbon dioxide**	**T f**	**T initial - ocean**	**T f– T initial ocean**	**C, carbon dioxide**	**C ocean**	**M, carbon dioxide**	**M, ocean**
4106356	4106385	30	29	1	844	3911	4006057500	3550000000000000
6159535	6159564	30	29	2	844	3911	4006057500	3550000000000000
8212713	8212742	31	29	2	844	3911	4006057500	3550000000000000
10265891	10265920	31	29	3	844	3911	4006057500	3550000000000000
12319069	12319098	32	29	3	844	3911	4006057500	3550000000000000
14372248	14372277	32	29	4	844	3911	4006057500	3550000000000000
16425426	16425455	33	29	4	844	3911	4006057500	3550000000000000
18478604	18478633	33	29	5	844	3911	4006057500	3550000000000000
20531782	20531811	34	29	5	844	3911	4006057500	3550000000000000
22584961	22584990	34	29	6	844	3911	4006057500	3550000000000000
24638139	24638168	35	29	6	844	3911	4006057500	3550000000000000