II. LITERATURE REVIEW

2.1 Carbon Cycle

Carbon is exchanged between atmosphere and the ocean by physical and chemical process. Human activities are involved with global carbon cycle. In particular, human activities create two new flux of carbon released to atmosphere. When forests are cleared for timer production or agricultural process, some of the carbon stored in the trees and soil is released to the atmosphere. Fossil fuel contained carbon molecule. The burning of fossil fuel for automobile and industrial uses released a several giga ton of carbon per year to the atmosphere. Figure 2.1 show the diagram of carbon cycle, at right side of the figure indicates a natural production of carbon cycle and left side indicates human activities involved to the carbon cycle.

(Source: http://esd.ornl.gov)

Figure 2.1 Global diagram of carbon cycle

Based on the data from Intergovernmental Panel on Climate Change (IPCC, 2001), CO₂ concentration in the atmosphere increase rapidly becomes 367 in 1999. Based on the data recorded and model prediction that has developed,
IPCC (2001) predicted that the concentration of CO$_2$ in the atmosphere will increase 540 – 970 ppm in the beginning of 22 centuries (year 2100). Various sources may account for the excess of CO$_2$ in the atmosphere, especially fossil fuel burning. The input of fossil CO$_2$ due to fossil fuel burning and cement production is now about 5 x $10^{15}$ gC year$^{-1}$.

In order to control the global carbon balance in the atmosphere, forestry sector have the important key. Indonesia is one of the countries with large area of tropical rain forest that have capabilities as carbon sink. Tropical forest is the biggest carbon sink (Lloyd et al. 1995; Malhi et al., 2000), with carbon stock reach 254 MgCha$^{-1}$ and NPP 1560 gCm$^{-2}$ year$^{-1}$. The increasing need of forest product every year should be follow with the other activity to control the carbon balance in the atmosphere and one example of activity to control the carbon balance in the atmosphere is reforestation activity at disturbed areas.

### 2.2 Net Primary Production

As a major part of terrestrial ecosystems, vegetation plays an important role in the energy, matter, and momentum exchange between the land surface and the atmosphere. Through the process of photosynthesis, plants assimilate carbon in the atmosphere and incorporate it into the biomass, and part of the carbon is emitted into the atmosphere again through plant respiration (autotrophic respiration). The difference between photosynthesis and autotrophic respiration is the net primary productivity (NPP).

Vegetation also acts as a source or sink, for the greenhouse gas CO$_2$. Net primary productivity (NPP) is an important component of the carbon cycle and a key indicator of ecosystem performance. NPP includes maintenance and growth respiration costs to the plant and the net assimilation of atmospheric CO$_2$ into organic matter. NPP is driven by solar radiation and can be constrained by light, precipitation and temperature (Field et al., 1995).

Net primary production is the difference between total photosynthesis (Gross Primary Production) and total plant respiration in an ecosystem. In the
field, however, NPP cannot be assessed in terms of this difference. An alternative definition of NPP is the total organic matter produced over a given interval. Although this production cannot be directly measured because of transformations such as consumption and decomposition during the measurement interval, it can be estimated based on a suite of diverse measurements and underlying assumptions. It is conceptually useful, therefore, to define the quantity NPP as the field-measurement-based, operational estimate of actual NPP (Clark et al. 2001).

NPP comprises all materials that together represent: (1) the amount of new organic matter that is retained by live plants at the end of the interval, and (2) the amount of organic matter that was both produced and lost by the plants during the same interval. In forests, these materials are: aboveground biomass increment, fine litter fall, aboveground losses to consumers, emissions of biogenic volatile organic compounds (BVOCs), aboveground losses of leached organic compounds, net increments in biomass of coarse and fine roots, dead coarse and fine roots, root losses to consumers, root exudates (Clark et al. 2001).

Net primary productivity (NPP) is defined as the net flux of carbon from the atmosphere into green plants per unit time. NPP refers to a rate process, i.e., the amount of vegetable matter produced (net primary production) per day, week, or year. However, the terms net primary productivity and net primary production are sometimes used rather liberally and interchangeably, and some scientists still tend to confuse productivity with standing biomass or standing crop. NPP is a fundamental ecological variable, not only because it measures the energy input to the biosphere and terrestrial carbon dioxide assimilation, but also because of its significance in indicating the condition of the land surface area and status of a wide range of ecological processes.

### 2.3 Distribution of Net Primary Production

Humans are changing the natural rate of exchange of carbon between the atmosphere and the terrestrial biosphere through land use, land-use change, and forestry activities. Consequently, it is important to examine how carbon flows
between different pools and how carbon stocks change in response to afforestation, reforestation, and deforestation (ARD) and other land-use activities. Distribution of NPP can be in any place in the world, i.e. forest, agricultural, wetland, urban areas which will have different rate in NPP and carbon sequestration. Changes in the proportion and spatial distribution of land use could enhance or degrade the area’s ability to sequester carbon in terrestrial ecosystem.

Figure 2.2 shows the global, annual average net primary production of vegetation on land during January to February 2010. On this map, vegetation is pictured as a scale or index of greenness. Greenness is based on several factors: the number and type of plants, how leafy they are, and how healthy they are. In places where foliage is dense and plants are growing quickly, the index is high, represented in dark green. Regions where few plants grow have a low vegetation index, shown in tan. The pattern that the maps show is a global one, vegetation greenness is high around the equator all year long, where temperatures, rainfall and sunlight are abundant. Between the equator and the poles, the vegetation greenness rises and falls as the seasons change.

2.4 Estimation Method of Net Primary Production

Many models have been established to estimate regional and global NPP and can be classified into three types: climate models, process models, and energy use efficiency models. Climate models estimate NPP by establishing the statistical
relation between NPP and climate data. Process models estimate NPP based on plant physiological and ecological processes. Energy use efficiency models use energy use efficiency and the relationship between vegetation index and FPAR to estimate radiation absorbed by plants to estimate NPP. Because an energy use efficiency model is simple and uses remotely sensed data, it is widely used.

Net primary productivity (NPP) is defined as the net flux of carbon from the atmosphere into green plants per unit time or the total new organic matter produced during a specified interval. This production is only conceptualized because they cannot measure directly in the field. Instead, NPP must be estimated based on a suite of measurement of various types and numerous underlying assumptions.

As documented in Potter (1999), the monthly NPP flux, defined as net fixation of CO2 by vegetation, is computed in NASA Carnegie Ames Stanford Approach (CASA) on the basis of light-use efficiency (Monteith, 1972). Monthly production of plant biomass is estimated as a product of time-varying surface solar irradiance ($S_r$) and EVI from the MODIS satellite, plus a constant light utilization efficiency term ($e_{\text{max}}$) that is modified by time-varying stress scalar terms for temperature ($T$) and moisture ($W$) effects.

The equation for estimation monthly NPP values is:

$$NPP = S_r \cdot EVI \cdot e_{\text{max}} \cdot T \cdot W$$ ................................................................. (1)

Where:

- $NPP$ = Net primary production (gC m$^{-2}$year$^{-1}$)
- $S_r$ = Solar irradiance
- $EVI$ = Enhanced Vegetation Index from MODIS
- $e_{\text{max}}$ = Constant Light Utilization Efficiency Term
- $T$ = Optimal temperature for plant production
- $W$ = Monthly water deficit
2.5 Vegetation Indices

The vegetation index is an empirical measure of vegetative cover. In the area of applications and research in satellite remote sensing, dozens of vegetation indices have been developed for different requirements. Vegetation Indices (VI) are optical measures of vegetation canopy ‘greenness’, a direct measure of photosynthetic potential resulting from the composite property of total leaf chlorophyll, leaf area, canopy cover, and structure. VI’s are widely used as proxies in estimating canopy state variables (leaf area index, fraction of absorbed photosynthetically-active radiation, chlorophyll content, vegetation fraction) and canopy biophysical processes (photosynthesis, transpiration, net primary production). The Vegetation Index includes the Normalized Difference Vegetation Index (NDVI) and an Enhanced Vegetation Index (EVI) at coarse (~5-8km) and moderate (~250m -1km) resolutions to effectively characterize ecosystem states and processes for long-term climate change and near real-time operational applications.

The first use of multi-temporal AVHRR NDVI to monitor the dynamics of vegetation at the continental and global scales was in 1985. Tucker et al. (1985), found the differences in temporal dynamic of vegetation reflected by NDVI are associated with variations in climate and dependent on biome types, and that the integrated NDVI over a given time interval is related to NPP.

Goward et al. (1985) was the first demonstrated of linear relationship between the growing seasons integrated with NDVI and ground-based observations of NPP for different biomes over North America. In the following year, Fung et al. (1987) was the first study to relate NDVI to annual NPP at the global scale, to study atmosphere-biosphere exchange of CO2 and to study simply distributed annual NPP into monthly level based on the monotonic function of monthly NDVI, without considering solar radiation or environmental stresses.

Satellite monitoring of vegetation phenology has often made use of a vegetation index such as NDVI because it is related to the amount of green leaf biomass. Annual time series of NDVI data from AVHRR, for example, have been used to estimate the onset of leaf development in relation to inter annual
variations in average global air temperature for the past twenty years (Tucker et al., 2001).

Although NDVI provides researchers with a way to monitor vegetation, the sensitivity of NDVI to background reflectance and the tendency of NDVI to saturate at high leaf area may limit the use of this technique across a variety of vegetation types (Huete et al., 2002). Recent efforts have focused on improved methods for calculating specific dates of vegetation phenological transitions using improved satellite data products e.g., MODIS–EVI/LAI.

The Normalized Different Vegetation Index (NDVI) was calculated from reflectance in the Near Infrared ($\rho_{\text{Nir}}; 841$-$876$ nm) and red ($\rho_{\text{RED}}; 620$-$670$ nm) wavelength. The equation as below:

$$ \text{Equation (2)} $$

The Enhanced Vegetation Index (EVI) is often employed as an alternative to NDVI because it is less sensitive to these limitations, but requires information on reflectance in the blue wavelengths, which is not available on some satellites and is difficult to extract from broadband radiation measurements.

A few remote sensing studies have explored the combination of blue, red, and near infrared (NIR) bands for development of improved vegetation indices that are related to vegetation greenness (Huete et al. 1997 and Gobron et al. 2000). The main requirement of a vegetation indices is to combine the chlorophyll absorbing red spectral region with spectral region with the non absorbing, leaf reflectance signal in the near – infrared (NIR) to provide a consistent and robust measure of area-averaged canopy photosynthetic capacity.

The enhanced vegetation index (EVI) is an ‘optimized’ vegetation index with improved sensitivity in high biomass regions and an improved vegetation monitoring characteristic via a decoupling of the canopy background signal and a reduction in atmospheric influences, and it is calculated from (Huete et al., 1997).

The equation for as below:

$$ \text{Equation (3)} $$
Where:

\[ EVI = \text{Enhanced vegetation index} \]
\[ G = \text{Gain factor} \ (2.5) \]
\[ NIR = \text{Near infrared and } \rho_{\text{Red}} - \rho_{\text{Blue}} \text{ is the red/blue reflectance} \]
\[ C1 \ C2 = \text{Atmospheric resistance red and blue correction coefficients are} \ (1 \text{ and } 6.0) \]
\[ L = \text{The canopy background brightness correction factor is } 7.5 \]

2.6 Light utilization efficiency, Temperature and Water

The \( \epsilon_{\text{max}} \) term is set uniformly at 0.39 g C MJ-1 PAR, a value that derives from calibration of predicted annual NPP to previous field estimates (Potter et al., 1993). \( T_{\text{scalar}} \) is computed with reference to derivation of optimal temperatures \( (T_{\text{opt}}) \) for plant production. \( T_{\text{opt}} \) setting will vary by latitude and longitude, ranging from near 0°C in the Arctic to the middle thirties in low-latitude deserts. \( W_{\text{scalar}} \) is estimated from monthly water deficits, based on a comparison of moisture supply (precipitation and stored soil water) to potential evapotranspiration (PET).

\( T_{\text{scalar}} \) is estimated using the equation developed for the terrestrial ecosystem model (Raich, J.W. et al, 1991). The equation for \( T_{\text{scalar}} \) as below:

\[
\text{----------------------------------------} \quad \text{----------------------------------------} \quad (4)
\]

Where \( T_{\text{min}} \), \( T_{\text{max}} \) and \( T_{\text{opt}} \) are minimum, maximum and optimal temperature for photosynthesis, respectively. When air temperature falls belows \( T_{\text{min}} \), \( T_{\text{scalar}} \) is set to 0.

\( W_{\text{scalar}} \) is the effect of water deficit on plant photosynthesis, has been estimated as a function of rainfall, run off, groundwater reserves and potential evapotranspiration and potential evapotranspiration. The equation for \( W_{\text{scalar}} \) as below:

\[
\text{----------------------------------------} \quad \text{----------------------------------------} \quad (5)
\]
Where EET and PET is potential evapotranspiration estimation and, with Wscalar ranged between 0.5 (dry) to 1 (wet).

Therefore, the barrier function in $W_{\text{scalar}}$ can be described as below:

$$\text{.......................................................... } (6)$$

Where, PPT is the total of precipitation. Meanwhile, water run-off, and groundwater reserves are ignored. Meanwhile, PET is calculated based on the Priestley and Taylor (1972) with the equation as below:

$$\text{.......................................................... } (7)$$

Where, $R_n$ is the net-radiation (MJ m-2 day-1), $G$ is the heat flux at ground level, with the assumption of 0, $\delta$ is the psychometric constant with a value of about 66 Pa K-1. And $\lambda$ row is the latent heat of evaporation of 2.5 mm MJ-1 and the empirical factor of 1:26. While $\text{...............................}$, is calculated using a mathematical equation as follows:

$$\text{................................. } (8)$$

Where $\text{..................}$ is the slope vapor pressure curve (kPa °C-1), air temperature $T$ (°C).

### 2.7 Photosynthetically Active Radiation (PAR)

Along with the above studies to directly relate vegetation indices to NPP and the carbon cycle, additional studies were conducted to develop the physiological linkage between EVI and NPP. Professor Monteith was the pioneering scientist who proposed the concept of photosynthesis efficiency logic. Monteith (1972) found that crop production under non-stressed conditions is linearly related to the amount of photosynthetically active radiation solar radiation (PAR) that is absorbed by green leaf (APAR). Leaf and canopy photosynthesis is one of the key processes of the carbon cycle in the terrestrial ecosystems and requires photosynthetically active radiation (PAR), CO2, water,
and nutrients. Vegetation canopies intercept various amounts of PAR over the plant-growing season because of differences in leaf types and seasonal dynamics of leaf phenology, i.e., leaf flush, leaf expansion, leaf fall (Xiao, 2006).

In the term of plant physiology process, there is a parameter called $f_{\text{PAR}}$ (fraction of absorbed photosynthetically active radiation). This parameter is the fraction between APAR and PAR. $f_{\text{PAR}}$ have linear relationship with NDVI value. Vegetation type and climate condition have influence the gradient of linear relationship between $f_{\text{PAR}}$ and NDVI (Sugiarto, 2005).

Ruimy et al. (1994) introduced relationship between $f_{\text{PAR}}$ and NDVI with equation as:

$$f_{\text{PAR}} = 1.25 \times NDVI - 0.025 \quad \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots (9)$$

Other research for production forest in Australia (Prince and Goward, 1996) found the relationship equation as:

$$f_{\text{PAR}} = 1.67 \times NDVI - 0.08 \quad \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots (10)$$

Dye and Hooda (1996) found relationship between $f_{\text{PAR}}$ and NDVI using NOAA-AVHRR data for forest vegetation in India with equation as:

$$f_{\text{PAR}} = 1.9 \times NDVI - 0.31 \quad \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots (11)$$

Leaf and forest canopies are composed of photosynthetically active vegetation (PAV, chloroplasts) and non-photosynthetic vegetation (NPV, mostly senescent foliage, branches, and stems). Photosynthetic activity of vegetation canopy is in part determined by the amount of PAR absorbed by PAV for photosynthesis. This version of the vegetation photosynthesis model, $f_{\text{PAR}_{\text{PAV}}}$ within the photosynthetically active period of vegetation is estimated as a linear function of EVI, and the coefficient $a$ is set to be 1.0 (Xiao, 2006). The $f_{\text{PAR}_{\text{PAV}}}$ which can be estimated using equation as:

$$f_{\text{PAR}_{\text{PAV}}} = a \times EVI \quad \cdots \cdots \cdots \cdots \cdots \cdots \cdots \cdots (12)$$
2.8 Remote Sensing System and MODIS Data

Solar radiation in the wavelength interval between 400 and 700 nm provides the energy for photosynthesis and this information can be used for estimating NPP of plants. NPP of forest has been calculated from annual sum of daily photosynthetic absorbed in radiation and the radiation use efficiency of different plant species.

Remote sensing technology approach can also used in relatively simple modeling framework to estimate global NPP of terrestrial vegetation using the relationship between reflectance properties and absorption of photosynthetically active radiation, if net conversion efficiencies can be approximated or assumed nearly constant (Ruimy et al. 1994). As a result, the efficiency with which canopy PAR absorption is covered to dry matter (biomass) has become the subject of much recent research.

Remote sensing is the science and art of obtaining information about an object, area, or phenomenon through the analysis of data required by a device that is not it contact with the object, area or phenomenon under investigation (Lillesand and Kiefer, 1994). Remote sensing is one of the methods of spatial data acquisition, which are based on the use of image data acquired by a sensor such aerial cameras, scanners or radar. Taking a remote sensing approach means that the information is derived from the image data, which from a (limited) representation of the real world (Jansen, 2000).

In principle, remote sensing system could measure energy emanating from the earth’s surface in any sensible range of wavelengths. However technological considerations, selective opacity of the earth atmosphere, scattering from atmospheric particulates and the significance of the data provided exclude certain wavelength. The major length utilized for earth resources sensing are between about 0.4 and 12µm as the visible/infrared range and the between about the 30 to 300 mm as microwave range. Under controlled condition, remote sensing can provide fundamental biophysical data, including: x, y location, z elevation or depth, biomass, temperature, moisture content, etc (Jensen, 2000).
Remote sensed data are collected using either passive or active remote sensing systems. Passive sensor is record naturally occurring electromagnetic radiation that is reflected or emitted from the surface. For example, cameras and video recorders may be used to record visible and near infrared energy reflected from the surface, and a multispectral scanner may be used to record the amount of thermal radiant flux emitted from the surface. Active sensors such as microwave (radar) measure the surface using man-made electromagnetic energy and the record the amount of radiant flux scattered back toward the sensor system.

Remote sensing can provide information on two different classes of variables, which area biophysical and hybrid. Biophysical variables may be measured directly by the remote sensing system. This means that the remotely sensed data can provide fundamental biological and/or physical information directly, without having to use others surrogate or ancillary data. For example, a thermal infrared sensor can record the apparent temperature of a rock outcrop by measuring the radiant flux emitted from its surface. Similarly, it is possible to conduct remote sensing in a very specific region of the spectrum and identify the amount of water vapor in the atmosphere. The second groups of variables that may be remotely sensed include hybrid variables, created by systematically analyzing more than one biophysical variable. For example, by remotely sensing a plant’s chlorophyll absorption characteristic, temperature, and moisture content, it may be possible to model these data to detect vegetation stress, a hybrid variable (Jensen, 2000).

MODIS might be so far, the most complex instrument built and flown on a spacecraft for civilian research purposes. The MODIS sensor provides higher quality data for monitoring terrestrial vegetation and other land processes than the previous AVHRR, not only because its narrower spectral bands that enhance the information derived from vegetation (Justice, et al., 2002).
Table 2.1. MODIS Instrument and specification

<table>
<thead>
<tr>
<th>Primary Use</th>
<th>Band</th>
<th>Bandwidth</th>
<th>Spectral Radiance</th>
<th>Required SNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land/Cloud/Aerosols Boundaries</td>
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<td>620 - 670</td>
<td>21.8</td>
<td>128</td>
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<td></td>
<td>2</td>
<td>841 - 876</td>
<td>24.7</td>
<td>201</td>
</tr>
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<td>35.3</td>
<td>243</td>
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<tr>
<td></td>
<td>4</td>
<td>545 - 565</td>
<td>29.0</td>
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<td></td>
<td>5</td>
<td>1230 - 1250</td>
<td>5.4</td>
<td>74</td>
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<td>6</td>
<td>1628 - 1652</td>
<td>7.3</td>
<td>275</td>
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<tr>
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<td>2105 - 2155</td>
<td>1.0</td>
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<td>438 - 448</td>
<td>41.9</td>
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<td>483 - 493</td>
<td>32.1</td>
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<td></td>
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<td>21</td>
<td>3.929 - 3.989</td>
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<td>36</td>
<td>14.085 - 14.385</td>
<td>2.08(220K)</td>
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</table>
The MODIS (Moderate-resolution Imaging Spectroradiometer) is a sensor onboard the NASA Terra satellite, launched in December 1999. There are 36 spectral bands in the MODIS sensor, seven spectral bands are primarily designed for the study of vegetation and land surface: blue (459–479 nm), green (545–565 nm), red (620–670 nm), near infrared (841–875 nm, 1230–1250 nm) and shortwave infrared (1628–1652 nm, 2105–2155 nm). Table 2.1. Show the spectral band and primary use of MODIS System.

The MODIS sensor acquires daily images of the globe at a spatial resolution of 250 m for red and near infrared (841–875 nm) bands, and at a spatial resolution of 500 m for blue, green, near infrared (1230–1250 nm) and shortwave infrared bands. Raw MODIS data stream could be received in real-time using a tracking antenna, and for alternatively, the scientific data is made available to the public via several World Wide Web sites.

The NASA Goddard Earth Sciences Distributed Active Archive Center (GES DAAC), known as GSFC-ECS in the Earth Observing System Data Gateway, distributes three major groups of MODIS products: Level 1 Radiometric and Geolocation data, and Level 2 and higher level of Atmosphere and Ocean products. Most MODIS data from GES DAAC are provided as Hierarchical Data Format-Earth Observing System (HDF-EOS) files. MODIS Level 1 and 2 data are 5-min “Swath” granules, while Level 3 are global “Grid” maps. Only Ocean Level 3 binned and all Level 4 (primary productivity) data are in the native HDF4 format. Depending on the science product, the spatial resolutions of Level 2 data vary from 1 to 10 km. Correspondingly, Levels 3 and 4 products are available in various spatial and temporal resolutions, ranging from 4.63 km to 1°, and from one day to a year. The MODIS product names start with “MO” and “MY” for Terra and Aqua products, respectively.

All MODIS land products are reprojected on the Integerized Sinusoidal (IS) 10-degree grid, where the globe is tiled for production and distribution purposes into 36 tiles along the east-west axis, and 18 tiles along the north-south axis, each ca 1200x1200 kilometers.
An illustration of the 10-deg grid used in MODIS land production is shown below. The color coding is as follows: land tiles with land products generated regularly are shown in Green (286 tiles globally), land tiles with land products not generated are in Orange, ocean tiles are in Blue, and tiles with only sea-ice product generated are in Pink. Figure 2.3 shown MODIS Tile Projection Characteristics.

![MODIS Tile Projection Characteristics](http://modis.gsfc.nasa.gov/)

**Figure 2.3 MODIS tile projection characteristic**

### 2.9 Climatic Variability

The term "climate variability" is often used to denote deviations of climate statistics (average weather conditions or distribution of weather events) over a given period of time (such as a specific month, season or year) from the long-term climate statistics relating to the corresponding calendar period. Climatic variability and climatic change can also change the amount of carbon held on land. Year-to-year variation in temperature and precipitation, in affecting rates of photosynthesis and respiration, is thought to be the major factor responsible for large year-to-year variation in the growth rate of atmospheric CO2. Rates of photosynthesis, plant respiration, decomposition, and fire frequency are affected by climatic factors such as sunshine, temperature and rainfall. Inter-annual
variations in climate cause most of the inter-annual variation in the strength of the land carbon sink (Houghton, 2002).

El Niño and La Nina are terms that many people have heard once or twice, especially in reference to abnormal weather conditions, but many do not fully understand what these phenomena are. ENSO, more commonly known as El Nino, is a climate event that occurs every three to seven years. It is caused by a rise in temperature of the Pacific Ocean as well as a change in surface pressure. Predicting when the next ENSO event is going to occur can be difficult, but there are a number of early warning signs, such as an increased surface pressure above the Indian Ocean (Wikipedia, 2010). Figure 2.4 show the historical data of ENSO years occurred in world region.

In particular, El Nino events are associated with high temperatures and droughts in many tropical regions and have contrasted effects on precipitation regimes in different world regions, either increasing or decreasing rainfall. In the western coastal regions of the Americas, an ENSO event is associated with increased precipitation. The effects of an ENSO event can be seen across the world, with floods, droughts, and other weather events. Extreme changes in weather and climate patterns can also affect local trade and industries in many countries.