CHAPTER 2

THEORY

2.1 Climate and the climate system [22]

Climate is usually defined as the “average weather”, or more rigorously, as the statistical description of the weather in terms of the mean and variability of relevant quantities over periods of several decades. These quantities are most often surface variables such as temperature, precipitation, and wind, but in a wider sense the “climate” is the description of the state of the climate system. The climate system consists of the following major components: (a) the atmosphere; (b) the oceans; (c) the terrestrial and marine biospheres; (d) the cryosphere (sea ice, seasonal snow cover, mountain glaciers and continental scale ice sheets); and (e) the land surface. These components interact with each other, and through this collective interaction, determine the Earth’s surface climate. These interactions occur through flows of energy in various forms, through exchanges of water, through flows of various other radiatively important trace gases, including CO2 (carbon dioxide) and CH4 (methane), and through the cycling of nutrients. The climate system is powered by the input of solar energy, which is balanced by the emission of infrared (“heat”) energy back to space. Solar energy is the ultimate driving force for the motion of the atmosphere and ocean, the fluxes of heat and water, and of biological activity. Figure

1.1 presents a schematic picture of the climate system, showing some of the key interactions between the various components and the component properties which can change

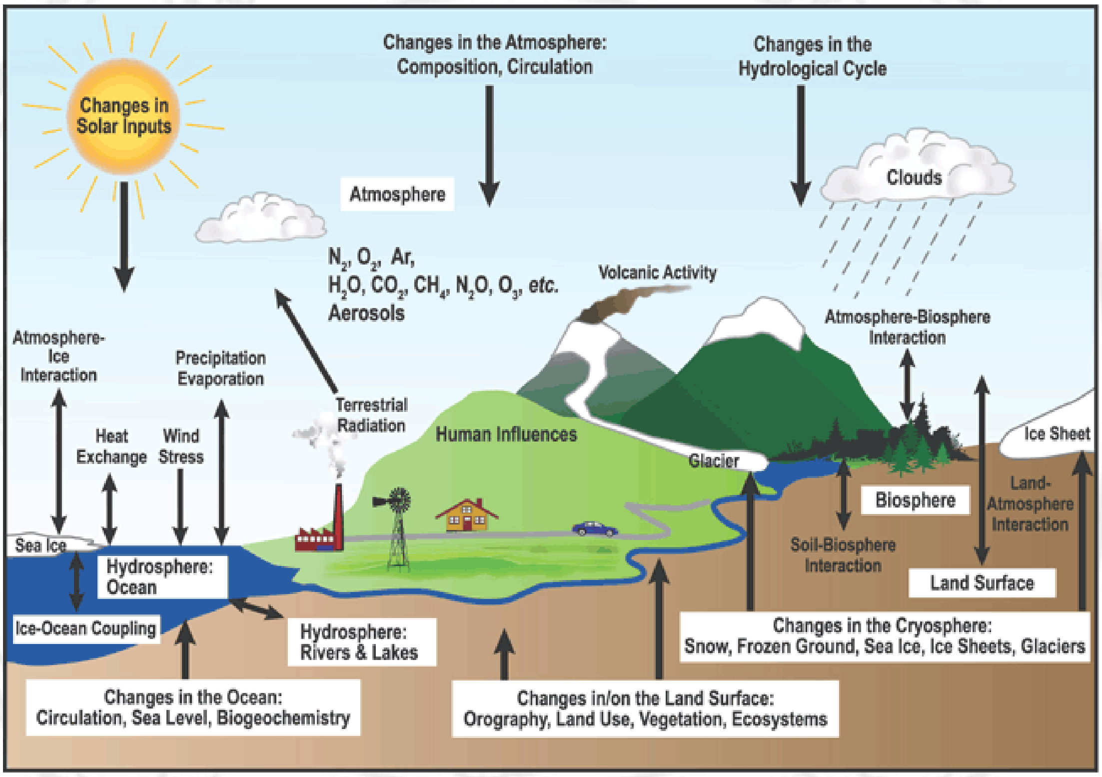

Figure 2.1 Schematic overview of the components of the global climate system that are relevant to climatic changes on the century time-scale (bold), their processes and interactions (thin arrows) and some elements that may change (bold arrows) [from FAQ 1.2, Figure 1 [1]]

The behavior of the atmosphere is prescribed by the basic laws of hydrodynamics and thermodynamics which concern the following principles: [23,24]

1. The conservation of mass and of water substance.
2. The 1st law of thermodynamics.
3. Newton's 2nd law of thermodynamics.

These principles form a coupled set of relations that must be satisfied simultaneously and that include sources and sinks in the individual expressions.

Using pressure (P) as the vertical coordinate, the momentum equation can be written:

$$\frac{\partial \vec{V}}{\partial t} = -\vec{V} g \vec{\nabla}\vec{\mathrm{V}} - \frac{\partial \vec{\mathrm{V}}}{\partial \mathrm{P}} + \mathrm{f}\hat{\mathrm{k}} \times \vec{\mathrm{V}} - \vec{\nabla}\Phi + \vec{\mathrm{D}}_{\mathrm{M}} \tag{1}$$

where $\vec{V}$ is the horizontal velocity, f = Coriolis parameter, $\hat{k}$ is a unit vector, $\vec{\nabla}$ is the gradient operator, $\Phi = gz$ is the geopotential and $\vec{\mathrm{D}}_{\mathrm{M}}$ is the dissipation of momentum by friction.

The expanded equations for the zonal and meridional components of motion are:

$$\frac{du}{dt} - \left(f - u\frac{tan\varphi}{r}\right)v = -\frac{1}{rcos\varphi}\frac{1}{\rho}\frac{\partial P}{\partial \lambda} + F_{\lambda} \tag{2}$$

$$\frac{dv}{dt} + \left(f + u\frac{tan\varphi}{r}\right)u = -\frac{1}{\rho}\frac{\partial P}{\partial \varphi} + F_{\varphi} \tag{3}$$

$$\frac{d}{dt} = \frac{\partial}{\partial t} + \frac{u}{rcos\varphi}\frac{\partial}{\partial \lambda} + \frac{v}{r}\frac{\partial}{\partial \varphi} + w\frac{\partial}{\partial z} \tag{4}$$

where λ = longitude, φ = latitude, ρ = air density, P =pressure, r = the Earth's radius , F_{λ}, F_{φ} are the zonal and meridional components of friction, and u, v, w are scalar components of velocity in Cartesian coordinates. (positive u, v and w correspond to winds moving from west to east, south to north, and lower to higher elevation, respectively) The mass continuity equation is:

$$\vec{\nabla} g \vec{V} + \frac{\partial \omega}{\partial P} = 0 \tag{5}$$

where ω = vertical velocity in pressure coordinates = $\frac{dP}{dt}$. The equation for continuity of water substance is:

$$\frac{\partial q}{\partial t} = -\vec{V}g\vec{\nabla}q - \omega\frac{\partial q}{\partial P} + E - C + D_q \tag{6}$$

where q = specific humidity, E = evaporation, C = condensation and D_q is the diffusion of moisture.

The thermodynamic equation is:

$$\frac{\partial T}{\partial t} = -\vec{V}g\vec{\nabla}T + \omega\left(\frac{\kappa T}{P} - \frac{\partial T}{\partial P}\right) + \frac{R_n}{c_P} + \frac{LE}{c_P} + D_H \tag{7}$$

where T =temperature

κ = 0.286,

c_P = the specific heat at constant pressure and

D_H = the diffusion of heat.

The term R_n = net radiation, LE = latent heat of evaporation, C = condensation, and the diffusion components are determined from equations for radiative transfer through the atmosphere, for the processes of evaporation/ condensation and precipitation, and for the turbulent transfers of heats, momentum, and moisture from the surface.

The above equations contain time derivatives of the independent variables and so are prognostic. In addition, there is the diagnostic equation for hydrostatic equilibrium:

$$\frac{\partial P}{\partial q} = -g\rho \tag{8}$$

which, combined with the ideal gas equation, $P = R\rho T$ (R = gas constant) gives:

$$\frac{\partial P}{\partial z} = -\frac{gP}{RT} \tag{9}$$

The above equations are known as "primitive equations" which are the fundamental equations of the atmosphere.

2.2 Modeling the climate system [25]

Climate change models allow the simulation of the effects of the buildup of greenhouse gases centuries into the future, based on current understanding of atmosphere physics and chemistry. The tropical horizontal resolution of a global climate model is about 100-200 km. combining global and regional models allows finer-scale examination of regional details of change to horizontal resolutions of 10-50 km.

The Global climate results from interactions between many processes in the atmosphere, ocean, land surface and cryosphere (snow, ice and permafrost) [figures 3]. The interactions are complex and extensive, so that quantitative predictions of the impact on the climate of greenhouse gas increases cannot be made just through simple intuitive reasoning. For this reason, computer models called Global Climate Model (GCMs) have been developed which try to mathematically simulate the climate, including the interaction between the component systems.

The essence of an atmospheric GCM is that the basic equations describing the atmosphere's large-scale motion and energetic are solved iteratively over a global grid with numerous vertical layer.

The most robust GCMs are coupled atmosphere-ocean general circulation models (also called AOGCMs). The most sophisticated coupled atmosphere–ocean general circulation models in current use were developed under the aegis of the Intergovernmental Panel on Climate Change (IPCC).They simulate the climate response to various forcing scenarios.

Aerosol or greenhouse gas emission can modify the radiant energy transferred between the Earth's surface and space by the atmosphere. So the scenarios of them are fed into biogeochemical cycle models to translate the emissions into concentrations of radioactively active constituents, which, in turn, 'force' the climate to change by perturbing the heat balance of the Earth–atmosphere system. SRES emission scenarios have been translated into radiative forcing to drive GCMs.

The resolution of GCMs is normally in the range of hundred kilometers, though it can represent the large-scale characteristic of general circulation and global climate, but it is not enough to describe the physical processes in regional scale.

Therefore, there is the need to convert the GCM outputs into a reliable data set with higher spatial resolution. The method used to convert GCM outputs into regional high-resolution meteorological fields is called downscaling techniques.

There are various downscaling techniques. Spatial downscaling relates the large-scale atmospheric predictor variables simulated by GCMs to local scale. Dynamical downscaling approach is one of the methods of extracting local-scale information from GCMs by developing regional climate model (RCMs) with the coarse GCM data used as boundary and lateral conditions.

The regional modeling techniques essentially originated from numerical weather simulations [26-27]. In RCM, the same equation set as GCMs are solved but cover only a limited spatial domain and the spacing between nodes is significantly smaller. It can describe climate feedback mechanisms acting at the regional scale. However, many physical processes operate on scales that are smaller than the grid element and cannot be directly resolved by the models. Such processes need to be represented by parameterization. Parameterization is the method in atmospheric models by which the subgrid-scale processes are determined from variables at model grid points by relating subgrid-scale effects to large-scale properties. It can be considered as emulating (modeling the effect of a process) rather than simulating (model the process itself).

The processes that are most commonly parameterized are :

- Boundary layer processes : Represent sub-grid vertical flux due to turbulences.
- Radiation processes: Solves radiation transfer equation to provide shortwave

and longwave radiational heating /cooling to the atmosphere, and to provide surface radiation for surface energy budget

- Convective cumulus: Represent sub-grid scale vertical flux and rainfall due to convective clouds.
- Surface schemes: Represent effects of land and water surfaces and provide sensible and latent heat flux.
- Microphysics: Represent treatment of cloud and precipitation processes.

From IPCC report, warming and related changes will vary from region to region around the globe. Climate changes in Thailand will be analyzed in this study focusing on heavy rainfall and temperature from future climate simulations. In this research , outputs from the simulations using dynamic downscaling technique have been used. The study based on the hypothesis that the intensity and frequency of heavy rainfall and temperature will undergo changes in the future assuming a special Report on Emission Scenarios (SRES) A1B scenario.

2.3 Emission Scenarios of Greenhouse Gases

The IPCC developed a special Report on Emission Scenarios (SRES). [1, 27] These scenarios have been widely used in the analysis of possible climate change and its impacts.

Since there is no agreement on how the future will unfold, the SRES tried to sharpen the view of alternatives by assuming that individual scenarios have diverging tendencies — one emphasizes stronger economic values, the other stronger environmental values; one assumes increasing globalization, the other increasing regionalization. Combining these choices yielded four different scenario families

(Figure 2.11). This two-dimensional representation of the main SRES scenario characteristics is an oversimplification. It is shown just as an illustration. In fact, to be accurate, the space would need to be multi-dimensional, listing other scenario developments in many different social, economic, technological, environmental, and policy dimensions.

The titles of the four scenario storylines and families have been kept simple: A1, A2, B1, and B2. There is no particular order among the storylines; they are listed in alphabetical and numerical order:

The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B).

The A2 storyline and scenario family describes a very heterogeneous world. The underlying theme is self-reliance and preservation of local identities. Fertility patterns across regions converge very slowly, which results in continuously increasing global population. Economic development is primarily regionally oriented and per capita economic growth and technological change are more fragmented and slower than in other storylines.

The B1 storyline and scenario family describes a convergent world with the same global population that peaks in mid-century and declines thereafter, as in the A1 storyline, but with rapid changes in economic structures towards a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The emphasis is on global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives.

The B2 storyline and scenario family describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability. It is a world with a continuously increasing global population at a rate lower than in A2, intermediate levels of economic development, and less rapid and more diverse technological change than in the B1 and A1 storylines. While the scenario is also oriented towards environmental protection and social equity, it focuses on local and regional levels.

Figure 2 shows the schematic illustration of SRES scenarios. The four scenario "families" are shown, very simplistically, for illustrative purposes, as branches of a two-dimensional tree. The two dimensions shown indicate global and regional scenario orientation, and development and environmental orientation, respectively. In reality, the four scenarios share a space of a much higher dimensionality given the numerous driving forces and other assumptions needed to define any given scenario in a particular modelling approach. The schematic diagram illustrates that the scenarios build on the main driving forces of Greenhouse gas

(GHG) emissions. Each scenario family is based on a common specification of some of the main driving forces.

The radiation disturbance caused by changes to the atmosphere components is responsible for a mean temperature increase and precipitation patterns change over this century (up to 2100). Scenarios for GHG emissions and projections of temperature changes from 2000 to 2100 are shown in figure 2.3. According to figure 2.3, the SRES scenario A1Fl has maximum temperature increasing related with maximum GHGs increasing and scenario B1 has minimum temperature increasing related with minimum GHGs increasing.

In this research the SRES scenario A1B which is in the middle range of the SRES scenarios was chosen according to the assumptions that a future world will have more global economic growth, high consumption, widespread education and technological progress and population growth that peaks in mid-century and declines thereafter.

Economic emphasis→

Global emphasis→

A1 storyline	A2 storyline
World: market-oriented **Economy**: fastest per capita growth **Population**: 2050 peak then decline **Technology**: three scenario groups; -***A1FI***: fossil intensive -***A1T***: non-fossil energy sources -*A1B* : balanced across all sources	**World**: differentiated **Economy**: regional oriented; lowest per capita growth **Population**: continuously growth **Technology**: slowest and most fragmented development
B1 storyline	**B2 storyline**
World: convergent **Economy**: service and information based; lower growth than A1 **Population**: same as A1 **Technology**: clean and resource efficient	**World**: local solution **Economy**: intermediate growth **Population**: continuously increasing at lower than A2 **Technology**: more rapid than A2; less rapid, more diverse than A1/B1

Regional emphasis→

←Environmental emphasis

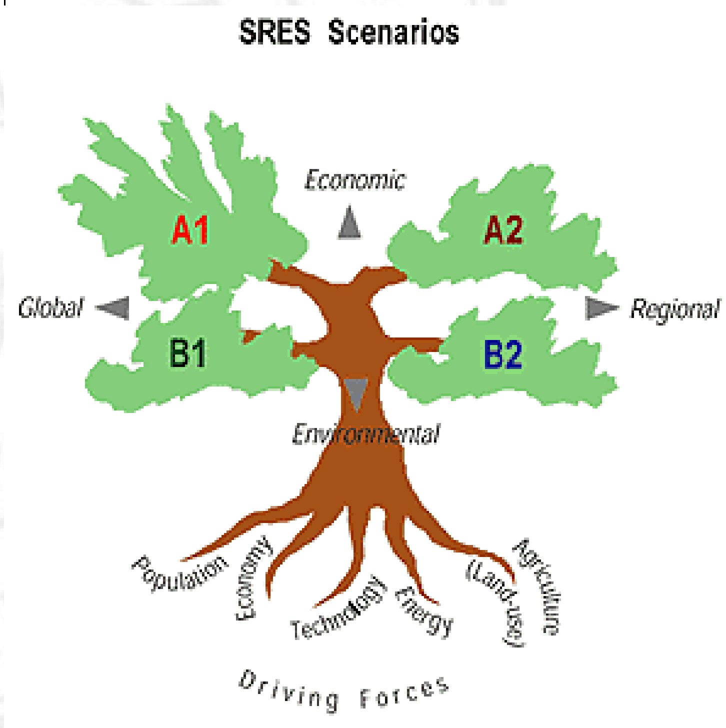

Figure 2.2 Schematic illustration of SRES scenarios [27]

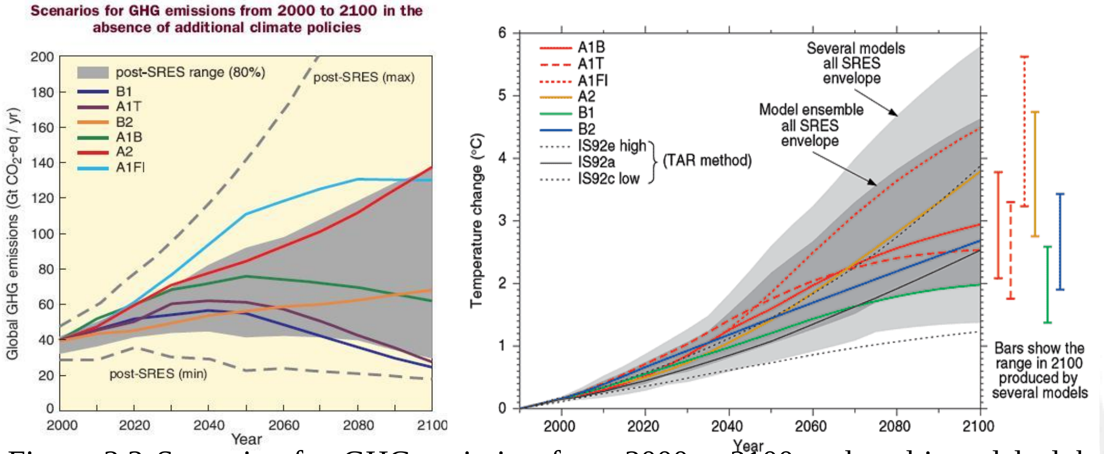

Figure 2.3 Scenarios for GHG emission from 2000 – 2100 and multi-model global averages of temperature changes (relative to 1980-1999) [27]

In IPCC Assessment Report 4 (AR4) on climate change, published in 2007, many types of models are available to study how the climate changes under the impact of human activities. The models and their complementarity are illustrated in diagram 1.

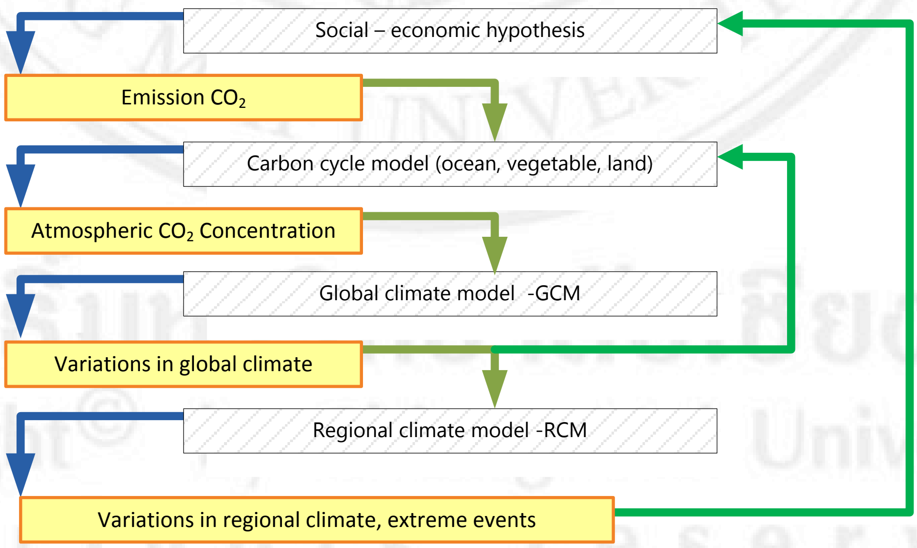

Figure 2.4 Diagram of the models and their complimentarity according to AR4 report

From the diagram, atmospheric CO_2 concentration is calculated from carbon cycle model using the emission CO_2 according to the selected social-economic hypothesis. This atmospheric CO_2 concentration is translated into radiative forcing (that disturbs the balance between incoming and outgoing radiation), which is one of the input of GCM. The GCM outputs are used as the initial and boundary conditions to drive the RCM to achieve the regional climate in details.

2.4 Cumulus Parameterizations [28]

Many mesoscale and global models have horizontal resolution of 4-50 km and 100-600 km, respectively. In both types of models, cloud development is a subgrid scale phenemenon and must be parameterized.

Several techniques have been developed to estimate the effect of sub-grid-scale cumulus cloud on the model-scale environment. These technique are called cumulus parameterizations and require input variables from the model-scale environment. Important model-scale variables used to predoct subgrid effects are horizontal and vertical wind speed, potential temperature, total water mixing ratios. Cumulua parameterization use these variables to adjust potential temperature, total water, and momentum fields and to predict precipitation rates. The effects of a cumulus parameterization on the model-scale environment are feedbacks.

2.4.1 The Betts-Miller scheme [29]

The Betts-Miller scheme (Betts and Miller 1993, Janjic 1994) is the deep-layer control scheme that, upon initiation of convection, adjusts the model profiles of temperature and moisture in each grid column toward specified reference profiles that correspond to a quasi-equilibrium condition that is associated with deep convection. [30] The convective heating (Q_T) and moistening (Q_q) terms are represented by [31]

$$Q_T = \frac{T_r - T_g}{\tau} \tag{10}$$

$$Q_q = \frac{q_r - q_g}{\tau} \tag{11}$$

where the subscript r denote the reference state and g the grid-point value before convection and the factor τ is the adjustment (or relaxation) time scale. The parameterized precipitation is calculated by [30]

$$P = \int_{P_B}^{P_T} \frac{q_R - q}{\tau_g} dp \tag{12}$$

Where q is grid-point specific humidity, q_R is based on the deep-convection reference profile for specific humidity, τ is the time scale over which the adjustment occurs, and the P_T and P_B are the pressures at the top and the bottom of the cloud.

2.4.2 The Kain-Fritsch Scheme

The Kain-Fritsch scheme [30 , 32] is an updated version of the Fritsch-Chappell scheme [28]. It is a dynamic scheme, where the impact of convection upon atmospheric fields is handled using mathematical equations. Both convective updrafts and downdrafts are considered. Both phenomena interact with the environment via entrainment and detrainment. The convection is activated if the parcel is deemed to overcome its convective inhibition (CIN) and thus be able to reach its level of free convection (LFC) . Here, the activation of convection is defined by low-level forcing, and is also a function of the convective available potential energy (CAPE) at a grid point. So it is both a low-level-and deep-layer-control scheme. The convective precipitation is calculated as

$$P = ES \tag{13}$$

Where E is the precipitation efficiency and S is the sum of the vertical fluxes of vapor and liquid at about 150 hPa above the lifting condensation level (LCL).