THE ESTIMATION OF ATMOSPHERIC WATER VAPOUR DURING MONSOON SEASON IN NORTHERN REGION OF PENINSULAR MALAYSIA

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Dedicated to my beloved family ☺

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ABSTRACT

Water vapour plays a significant role in the physical and chemical processes of the atmosphere. It is also considered as one of the major contributors to the greenhouse effect. Analyses of the water vapour would contribute greatly to atmospheric studies, such as weather forecasting and climate monitoring. With the rapid development of Global Positioning System (GPS), it will continuously provide a source of global data that can be used to extract tropospheric parameters. One of the parameters, the Zenith Wet Delay (ZWD), can be computed to Integrated Water Vapour (IWV) using an interpolation method with the surface meteorological data since there is no adjacent surface meteorological sensor located at the ground based GPS stations used in this study. One month data and every 15th day were processed to represent each monsoon season from four MyRTKnet stations and four Malaysia Meteorological Department (MMD) stations using the Bernese v5.0 software. A MATLAB programming was used to compute the GPS IWV and the plotting variation of water vapour during the monsoon seasons in northern region of Peninsular Malaysia. As Peninsular Malaysia is located in low latitude region, the result shows the water vapour amount is higher during the Northeast monsoon due to the heavy rains and the wind prevailing. Meanwhile, East coast of Peninsular Malaysia tends to get the higher value of rainfall and the water vapour values were higher compare to west coast area of Peninsular Malaysia. The result shows a strong relationship between the rainfall distribution and the water vapour values with the correlation range of 90% to 99% for every monsoon to prove that high rainfall values usually occurred with high water vapour amounts in these areas.

ABSTRAK

Wap air memainkan peranan penting dalam proses fizikal dan kimia atmosfera. Ia juga dianggap sebagai salah satu penyumbang utama kepada kesan rumah hijau. Analisis wap air akan memberi sumbangan besar kepada kajian atmosfera, seperti ramalan cuaca dan pemantauan iklim. Dengan perkembangan pesat Sistem Penentududukan Global (GPS), ia akan menyediakan sumber data atmosfera global yang boleh digunakan untuk mendapatkan parameter troposfera. Kelewatan Zenith Basah (ZWD) boleh digunakan untuk mengira GPS Bersepadu Air Wap (GPS IWV) oleh kaedah interpolasi bersama-sama dengan data permukaan meteorologi. Satu bulan data dan data hari ke-15 daripada empat stesen Jabatan Meteorologi Malaysia (MMD) dan empat stesen MyRTKnet telah diproses bagi mewakili setiap musim monsun menggunakan perisian Bernese v5.0. Pengaturcaraan MATLAB digunakan untuk menghitung GPS IWV dan melihat perubahan wap air diplot semasa musim monsun di wilayah Utara Semenanjung Malaysia. Oleh kerana semenanjung Malaysia berada di latitud rendah, hasilnya menunjukkan bahawa jumlah wap air adalah lebih tinggi semasa monsun timur laut akibat hujan lebat dan angin lazim. Sementara itu, Pantai Timur Semenanjung Malaysia cenderung untuk mendapatkan nilai yang lebih tinggi daripada jumlah hujan dan nilai wap air lebih tinggi berbanding dengan kawasan pantai barat Semenanjung Malaysia. Keputusan menunjukkan ada hubungan yang kuat antara taburan hujan dan nilai wap air dengan korelasi 90% hingga 99% bagi setiap monsun membuktikan bahawa kadar hujan yang tinggi biasanya berlaku dengan jumlah wap air tinggi di kawasan ini.

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LIST OF SYMBOLS

L5	GPS frequency of 1176.45 MHz
L1	GPS frequency of 1575.42 MHz
L2	GPS frequency of 1227.60 MHz
ρ	Pseudorange
r	Geometric range from receiver to satellite
δt_u	Offsets of the receiver clock
δt^s	Offsets of the satellite clock
I_p	Delays from Ionosphere
T	Delays from Troposphere
ε_p	Multipath and receiver noise
λ	Wavelength
N	Integer ambiguity
f	Carrier frequency
I_Φ	Delay imparted from Ionosphere delay
T	Delay imparted from Troposphere delay
ε_Φ	Un-modelled effects, modeling error, and measurement error
P_{IF}	Ionosphere free pseudorange measurement
Φ_{IF}	Ionosphere free phase measurement
P_{L1}	Pseudorange measurement at L1
Φ_{L1}	Phase measurement at L1
P_{L2}	Pseudorange measurement at L2

Φ_{L2}	Phase measurement at L2
Δ^{trop}	Tropospheric delay
n	Refractive index
ds_0	Path length
N^{trop}	Refractivity of troposphere
N_h^{trop}	Hydrostatic delay
N_w^{trop}	Wet delay
Z	Zenith angle of the satellite
p	Atmospheric surface pressure in milibar
T	Temperature in Kelvin
e	Partial pressure of water vapour in milibar
B	Correction quantities interpolate
δR	Correction quantities interpolate
e	Partial pressure of water vapour
E	Elevation angles
h	Height above the sea level in kilometers
m	Mapping function
$m_h(E)$	Hydrostatic mapping function
$m_w(E)$	Wet mapping function.
k'_2	Atmospheric refractivity constants
k_3	Atmospheric refractivity constants
R_v	Specific gas constant
ρ	Water vapour density
T_m	Weighted mean temperature of atmosphere
P_v	Partial water vapour pressure

LIST OF ABBREVIATIONS

ARNS	Aeronautical Radio Navigation Service
ASCII	American Standard Code for Information
CC	Control Centre
COSMIC	Constellation Observing System for Meteorology, Ionosphere and Climate
DSMM	Department of Survey and Mapping Malaysia
GHz	Giga-Hertz
GLONASS	GLObalnaya NAvigatsionnaya Sputnikovaya System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GPS-RO	GPS and Radio Occultation
IGS	International GNSS Services
ITRF 2005	International Terrestrial Reference Frame (2005)
IM	Inter Monsoon
IWV	Integrated Water Vapour
LEO	Low Earth Orbit
MMD	Malaysia Meteorological Department
MSL	Mean Sea Level
MyRTKnet	Malaysia Real-Time Kinematic GPS Network
NEM	North-East Monsoon
RINEX	Receiver Independent Exchange Format
RNSS	Radio Navigation Satellite Service

SWM	South-West Monsoon
US	United State
WVR	Water Vapour Radiometer
ZHD	Zenith Hydrostatic Delay
ZTD	Zenith Total Delay
ZWD	Zenith Wet Delay

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CHAPTER 1

INTRODUCTION

1.1 Background of the Study

Water vapour is one of major contributors for the greenhouse effect and a significant element in the hydrologic cycle of the Earth. It is primarily in the vapour phase that water substance is transported into air on a global scale (Guerova, 2003). Water vapour accumulates in droplets before condensation takes place which results in rainfall on earth. The distribution of water vapour is closely related to distribution of clouds and rainfall. In the last few decades, the raw data recorded by means of ground based Global Positioning System (GPS) networks are used to analyze the estimation of atmospheric water vapour.

GPS is widely used in many important applications such as geographical positioning, air craft navigation, surveying, and earth tectonic movement monitoring. The large network of ground-based GPS also discovers a new potential of GPS signals which comprises the atmospheric features. Atmospheric studies are initiated in 1990's (Bevis et al., 1992) with the research on the benefits of GPS signals when passed through atmospheric layers. However, it is noted that the accuracy of GPS data is often distracted by the GPS signal refraction caused by the atmosphere layers, mostly due to troposphere layer. Troposphere layer is the neutral part of atmosphere where most of the weather event such as seasonal monsoon phenomena's occurred within this layer. Furthermore, the amount of water vapour is reliably high in low latitude region and varies with temperature and pressure of the troposphere air (Musa, T.A., 2007).

Peninsular Malaysia is geographically located in low latitude region and surrounded by seas (South China Sea and Strait of Malacca), it is expected that the higher amount of water vapour and rainfall distribution occurred within this area. As for the rainfall distribution, the seasonal wind flow patterns due to the local topographical features will determine the accumulation of the rainfall. During the northeast monsoon season, the areas like the east coast of Peninsular Malaysia, Western Sarawak and the northeast coast of Sabah experience heavy rain spells (Malaysia Meteorological Department, 2008). On the other hand, the inland areas or areas of Peninsular Malaysia which are sheltered by mountain ranges such as Titiwangsa range, relatively free from Northeast Monsoon influence. This study focused on the relationship between atmospheric water vapour from ground based GPS observation with the rainfall distribution during the seasonal monsoon within the northern part of Peninsular Malaysia. The estimation of atmospheric water vapour values from ground based GPS observation will be highlighted. Further investigation includes the analysis of atmospheric water vapour and rainfall data during the peak of the monsoon periods. These outcomes provide useful information to understand the sequences of local weather forecasting development at low latitude areas such in Peninsular Malaysia.

1.2 Problem Statement

The weather condition in Peninsular Malaysia is mainly characterized by two monsoon seasons which are the Southwest Monsoon and Northeast Monsoon. The Southwest Monsoon season starts from late May to September and Northeast Monsoon occurred from November to March yearly. During these monsoon periods, the variability of refractive indices, the wind motion circular of the globe, and the various water vapour contents within the troposphere layer induces the latency in GPS satellite signals propagation. Near the equator regions, the sun’s zenith distance remains relatively low compares to other regions. Therefore, this area is exposed to the intense sunlight all year around, and the temperature varies from 20° Celsius to 39° Celsius (exception for the desert areas) (Musa, T.A., 2007). This phenomenon has an impact on the hydrological cycle of atmosphere in equatorial region. As the temperature rises, the condensation of the air occurred and the water vapour forms into cloud and droplets, which ends producing rainfall back to the Earth surface. Since the atmosphere in the equatorial region contains large amounts of water vapour, it contributes to many weather events phenomena, such as El-Nino, tropical storms and floods. In addition, the rainfall distribution are scattered in Peninsular Malaysia areas and due to the high ranges lied in the middle of the Peninsular Malaysia (i.e. Titiwangsa range), the amounts of rainfall are dispersed between east and west coast area. The inconsistency in rainfall distribution and water vapour contents in atmosphere makes GPS as one of the beneficial tools in providing information for studying this water vapour variability. It would be interesting to investigate the problems occurred in water vapour amounts related with the weather events in low latitude region especially for Peninsular Malaysia area. A very significant and continuous water vapour observations and estimations is very important in order to give better understanding in the weather forecasting and climate monitoring awareness.

Atmospheric expertise has developed many measurement techniques in order to give a better estimation of the atmospheric water vapour distribution. The conventional global observing systems such as Radiosondes (Geurova, 2003), Satellites images (Agustan, 2004), and water vapour radiometer (Geurova, 2003) have been used few decades but considering the high temporal and variability of water vapour, this systems are not suited to provide sufficient information. Thus, additional water vapour data from new observation techniques are highly desirable to achieve adequate observation coverage, accuracy, and long-term stability (Heise et al, 2009). These studies have found the new application in GPS signals for remote sensing atmospheric water vapour in early

90’s (Bevis et al., 1992 and 1994) by using a network of GPS Continuously Operating System (CORS) stations. Provided appropriate strategies were employed, dual-frequency GPS measurements over a CORS network can be processed to obtain the slant Integrated Water Vapour (IWV) values along the signal paths from the GPS satellites to the ground receivers, or the vertical IWV over the CORS stations with an accuracy of about 1mm (Bevis et al., 1992; Morland et al., 2006). Moreover, the applicability of the GPS to support numerical weather predictions has been developed in the past few years (Guerova, 2003; Wang et al., 2007). Most of the studies are focused on the mid-latitudes and near tropics areas but only a few studies have been conducted in the tropic areas perhaps due to the availability and the lack of GPS CORS stations and meteorological stations in this area. Therefore, this thesis will aimed on the accuracy of water vapour estimates derived from a network of ground based GPS receivers and look at the meteorological applications of the data, including the suitability of the data for climate applications such as rainfall.

1.3 Research Objectives

The research objectives are as follows:

1. To investigate the variability and trends of meteorological data (temperature, relative humidity, and MSL pressure) during the monsoon periods for the water vapour estimation to observe the water vapour variability.

2. To calculate and analyze the GPS derived Integrated Water Vapour (IWV) from the Malaysia Real Time Kinematic GNSS Network (MyRTKnet) stations and meteorological stations.

3. To analyze the relationship between the GPS derived IWV and the rainfall distribution during monsoon periods.

1.4 Research Scopes

The scopes of this research are as follows:

1. The research area for this study is in the northern part of Peninsular Malaysia. There are four MyRTKnet stations, two MyRTKnet stations in the east coast area at Kota Bharu, (GETI) in Kelantan and PEKN in Kuantan, Pahang. Another two MyRTKnet stations in the west coast area in Penang (USMP) and at Banting (BANT), Selangor (Figure 1.1).

2. The meteorological data obtained from four meteorological stations that will be used for the interpolation methods in atmospheric water vapour calculations. Two meteorological stations in the east coast area at Kota Bharu, Kelantan and Kuantan, Pahang and two meteorological stations more at west coast area in Bayan Lepas at Penang and at KLIA in Selangor. These stations are chosen due to their distance which is approximately close to the MyRTKnet stations and can be used to interpolate GPS IWV calculation.

3. One year (2008) with one month (every 15^{th}) of GPS data and meteorological data are used in analysis and divided into the period of Southwest Monsoon, Northeast Monsoon, and Inter Monsoon seasons.

4. Reference monument at each GPS and meteorological stations are assumed to be stable and free from any disturbance.

5. All of GPS data is post processed using Bernese v5.0 to come out with the total GPS Zenith Total Delay (ZTD).

6. The analysis on water vapour variation during the seasonal meteorological condition is based on four parameters; MSL pressure, temperature, humidity, and rainfall amounts.

7. The analysis on atmospheric water vapour values is being compared with the rainfall distribution amounts in order to clarify the relationship between atmospheric water vapour with the rain amounts.

8. In order to see the significance relatonship between GPS derived atmospheric water vapour and the rainfall distribution, some of the graphs are plotted using Microsoft Excel and MATLAB software.

9. Ground-based GPS receivers have been developed to an efficient tool for determining atmospheric water vapour, which is originally developed for precise geodetic applications. Besides, ground-based GPS receivers can provide continuous water vapour estimates with higher temporal resolution. This study will focus the area of ground-based GPS meteorology.

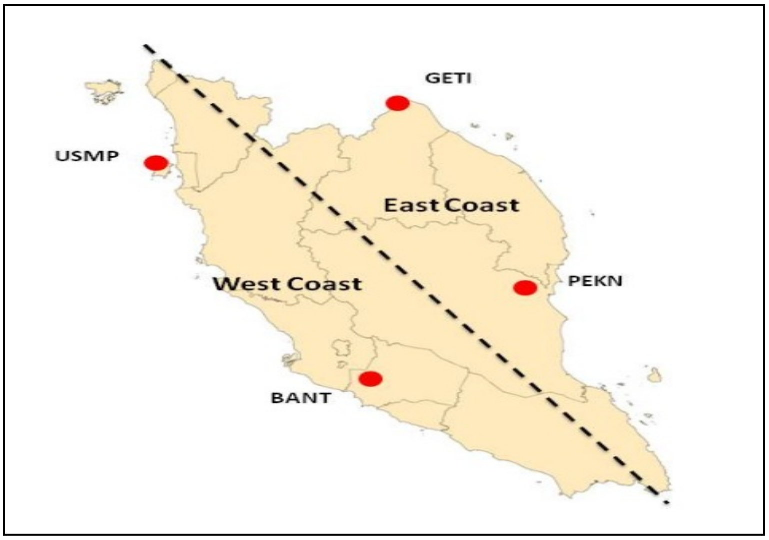

Figure 1.1: Research area for this study.

1.5 Research Methodology

The general of research methodology of this study consists of four major phases (see Figure 1.2). The methodology is initiated with the data collection phases, followed by data processing phases and end up with data analysis and assessment phases. The mission planning defined as the process to develop the strategies and outlining tasks and schedules to accomplish the objectives within the scopes of research. Data collection and data processing are the important phases in this study. During data collection phase, the data is collected in post-processed mode from Department of Survey and Mapping (DSMM) for GPS data and Malaysia Meteorological Data (MMD) for meteorological data. These two types of data are assembled for one year data and separated into 3 sets data according to the monsoons regimes. In data processing stage, the Integrated Water Vapour (IWV) calculation using GPS and meteorological data were conducted. In order to understand and get better results, few analyses were conducted to examine the water vapour calculated with relation to the amounts of rainfall. In addition, all those water vapour computed will be display in the plotting graphs to give a brief view variation of water vapour distribution over Northern part of Peninsular Malaysia. These two phases will reflect the outcomes of the study. The crucial part of the study would be the data analysis and assessment phases. These phases will give the results and determine the objectives of study are well conducted.

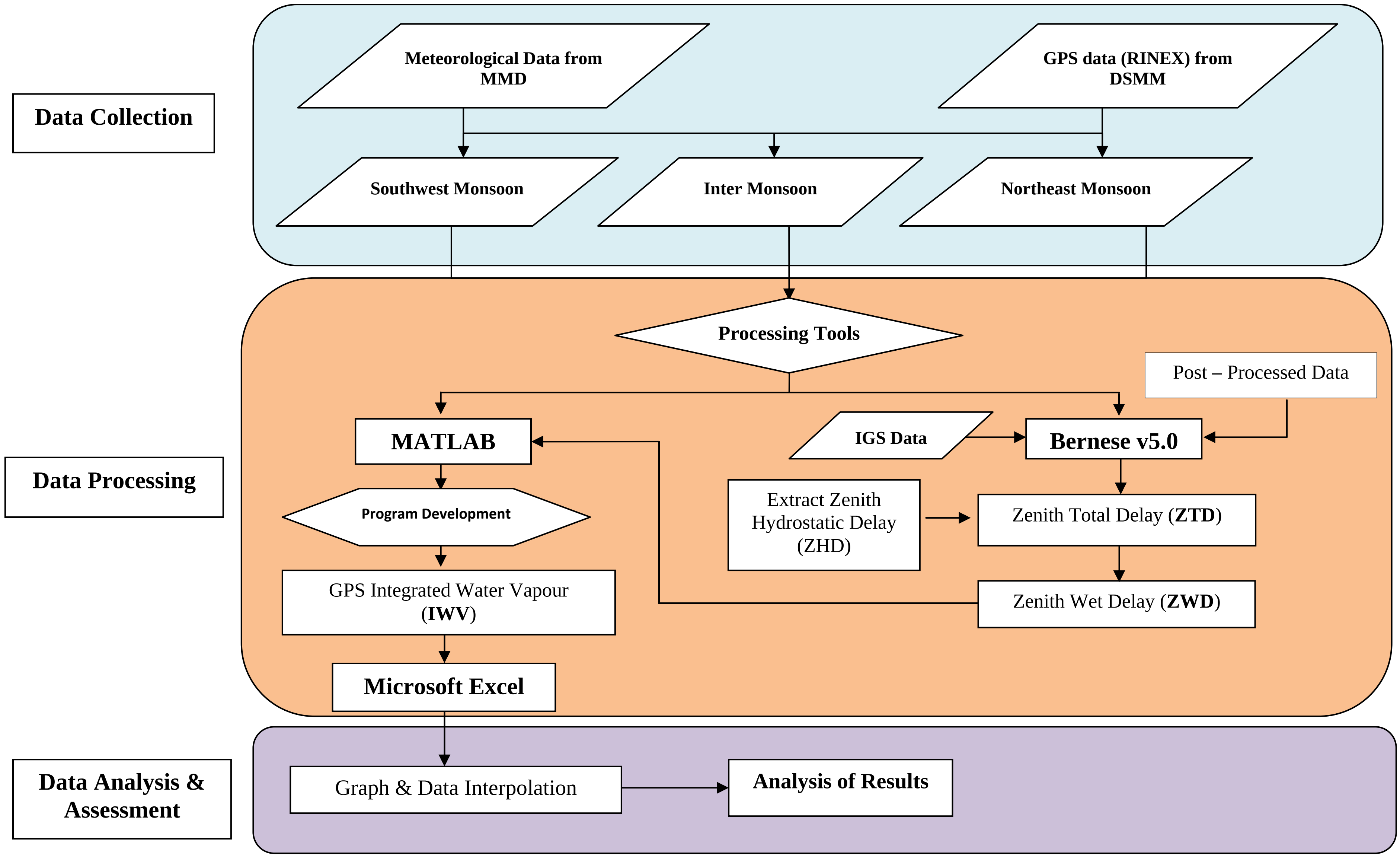

Figure 1.2: Phases of research methodology.

1.6 Significant of Study

The expected contributions from this study are as follows;

1. There are many severe weather conditions happened all around the world such as strong wind breezes, fluctuating temperatures, seasonal monsoons, flash flooding, and heavy rainfall. All of these weather phenomena are unpredictable and they can happen in a flash of time and continuously on the Earth's surface. Besides, these phenomena can affect the agricultural cycle, economic growth and societal activities. The location of Peninsular Malaysia which surrounded with islands and seas are included in tropical region where most of the atmospheric parameters are heterogeneous and greatly varies. Moreover, Peninsular Malaysia also experienced seasonal monsoon period throughout the year. Based on the analysis on series of meteorological data and GPS data during over one period of 2008, it will give a brief understanding on how the variation of these data during the monsoon period. With the overview of the data availability pattern, this study might contribute as an initial input for the local weather predictions and environmental studies.

2. Peninsular Malaysia is included in the low latitude region. As the previous studies on atmospheric conditions, this region had the highest possibility of experiencing of excessive satellite-to-receiver signal delay due to this region mostly surrounded by seas. Therefore, this study leads to give the knowledge, the experience, and the technical information on how the GPS data can be used in weather predictions. This study is one of complimentary studies in atmospheric water vapour extraction using GPS data. This atmospheric water vapour computation is in order to enhance the conventional method such as Radiosonde and satellite images used in GPS atmospheric water vapour extraction.

Moreover, it will be a special interest for meteorologists to explore the benefits of atmospheric water vapour derived from GPS data from this region. This can provide meteorologists to investigate a range of questions related to weather and climate condition at the northern part of Peninsular Malaysia.

1.7 Thesis Outline

This study was reported in five main chapters. A concise understanding of the research background, the research objectives, the research scopes, the research methodology, and the significance are written in Chapter 1. Chapter 2 give review on GPS meteorology in order to give a brief knowledge on GPS advantageous and the overview of Peninsular Malaysia seasonal monsoon seasons. It entails the GPS system, the troposphere layer that contributes much to the water vapour distribution, and various tropospheric refractivity. It includes the tropospheric modeling and the mapping functions in order to get the tropospheric delays to the precipitable water vapour. In Chapter 3, concentrates on the data sets being collected, processing data strategies, the precipitable water vapour calculation, and the data mapped spatially. Chapter 4 outlines the analyses and discussions of the results. In Chapter 5, the summary of the research findings, represent some conclusions and proposed some recommendations for future research.

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