APPLICATION OF HYDRO-METEOROLOGICAL MODEL AND GIS IN SHORT RANGE SEVERE FLOOD FORECASTING AND MAPPING

By

LAWAL BILLA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia in Fulfilment of the Requirement for the Degree of Doctor of Philosophy

May 2006

DEDICATION

To my dear Parents, Brother and Sisters your patients and support has been my motivation

&

To the rest of my extended families your encouragement has seen me through this long journey

I love you all

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

APPLICATION OF HYDRO-METEOROLOGICAL MODEL AND GIS IN SHORT RANGE SEVERE FLOOD FORECASTING AND MAPPING

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May 2006

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Floods resulting from severe seasonal monsoon rainfall are the most important significant natural disaster affecting Malaysia in terms of their impact on the economic, damage to property and sometimes-tragic losses of lives. One of the greatest deficiencies of the current flood models used in the country is the inability to provide cloud and mesoscale rainfall information in the earliest portion of 0-6h of their forecasting period. In this study NOAA- AVHRR and GMS satellite data were processed for grid based rainfall and rainfall intensity mapping to improve short-range quantitative precipitation forecasting (QPF) of severe monsoon weather and also to facilitate the assimilation of QPF into operational flood forecasting.

A 1D cloud model based QPF modeling process was developed, that relates cloud top temperature below 235^{o}K, reflectance above 28% and cloud heights above 12000m with tropical rainfall formation within the range of 3-12 mm/hr. A grid based rainfall intensity map was thus produced for Langat River Basin. High correlations of R^2 above 0.75 were observed for cloud top temperature processed

from GOES data and recorded rainfall of severe monsoon weather of selected stations in Terengganu, Kuantan and Kota Bahru.

Hydrodynamic and rainfall-runoff simulation were performed using MIKE 11 hydrological model and a suitably auto-calibrated NAM runoff model. The hydrological model was tested for rainfall runoff process using observed hourly rainfall data for the flood event of 27 Sept. to 8 Oct. 2000 as well as rainfall estimation derive from the cloud model QPF using hourly GMS temperature reading for the same storm period. The rainfall- runoff hydrographs generated for the two rainfall sources showed similarities with R^2 of 0.9028.

The results of the runoff modeling were integrated in MIKE11 GIS model for flood inundation mapping. Separate inundation maps were generated for the observed rainfall and the QPF derive rainfall runoff results for comparison. The accuracies of both maps were verified using grid point location data for flooded areas published in the DID Annual Flood Report. The verification results showed an accuracy of 70% for both flood maps.

The methods and processes developed by this study are flexible enough to be applied in other mesoscale and severe storm forecasting particularly a tropical setting. In using NOAA satellite, AVHRR data can be received and processed in advance of 6h of the actual rainfall event. This study should thus prove very useful for the assimilation of grid based rainfall intensity into and improve short- range operational flood forecast.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

APLIKASI MODEL HIDRO-METEOROLOGIKAL DAN GIS DALAM PEMETAAN DAN RAMALAN JANGKA PENDEK BANJIR BESAR

Oleh

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Banjir yang berasal daripada hujan lebat monson bermusim merupakan bencana alam yang sangat penting dan signifikan terhadap Malaysia dari segi kesan ekonomi, kerosakan harta benda dan kehilangan nyawa. Di antara kekurangan model-model banjir yang sedia ada adalah ketidakupayaan menyediakan data awan dan hujan berskala meso enam jam sebelum banjir berlaku. Di dalam kajian ini data satelit NOAA-AVHRR diproses untuk menghasilkan grid lokasi hujan serta intensiti hujan untuk meningkatkan ramalan presipitasi kuantitatif (QPF) bagi cuaca monson dalam jangkamasa pendek dan juga untuk memudahkan kemasukkan QPF dalam ramalan banjir secara operasional.

Pemodelan proses QPF berasaskan model awan 1D dibangunkan dan berhubungkait terhadap suhu atas awan (< 235^{o}K), pembalikan awan (> 28%) dan ketinggian awan (<12000m) dengan hujan tropika di antara 3-12mm/hr. Kemudian peta intensiti hujan kawasan kajian – lembangan Sungai Langat telah dihasilkan. Korelasi R^2 yang tinggi melebihi 0.75 didapati daripada suhu atas awan daripada data GOES yang telah

diproses dan hujan bagi cuaca monson yang direkod di stesen Terengganu, Kuantan dan Kota Bharu.

Simulasi hidrodinamik dan aliran permukaan-hujan dilaksanakan dengan menggunakan model MIKE 11 dan model auto-kalibrasi NAM. Model hidrologikal ini diuji menggunakan data cerapan hujan setiap jam bagi tempoh banjir dari 27 September hingga 8 Oktober 2000. Anggaran hujan sekali lagi dikomputkan berasaskan kepada QPF daripada bacaan suhu data GMS setiap jam dan digunakan untuk simulasi banjir yang melanda. Hidrograf aliran permukaan hujan yang terjana untuk dua sumber hujan menunjukkan kesamaan dengan R^2 - 0.9028.

Model aliran permukaan yang dihasilkan daripada kedua-dua sumber hujan seterusnya digunakan untuk menghasilkan peta banjir dan diintegrasikan ke dalam MIKE11 GIS. Peta banjir yang dijana daripada cerapan hujan dan simulasi hujan QPF dibandingkan. Ketepatan kedua-dua peta disahkan menggunakan data lokasi titik grid bagi kawasan banjir yang diterbitkan di dalam laporan tahunan banjir (JPS). Ketepatan kedua-dua jenis peta banjir yang dicapai adalah 70%.

Kaedah dan proses yang dibangunkan di dalam kajian ini adalah mencukupi untuk diaplikasikan dalam skala meso dan ramalan hujan lebat di dalam kawasan tropika yang lain. Data NOAA-AVHRR boleh diperolehi dan diproses untuk ramalan hujan enam jam sebelum kejadian banjir. Kajian ini membuktikan kepentingan assimilasi grid berasaskan intensiti hujan dan meningkatkan jarak operasi ramalan banjir dengan kadar masa yang lebih panjang.

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I certify that and Examination Committee has met on 10 May 2006 to conduct the final examination of Lawal Billa on his Doctor of Philosophy thesis entitled "Application of Hydro-Meteorological Model and GIS in Short Range Severe Flood Forecasting and Mapping" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

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DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institution.

LAWAL BILLA

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LIST OF ABBREVIATIONS

A_r	Rainfall Area
AVHRR	Advance Very High Resolution Radiometer
AV_r	Average Rain-rate
CST	Convective Stratiform Technique
CTR	Cloud Top Reflectance
CTT	Cloud Top Temperature
DEM	Digital Elevation Model
DID	Drainage and Irrigation Department
DMS	Disaster Management System
DN	Digital Number
DOA	Department of Agriculture
DSS	Decision Support System
DTM	Digital Terrain Model
FAR	False Alarm Ratios
FEMA	Federal Emergency Management Unit
FF	Flood Forecasting
FSU	Florida State University
GCP	Ground Control Points
GEOREX	Geo-spatial Data Exchange System
GFOV	Ground Field of View
GMS	Geostationary Meteorological Satellite
GOES	Geostationary Operational Environmental Satellite
GIS	Geographical Information System

GUI	Graphical User Interface
hr	Hour
HD	Hydrodynamic
HEC	Hydrological Engineering Center
HGL	Hydraulic Grade Line
HIS	Hydrological Information System
HRPT	High Resolution Picture Transmission
IFOV	Instantaneous Field of View
IR	Infrared
ISCCP	International Satellite Cloud Climatology Project
JUPEM	Malaysian Survey Department
K	Kelvin
LAC	Local Area Coverage
MACRES	Malaysian Center for Remote Sensing
MIR	Mid Infrared
mm	millimeter
MOA	Ministry of Agriculture
msl	Mean Sea Level
MSLP	Mean Sea Level Pressure
MSS	Malaysian Meteorological Service
MW	Microwave
NAM	Lumped Conceptual Rainfall-Runoff Model
NEXRAD	Next Generation Radar
NIR	Near Infrared
NOAA	National Oceanic and Atmospheric Administration

NWP	Numerical Weather Prediction
NWS	National Weather Service
PR	Precipitation Radar
QPF	Quantitative Precipitation Forecasting
RM	Malaysian Ringgit
RMSE	Root Mean Square Error
ROF	Runoff Factor
RR	Rainfall Runoff
RS	Remote Sensing
RSO	Rectified Skew Orthomorphic
SAR	Synthetic Aperture Radar
SCS	Soil Conservation Service
Sg.	Sungai (river)
SMI	Soil Moisture Index
SOA	Statistical Objective Analysis
SSARR	Streamflow Synthesis and Reservoir Regulation Model
T_B	Brightness Temperature
TCP	Tropical Cyclone Program
TIN	Triangulated Irregular Network
TIR	Thermal Infrared
TMI	TRMM Microwave Imager
TOA	Top of Atmosphere
TOPEX	Typhoon Operation Experiment
TRMM	Tropical Rainfall Measuring Mission
UHM	Unit Hydrograph Module

USGS	United States Geological Survey
VIRS	Visible and Infrared Scanner
VIS	Visible
VR_r	Volume Rain-rate
VSRF	Very Short Range Forecasting
WMO	World Meteorological Organization
W/sr m^2	Watts Per Steradian and Square Meter