UNIVERSITI PUTRA MALAYSIA

PREDICTING ATMOSPHERIC HUMIDITY AND TEMPERATURE BASED ON SATELLITE SIGNAL FIELD STRENGTH MEASUREMENTS

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FS 2015 17

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By

MOHD IZZAT BIN SAIRI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

October 2015

DEDICATION

To my beloved mother Habibah binti Rahim Bakhas,

father Sairi bin Saimon,

Brother and Sisters

Thank You for everything

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

PREDICTING ATMOSPHERIC HUMIDITY AND TEMPERATURE BASED ON SATELLITE SIGNAL FIELD STRENGTH MEASUREMENTS

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October 2015

Chairman : Zulkifly Abbas, PhD

Faculty : Science

Early measurements of rainfall made using radar systems although have been used qualitatively by weather forecasters for more than 40 years, and by some operational hydrologists, acceptance still contain a lot of uncertainties in the quality of the data. As most of the communication satellites (ie: MEASAT) were limitedly used for communication purpose, very few were looking to extend the application of these satellites for other application such as weather forecasting. Furthermore, weather satellite currently present were expensive to buy, thus this project aims to find a cheaper method to forecast weather. Therefore, this work investigates the application of a communication satellite as a new method for predicting the atmospheric temperature and humidity. The chosen satellite was a MEASAT3 operating in the frequency range between 11 GHz and 12 GHz with 120 kW transmitting power. The electric field strengths of the satellite signals were measured using a Prodig-5 TV Explorer instrument. The measurements were carried out daily between 8.30 am to 5.00 pm from September 2012 to March 2014. The one-metre parabolic dish antenna was positioned on the roof top of the Department of Physics building (3° 1’ 19.1928’’ N, 101° 42’ 19.9476’’ E) of the Universiti Putra Malaysia. The mean field strength of the MEASAT3 signal (DVB-S) during clear sky was 83.6 dBμV. These signal strengths were affected by the ambient temperature and atmospheric humidity. Torrential rain reduced the field strength signal to 75 dBμV, i.e, the threshold detection level of the Low-noise Block Downconverter (LNB). Empirical models to predict the humidity and temperature based on the measured field strengths were established. The humidity and temperature data were obtained from the WeatherWatcher Live software based on the measured data collected at local meteorological station. The accuracies for temperature and humidity predictions obtained from this work were within 5.9%

and 5.5% when compared to the real data obtained from Meteorological Department database.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Sarjana Sains

RAMALAN SUHU DAN KELEMBAPAN ATMOSFERA BERDASARKAN PENGUKURAN MEDAN KEKUATAN ISYARAT SATELIT

Oleh

MOHD IZZAT BIN SAIRI

Oktober 2015

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Pengukuran hujan terdahulu yang dibuat dengan menggunakan sistem radar, walaupun telah digunakan secara kualitatif oleh peramal cuaca dan eloh beberapa ahli hidrologi operasi untuk lebih daripada 40 tahun, penerimaannya masih mengandungi banyak ketidaktentuan dalam kualiti data. Oleh kerana kebanyakan satelit komunikasi seperti MEASAT digunakan secara terhad untuk tujuan komunikasi, tidak ramai yang cuba untuk meluaskan penggunaan satelit ini untuk aplikasi lain seperti ramalan cuaca. Tambahan lagi, satelit cuaca yang telah sedia adalah mahal untuk dibeli, lalu projek ini menyasarkan untuk mencari kaedah yang lebih murah untuk meramal cuaca. Oleh itu, kerja ini mengkaji penggunaan satelit komunikasi bagi tujuan ramalan suhu dan kelembapan atmosfera. Satelit yang diguna pakai ialah MEASAT3 beroperasi pada rangkaian frekuensi di antara 11 GHz dan 12 GHz dengan kuasa pemancaran 120 kW. Medan kekuatan isyarat elektrikal satelit diukur menggunakan alat Prodig-5 TV Explorer. Pengukuran dilakukan pada setiap hari di antara 8.30 pagi dan 5.00 petang dari September 2012 sehingga Mac 2014. Antenna parabola berdiameter satu meter telah diletakkan di atas bumbung bangunan Jabatan Fizik (3° 1’ 19.1928’’ N, 101° 42’ 19.9476’’ E) Universiti Putra Malaysia. Julat medan kekuatan isyarat MEASAT3 (DVB-S) sewaktu cuaca cerah ialah 83.6 dBμV. Kekuatan isyarat ini dipengaruhi oleh kelembapan atmosfera dan suhu persekitaran. Hujan lebat mengakibatkan medan kekuatan isyarat menurun serendah 75 dBμV, i.e, paras terendah pengesanan blok penukar bawah rendah bunyi (LNB). Model empirikal bagi meramal kelembapan dan suhu berdasarkan kepada medan kekuatan yang diukur telah di wujudkan. Data kelembapan dan suhu telah diperolehi daripada perisian WeatherWatcher Live berdasarkan data yang diukur di stesen kaji cuaca tempatan. Ketepatan ramalan kelembapan dan suhu adalah di antara 5.9% dan

5.5% berbanding dengan data sebenar yang diperolehi dari pangkalan data Jabatan Meteorologi.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

NWP	-	Numerical Weather Prediction
MEASAT	-	Malaysia East Asia Satellite
GHz	-	Giga Hertz
dBμV	-	Decibel Micro Volt
UTM	-	Univesity Teknologi Malaysia
ANN	-	Artificial Neural Network
MLP	-	Multilayer Perceptron Networks
ERNN	-	Elman Recurrent Neural Network
RBFN	-	Radial Basis Function Network
HFM	-	Hopfield Model
MSE	-	Mean Square Error
RMSE	-	Root Mean Square Error
MAE	-	Mean Absolute Error
MSL	-	Mean Sea Level
US	-	United States
ºC	-	Degree Celcius
ºF	-	Degree Fahrenheit
K	-	Kelvin
SI unit	-	International System of Units
F	-	Focal Point
D	-	Diameter
kW	-	Kilo Watt
LNB	-	Low-Noise Block Downconverter
MHz	-	Mega Hertz
ULPC	-	Up-Link Power Control
BCCS	-	Bare Copper-covered Steel
FPE	-	Foam Polyethylene
PVC	-	Polyvinyl-chloride

Rx	-	Receiving Signal
Tx	-	Transmitting Signal
CATV	-	Community Antenna Television
Δx	-	absolute deviation
PDF	-	Probability Density Function
$\bar{x}$	-	Mean
σ^2	-	Variance
f	-	Frequency
c	-	Speed of Light
Gt	-	Transmitter Gain
Gr	-	Receiving Gain
km	-	Kilo Meter
MRE	-	Mean Relative Error
%	-	Percentage

CHAPTER 1

INTRODUCTION

1.1 Research Background

Many numerical models for weather forecasting have been proposed since the 1940s. These interdependence of remotely sensed data and Numerical Weather Prediction (NWP) models and their outputs are progressively driving the further development of radar and other remote sensing methodologies for measuring and forecasting rainfall. Palmer (2001) notes that conventional parametrization schemes in weather-and-climate prediction models describe the effects of sub-grid-scale physical processes. Indeed, he suggests that the remaining errors in these models may have their origin in the neglect of grid-scale variability, and he proposes that such variability should be parametrized by non-local dynamically based parametrization schemes. A complementary approach to the parametrization of sub-grid-scale variability is the assimilation of remotely sensed observational data explicitly representing such variability using complex numerical schemes. The problem with such an approach is that these data contain errors which may cause numerical integrations to become unstable whatever numerical methods are used. Hence small differences in input data may lead to very different forecast outcomes. This problem is causing major effort being devoted to the development of ensemble prediction schemes (Trevisan et al . 2001). Numerical predictions also provides fresh impetus efforts to improve the quality of radar estimation of precipitation, however this need is called for by the requirements of nowcasting (forecasts from 0 to 3–6 hours ahead).

It is worth noting in the past that the introduction of advanced computing technologies into hydrology, such as more complex distributed models can be run cost effectively (Apostolopoulos & Georgakakos 1997), but will not lead to improvements in operational flood forecasts due to this error-propagation problem. In spite of the difficulties in using remotely sensed data, it is clear that major improvements in rainfall and flood forecasting are only likely to come through improvements with these data and the methods in which they are used.

1.2 Effect of Rain on Satellite Field Strength

Microwave signals are transmitted directly from a source to a receiver site. A microwave communication satellite is equipped with antennas and transponders that receive and retransmit signals. It is generally located at its geostationary orbit, i.e, stationary at one spot from the Earth. The Malaysia East Asia Satellite (MEASAT) carries 24 transponders for each C-band and Ku-band microwave transmitter in order to provide good quality services. The presence of rain can have a significant detrimental effect on the propagation of an electromagnetic signal. The rain degradation increases as the frequency increases. At C- band (6/4 GHz), rain has little effect, except for brief periods of unusually heavy rain, but at Ku-band (14/12 GHz) it can be important. Nevertheless, typical rain margins on the order of 7 dB can be allocated to accommodate loss at Ku-band in most geographic regions to ensure availability comparable to that of C-band. At higher frequencies in Ka-band (30/20 GHz), rain can have a very large effect that simply cannot be overcome at the usual levels of availability. Thus the field strengths from satellite wave transmission is very much affected by rainfall.

However, at frequency above 10 GHz (Ku-band), signal attenuation by ambient conditions such as humidity, temperature and in particular, rain have to be considered. Therefore, data need to be measured and analysed in order to understand the behaviour and relation of these parameters with the strength of the satellite signal, also known as the field strength measured in dBµV.

1.3 Problem statement

In Malaysia the accuracy of forecasting unexpected severe or hazardous weather within the next six hours (often referred to as nowcasting) is crucial to protect life and property. While operational hydrologists use numerical weather prediction (NWP) forecasts to provide warnings of the likelihood of flood conditions on time-scales beyond 6 hours or so ahead, the basis of shorter-period forecasts depends upon the acquisition and use of observational data, particularly rain-gauge and radar data. Unfortunately, measurements of rainfall made using radar systems although have been used qualitatively by weather forecasters for more than 40 years, and by some operational hydrologists, acceptance has been limited as a consequence of uncertainties in the quality of the data. New algorithms for improving the accuracy of radar measurements of rainfall have been developed where data from mesoscale numerical models are being blended with observational data, and remotely sensed data are being inputted to NWP, to improve both measurements and forecasts of precipitation (Golding 2000). However, these data contain errors which may cause numerical integrations to become unstable whatever numerical methods are used. Rain attenuation model has been proposed by UTM researchers. However their application is for link budget estimation for microwave satellite communication systems (Abdul Rahman et al., 2010).

This project presents a new technique to predict humidity and temperature of the troposphere region from satellite field strength measurements. The proposed method involves deployment of a receiving parabolic antenna located on a rooftop building for measuring field strengths from MEASAT satellites. An empirical model relating humidity, temperature and field strength shall be established for temperature and humidity forecasting.

1.4 Objectives of the project

The investigation on the electric field strengths of the satellite involves many task and objectives:

- To investigate the daily diurnal field strength of a clear sky, cloudy and rainy conditions
- To determine the relationship between humidity, temperature and field strength in troposphere region
- To develop empirical model to predict temperature and humidity from field strength

1.5 Outline of the study

A brief introduction on communication satellite signal and atmospheric parameters were explained in Chapter 2. However, more details will be discussed on the field strength of the MEASAT3 communication satellite, rainfall, humidity and temperature as these are the parameters that were being investigated in this work. Previous study on information and the correlation of all these parameters have also been presented.

To understand the behavior of these atmospheric parameters towards the field strength of the satellite signal, it is important to find the correlation between them. Data analysis was done in order to investigate the way all three parameters interact with each other. This analysis was aided by finding the model regression in order to understand their relationship. In order to validate the relationships presented by these model equation, two means of error analysis were done. This is to make sure that the regression contains an acceptable amount of error besides relegating external factors in the form of random errors such as noise. The means to achieve all these are well presented in Chapter 3.

Chapter 4 studies the physics of the field strength of the communication satellite and the atmospheric parameters. Each of them were carefully elaborated and the theories behind them were emphasized on in details. Discussion on how they should interact with each other was also made.

Based on all the measurements made, the data was analyzed and studied thoroughly. The results were discussed and explained in details. The correlation between field strength towards humidity and temperature were perceived by finding the model regression. These model regressions translate the relationship between them quantitatively while further analysis were made to discuss qualitatively. Discussion on error analysis of the regression were made at the end of Chapter 5. At the end of this thesis, conclusion to this research is presented. Along with that, recommendations and suggestions for future work were presented as well.

REFERENCES

Abdulrahman, A. Y., Rahman, T. A., Rahim, S. K. B. A., & Rafi Ul Islam, M. (2010). A new rain attenuation conversion technique for tropical regions. *Progress In Electromagnetics Research B*, *26*, 53-67.

Berne, A., & Uijlenhoet, R. (2007). Path-averaged rainfall estimation using microwave links: Uncertainty due to spatial rainfall variability. *Geophysical research letters*, 34(7).

Bril, A., Oshchepkov, S., & Yokota, T. (2012). Application of a probability density function based atmospheric light-scattering correction to carbon dioxide retrievals from GOSAT over-sea observations. *Remote Sensing of Environment*, 117, 301-306.

Charney J. G., R. Fjortoft & J. von Neumann (1950). Numerical integration of the Barotropic vorticity equation. *Tellus* 2, 237-254.

Charney, J. G. (1949). On a physical basis for numerical prediction of large-scale motions in the atmosphere. *Journal of Meteorology*, 6(6), 372-385.

Chu, C. R., Parlange, M. B., Katul, G. G., & Albertson, J. D. (1996). Probability density functions of turbulent velocity and temperature in the atmospheric surface layer. *Water resources research*, 32(6), 1681-1688.

Collier C.G, & Knowles J.M. (1986). Accuracy of rainfall estimates by radar, Part III: Application for short-term flood forecasting. *Journal of Hydrology* 83: 237–249.

Davis, C. A., Ahijevych, D. A., Haggerty, J. A., & Mahoney, M. J. (2014). Observations of temperature in the upper troposphere and lower stratosphere of tropical weather disturbances. *Journal of the Atmospheric Sciences*, 71(5), 1593-1608.

Deque, M. (2003), Uncertainties in the temperature and precipitation response of PRUDENCE runs over Europe. Abstract from the *European Science Foundation and PRUDENCE 3rd Annual Conference on "Regional Climate Change in Europe"*, Wengen, Switzerland, September 29–October 3, 2003.

Ebert, E. E. (2002). Verifying satellite precipitation estimates for weather and hydrological applications. In *International Precipitation Working Group 1st Workshop*, Madrid Spain.

Elfadil, N., Nadir, Z., Salam, M. A., & Rao, J. (2005). Microwave attenuation studies due to rain for communication links operating in Malaysia. *Georgian Electronic Scientific Journal*: Computer Science & Telecommunication, (5).

Flatté, S. M., Bracher, C., & Wang, G. Y. (1994). Probability-density functions of irradiance for waves in atmospheric turbulence calculated by numerical simulation. *Journal of the Optical Society of America A* (JOSA A), 11(7), 2080-2092.

Goddard, L., Barnston, A. G., & Mason, S. J. (2003). Evaluation of the IRI's "Net assessment" seasonal climate forecasts: 1997-2001. *Bulletin of the American Meteorological Society*, 84(12), 1761-1781.

Golding B.W (2000) Quantitative precipitation forecasting in the UK. *J Hydrol*, 239 (14):286-305.

Grabner, M., & Kvicera, V. (2011). Analysis of rain effect on free space optical and microwave communication links. In Proceedings of the *11th International Conference on Telecommunications.*

Held, I. M., & Shell, K. M. (2012). Using relative humidity as a state variable in climate feedback analysis. *Journal of Climate*, 25(8), 2578-2582.

Hippert, H. S., Pedreira, C. E., & Souza, R. C. (2000). Combining neural networks and ARIMA models for hourly temperature forecast. *In The International Joint Conference on Neural Networks* (IJCNN) (p. 4414).

Howard, L. (1803). XVIII. On the modifications of clouds, and on the principles of their production, suspension, and destruction; being the substance of an essay read before the Askesian Society in the session 1802–3. *The Philosophical Magazine: Comprehending the Various Branches of Science, the Liberal and Fine Arts, Agriculture, Manufactures, and Commerce*, 16(62), 97-107.

Karl, T. R., Hassol, S. J., Miller, C. D., & Murray, W. L. (2006). Temperature trends in the lower atmosphere. *Steps for understanding and reconciling differences*.

Labajo, J. L., de Pablo, F., & García, E. L. (1991). An equation relating temporal changes of relative humidity and temperature: case of variable intervals of time. *Atmósfera*, 4(4), 257-264.

Leijnse, H., Uijlenhoet, R., & Stricker, J. N. M. (2007). Rainfall measurement using radio links from cellular communication networks. *Water resources research*, 43(3).

Mason I.T. (2003). Binary events. Forecast Verification: A Practitioner's Guide in Atmospheric Science. *Wiley: Chichester*; 37–76.

Mclaren, J. R., Thomas, J. C., Mackintosh, J. L., Mudge, K. A., Grant, K. J., Clare, B. A., & Cowley, W. G. (2012). Comparison of probability density functions for analyzing irradiance statistics due to atmospheric turbulence. *Applied optics*, 51(25), 5996-6002.

Mostafa, H., Hassan, S. I. S., Mandeep, J. S., Ain, M. F., & Khedher, H. A.

(2007). Study of the Effect of Simulated Rain on the Offset Parabolic Antenna at Ku-Band with Different Elevation Angles. *International Journal of Antennas and Propagation*, 2007.

Murphy, A. H. (1988). Skill scores based on the mean square error and their relationships to the correlation coefficient. *Monthly weather review*, 116(12), 2417-2424.

Palmer, T. N. (2001), A nonlinear dynamical perspective on model error: A proposal for non-local stochasticdynamic parametrization in weather and climate prediction models, *Q. J. R. Meteorol. Soc.*, 127, 279–304.

Pascal, (2006) On the role of heat flow, lithosphere thickness and lithosphere density on gravitational potential stresses, *Tectonophysics*, 425 (2006), pp. 83–99

Pasternack's Free Space Path Loss Calculator, Pasternack Enterprises, Inc. 1999-2015 Retrieved from http://www.pasternack.com/t-calculator-fspl.aspx

Pessoa, M. L., Bras, R. L., & Williams, E. R. (1993). Use of weather radar for flood Forecasting in the Sieve river basin: a sensitivity analysis. *Journal of Applied Meteorology*, 32(3), 462-475.

Potgieter, A. B., Hammer, G. L., Doherty, A., & De Voil, P. (2005). A simple regional Scale model for forecasting sorghum yield across North-Eastern Australia. *Agricultural and Forest Meteorology*, 132(1), 143-153.

Richardson L. F. (1965), Weather Prediction by Numerical Processes. Cambridge Univ. Press, *Cambs. Reprinted Dover*, New York.

Satbeams SPRL 2007-2014, Retrieved from https://www.satbeams.com/footprints?beam=5610

Simmons, A. J. (1986). Numerical prediction: Some results from operational forecasting at ECMWF. *Advances in geophysics*, *29*, 305-338.

Simmons, A. J., Burridge, D. M., Jarraud, M., Girard, C., & Wergen, W. (1989). The ECMWF medium-range prediction models development of the numerical formulations and the impact of increased resolution. *Meteorology and Atmospheric Physics*, 40(1-3), 28-60.

Soon, W., & Baliunas, S. (2003). Lessons & Limits of Climate History: Was the 20th Century Climate Unusual? *George C. Marshall Institute*, 32 p.

Stephenson, D. B., Coelho, C. A. S., Doblas-Reyes, F. J., & Balmaseda, M. (2005). Forecast assimilation: a unified framework for the combination of multi-model weather and climate predictions. *Tellus A*, 57(3), 253-264.

Suzuki, K., Stephens, G., Bodas-Salcedo, A., Wang, M., Golaz, J. C., Yokohata, T., & Koshiro, T. (2015). Evaluation of the warm rain formation process in global models with satellite observations. *Journal of the Atmospheric Sciences*, 72(10), 3996-4014.

Terai, C. R., Wood, R., Leon, D. C., & Zuidema, P. (2012). Does precipitation susceptibility vary with increasing cloud thickness in marine stratocumulus?, *Atmospheric Chemistry and Physics*, 12(10), 4567-4583.

Theodore K. Apostolopoulosa, & Konstantine P. Georgakakosb, (1997), Parallel computation for streamflow prediction with distributed hydrologic models, *Journal of Hydrology*, Volume 197, Issues 1–4, 1 October 1997, Pages 1–24

Thomas C. Peterson, Peter A. Stott, & Stephanie Herring, (2012). Explaining Extreme Events of 2011 from a Climate Perspective. *Bull. Amer. Meteor. Soc.*, 93, 1041–1067.

Trevisan, A., Pancotti, F. & Molteni, F. (2001), Ensemble prediction in a model with Flow regimes. *Q.J.R. Meteorol. Soc*., 127: 343–358. doi: 10.1002/qj.49712757206

US National Oceanic and Atmospheric Administration Sky, National Weather Service, Retrieved from http://w1.weather.gov/glossary/index.php?letter=s

Wagner, T., Beirle, S., Dörner, S., Friess, U., Remmers, J., & Shaiganfar, R. (2013). Cloud detection and classification based on MAX-DOAS observations. *Atmospheric Measurement Techniques Discussions*, 6, 10297-10360.

Wilkes, A., & Williams, D. (2015). Measurement of humidity. *Anaesthesia & Intensive Care Medicine*, 16(3), 128-131.

Wilks, D. S., & Godfrey, C. M. (2002). Diagnostic verification of the IRI net assessment forecasts, 1997-2000. *Journal of climate*, 15(11), 1369-1377.