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Identification of the distribution of hydroclimatic cycles of field observations in Southeast Asia

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Abstract The study of hydro-climatic cycles in Southeast Asia is carried out by analysing time series of rainfall, streamflow, evapotranspiration and net radiation from three representative regions: Northern Thailand, Peninsular Malaysia and Borneo. The method used is a Data-Based Mechanistic tool called the Unobserved Component – Dynamic Harmonic Regression (UC-DHR) model, used here to identify both the diurnal and inter-annual variability patterns of existing plot studies datasets.

Key words Southeast Asia; field observations; temporal cycles; DBM modelling

INTRODUCTION

The increasing use of modelling within hydrology and meteorology has highlighted the need to provide an accurate description and quantification of the hydro-climatic processes involved (Bonell, 2004). This is required to improve the definition of model structures and model evaluation that will eventually lead to further improvements in climate change prediction.

General Circulation Models (GCMs), which link hydrological and meteorological phenomena (rainfall, evapotranspiration and rainfall-runoff processes) within land surface schemes (LSSs), are found to be very sensitive to water flux interactions in SE Asia. In particular, one of the problems identified relates to the representation of the inter-annual climate cycles and daily patterns of convective rainfall, e.g. (Neale and Slingo, 2003).

This study intends to contribute to the understanding of spatial variability in hydro-climatic cycles in SE Asia, focusing on three representative geographical areas: Northern Thailand, Peninsular Malaysia and Borneo. These regions have been chosen because they represent the hydro-climatic gradient from the Equator to Tropic of Capricorn and because of the availability of catchment/plot studies within the area.

METHOD

Data-based mechanistic modelling

Time series data sets of rainfall, riverflow, radiation and evapotranspiration have been analysed using the Data Based Mechanistic (DBM) methodology (Young, 2001), which uses only the available data to suggest the model structure, through the use of statistical techniques. The DBM methodology follows three steps: (a) Defining the different model structures and parameter estimates obtained using different methods to find models. (b) Application of statistics, RT^2 (Nash and Sutcliffe, 1970) to data obtained from controlled experiments or passive observations to define a model structure that describes the system behaviour. (c) Finding of a physical explanation of the model results.

By using fewer parameters, there are not as many structure and parameter combinations, which would result in greater parametric uncertainty. DBM techniques explicitly quantify parameter uncertainty (Young, 2001). The DBM methodology includes several different tools, the one used here is the Unobserved Components - Dynamic Harmonic Regression (UC-DHR) model.

Dynamic harmonic regression

UC-DHR is described in detail by (Young *et al.*, 1999) and is a simpler version of the Unobserved Component (UC) model type, i.e. its components are hypothetical and not readily measured or observed. Its general form is as follows:

$$y_t = T_t + S_t + e_t \qquad (1)$$

where $\boldsymbol{y_t}$ refers to the time series, $\boldsymbol{T_t}$ is the trend or less frequent component (i.e. it represents the inter-annual variability), $\boldsymbol{S_t}$ is the seasonal component (i.e. it represents the variability within the year) and $\boldsymbol{e_t}$ is the irregular component, which represents noise and uncertainty. S_t is the dominant component and is defined:

$$S_t = \sum_{i=1}^{R_s} \{a_{i,t} \cos(\omega_i t) + b_{i,t} \sin(\omega_i t)\} \quad (2)$$

where $a_{i,t}$ and $b_{i,t}$ are stochastic parameters that vary with time (TVPs) and ω_i, t = 1,…, R_s refer to the seasonal frequencies in the data series.

UC-DHR has been developed to work with the Matlab® software, as part of the Captain Toolbox, developed in Lancaster University for time series analysis and forecasting (see Centre for Research on Environmental Systems (CRES) in *http://www.es.lancs.ac.uk/cres/*). UC-DHR is used in this study to identify the temporal components included in the time series data sets of rainfall, runoff, radiation and evapotranspiration obtained from field sites in Northern Thailand, Peninsular Malaysia and Northern Borneo.

Evaluation of model performance

The performance of the model is assessed using the simplified Nash & Sutcliffe (1970) efficiency measure, R_T^2 (Young, 2001) or *E* (Krause *et al.*, 2005):

$$R_T{}^2 = 1 - \frac{\sigma_r^2}{\sigma_o^2} \quad (3)$$

where σ_r^2 is the variance of the model residuals (i.e. model fit – observations) and σ_o^2 is the variance of the observed time series. R_T^2 varies between -∞ and 1 (perfect fit).

SITE AND DATA SETS

Fig. 1 shows a schematic map of Southeast Asia with the three geographical ‘boxes’ chosen for this study as being representative of the Southeast Asia region. Within these boxes, the field sites for the chosen data sets are shown. The size of the box is chosen to roughly match 5x5 pixels in HadGAM (The Hadley Centre General Atmospheric Model) mode, where the pixel resolution is 1.25° latitude and 1.875° longitude.

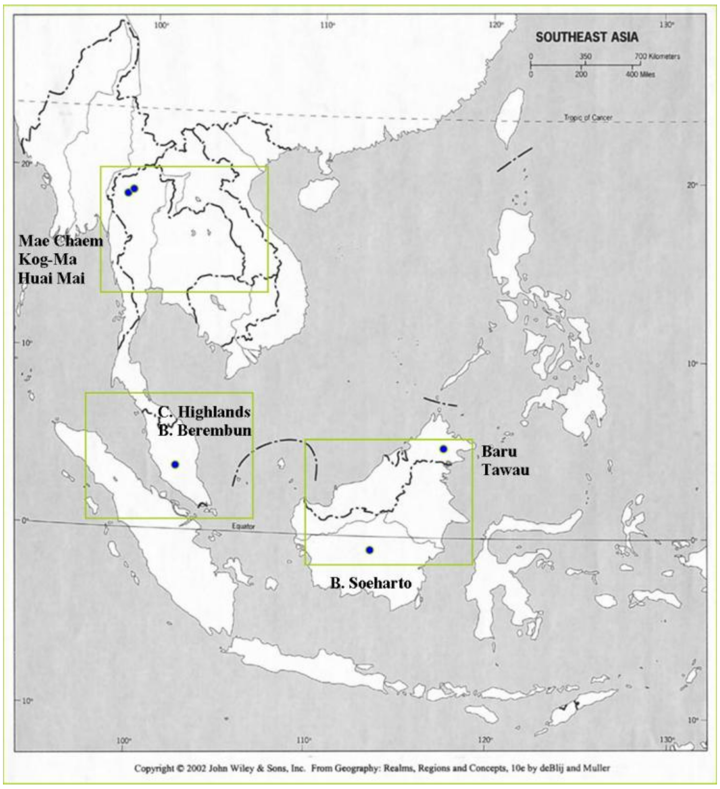

Fig. 1 Map of Southeast Asia showing the location of the dataset field sites

In Northern Thailand, the *Kog-Ma* dataset provides 4 years of hourly rainfall and radiation (1998-2001) and two years of hourly latent heat (1998-99), where January data is missing for both years. This data were collected from a 50 m tower (18°48.756'N – 98°54.012'E), located within a hill evergreen forest (Ohta *et al.*, 1999; Tanaka *et al.*, 2003; Hashimoto *et al.*, 2004). The *Mae Chaem* dataset provides 47 years of daily rainfall (1952-99) and 46 years of daily streamflow (1953-99) from the P14 sub-basin (area 3853 km^2). It belongs to the Royal Irrigation Department (RID) and is fully described elsewhere (Boochabun *et al.*, 2004). *Huai Mai*, a sub-basin of P14, provides 3 months of 15 min streamflow (Lim *et al.*, 2004).

In Peninsular Malaysia, the *Cameron Highlands* hourly rainfall dataset covers 6 months (April-September 1998). The rain gauge is located at 4°28'N 101°22'E, at an altitude of 1545 m and is part of the routine GAME-T2 observation programme network led by Professor Matsumoto of the Department of Earth and Planetary Science of the University of Tokyo, Japan. The *Bukit Berembun* dataset includes 7 years (1981-87) of daily rainfall and riverflow from a lowland dipterocard forest located at 2°46'N 102°6'E (Chappell *et al.*, 2005).

In Borneo, the *Bukit Soeharto* data set includes 2 years (2001/02) of 30 min rainfall and net radiation, although for net radiation, only the data until august 2002 is used. It also includes hourly latent heat with several data gaps. The data was collected from a 30 m tower (0°51' S 117°02'E), located in the Bukit Soeharto Education Forest (BSEF). The principal investigator is Minoru Gamo of the National Institute of Advanced Industrial Science and Technology (AIST), Ibaraki, Japan. The *Baru* 5 min riverflow data set (water year 1/7/95-30/6/96) was obtained from a 0.44 km^2 experimental catchment located in Sabah, (Chappell *et al.*, 1999). Finally, the *Tawau* dataset, 18 years (1980-98) of daily rainfall from a rain gauge located 83 km to the South-Southeast of the Danum Valley Field Centre (4°58'N - 117°48'E), Sabah, (Chappell *et al.*, 2001).

RESULTS AND DISCUSSION

This section describes some of the results obtained from the initial analysis of both the diurnal and annual cycles of the datasets described above.

The diurnal component

Table 1 shows a summary of the diurnal cycle amplitude (a) for the relevant time series. The units of rainfall and streamflow are mm h^{-1}, whilst latent heat and net radiation are in hourly means of W m^{-2}.

UC-DHR clearly identifies a 24 h diurnal cycle in the time series of net radiation for both equatorial and northern latitudes. The 24 h diurnal amplitude is shown in Fig. 2, where it can be seen that the northern Thailand amplitude is less variable and of lower magnitude to that nearer the equator. Also it appears to peak in the dry season, just before the wet season starts (May), as described by McGregor & Nieuwolt (1998).

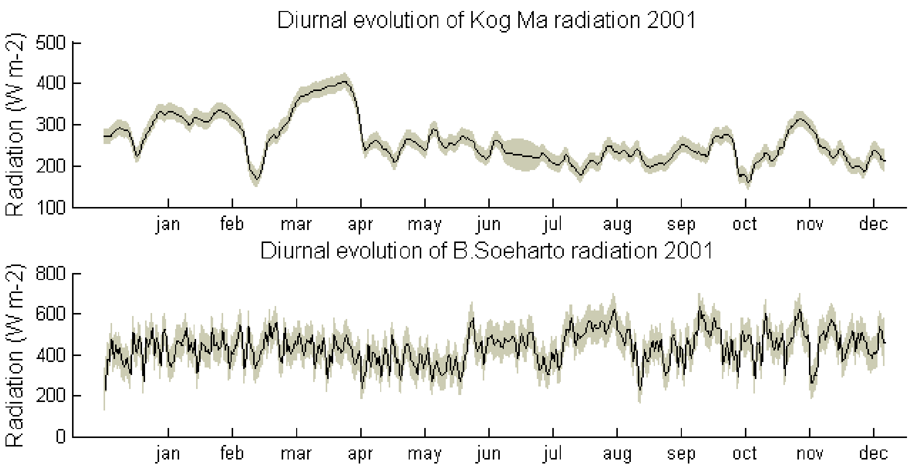

Fig. 2 Diurnal component (24 h) amplitudes of net radiation for the Northern Thailand and Equatorial sites. The greyed area indicates the 95% confidence bands.

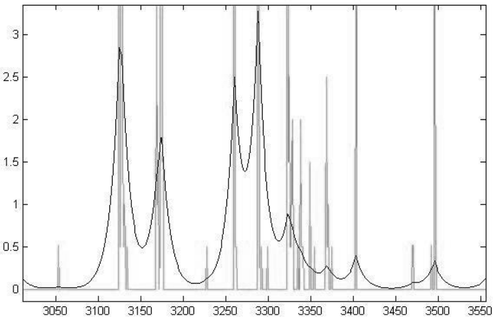

Fig. 3 Example of how filtering transforms datasets. Bars show the raw hourly rainfall, whilst the continuous black line shows the filtered rainfall using RW (random walk).

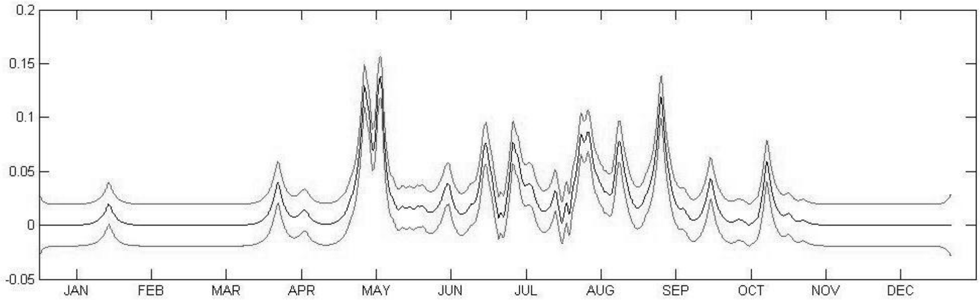

Fig. 4 Diurnal harmonic (24 h) for filtered Kog Ma 1998 rainfall.

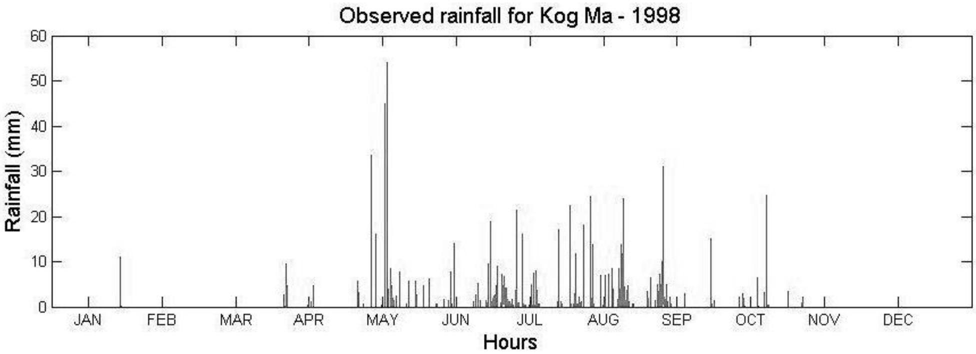

Fig. 5 Hourly time series of rainfall for Kog Ma 1998 (for comparison against Fig. 4).

Regarding rainfall and runoff, the UC-DHR fit may be poorer due to the characteristics of the raw data, which is not normally distributed, with 96% of the rainfall events measuring under 0.5 mm h^{-1} and a mean and median of 0.14 and 0 mm h^{-1} respectively. Because of the way UC-DHR works on the time series averages (W. Tych, personal communication), it is more difficult for UC-DHR to identify the cycles whilst obtaining a good model fit. As a way around this problem, it is thought that data pre-processing may improve the raw data set distribution. This work is currently underway. As an example, rainfall data for Kog-Ma (1998) were filtered using the Captain toolbox mentioned earlier. Fig 3 illustrates how filtering alters the original data set. Applying UC-DHR to the filtered rainfall results in a very good fit ($RT^2 = 0.9$) for the diurnal harmonic amplitude shown in Fig.4, which can be compared with the original hourly rainfall data set (Fig.5). Interpretation of the results is not as clearly marked though but may be provided in relative terms (e.g. information about the time of the year when the diurnal cycle has a stronger influence on rainfall patterns).

The seasonal component

Table 1 shows a summary of the dominant annual cycle amplitude (b) for the time series of all the analysed datasets (see Fig. 1 for location). The units of rainfall and streamflow are mm fortnight^{-1}, whilst latent heat and net radiation are in fortnightly means of W m^{-2}. A poorer fit is obtained this time from the equatorial data sets and this coincides with the fact that the annual seasonality for Northern Thailand is

Table 1 Magnitudes of the diurnal (a) and annual (b) harmonic amplitude.

a)	**Diurnal harmonic**				
North	range		mean	stdev	RT^2
rainfall[1]	*0.0*	*2.2*	*0.2*	*0.3*	*0.21**
riverflow[2]	*0.00*	*0.66*	*0.04*	*0.08*	*0.39**
net radiation[1]	85	406	252	56	0.92
latent heat[1]	31	206	135	35	0.94
West	range		mean	stdev	RT^2
rainfall[3]	*0.0*	*2.7*	*0.4*	*0.4*	*0.35*
Borneo	range		mean	stdev	RT^2
rainfall[4]	*0.0*	*2.2*	*0.3*	*0.3*	*0.27*
	0.0	*7.5*	*0.4*	*0.6*	*0.31*
riverflow[5]	*0.0*	*4.1*	*0.3*	*0.5*	*0.43*
net radiation[4]	222	637	436	74	0.89
	283	673	495	79	0.92
latent heat[4]	*0*	*195*	*68*	*38*	*0.78*

* log-transformed data
[+] 4 yrs, one year logged 0.39
[1] Kog Ma
[2] Huai Mai (subcatchment of Mae Chaem)
[3] Cameron Highlands
[4] Bukit Soeharto 2001/2
[5] Baru

b)	**Annual harmonic**				
North	range		mean	stdev	RT^2
rainfall[1]	14	159	45	20	0.78*
riverflow[1]	4	21	11	3	0.91*
West	range		mean	stdev	RT^2
rainfall[2]	7	30	19	7	0.6
riverflow[2]	0	8	5	2	0.64
Borneo	range		mean	stdev	RT^2
rainfall[3]	12	39	24	7	0.39

* log-transformed data
[1] Mae Chaem
[2] Bukit Berembum
[3] Tawau

stronger than that for the equatorial site, which shows virtually no change and is very close to zero. The lack of seasonality of equatorial rainfall and riverflow is translated into very high uncertainty bands (see Fig. 6), which include negative values. The model fit for the Mae Chaem datasets improved after log-transforming the data (see Fig. 7 for the annual component amplitude evolution over 40 years). The Y-axis units are log(mm $fortnight^{-1}$).

CONCLUSIONS AND FURTHER WORK

Initial results indicate that UC-DHR is very effective in identifying diurnal cycles of net radiation and latent heat, but obtains poorer RT^2 fits when concentrating on rainfall and riverflow datasets. Regarding the inter-annual variability, it highlights the difference in seasonality between Mae Chaem at 18°N and equatorial Bukit Berembun.

The above mentioned results are not entirely finalised, however they provide an example of the way UC-DHR works on the identification of diurnal and inter-annual cycles from different environmental variables. Once the analysis and interpretation of the results is completed, it will be used to identify the dominant hydro-climatic behaviour to be expected from the analysis of the GCM output, which will take place in the next stage of this project.

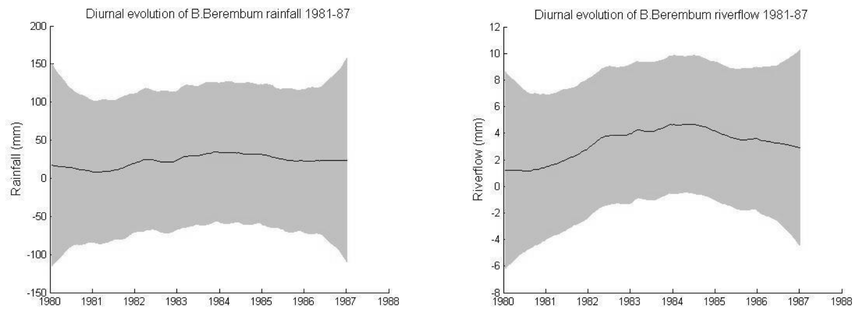

Fig. 6 Bukit Berembun annual evolution of rainfall and riverflow, 1981-87. The Yaxis corresponds to rainfall in mm fortnight^{-1}.

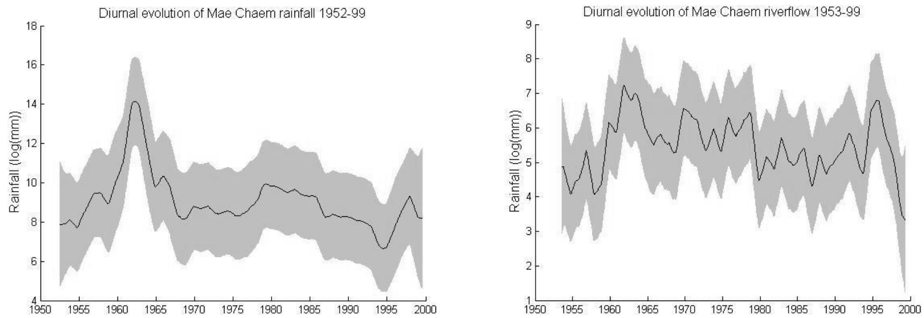

Fig. 7 Mae Chaem, annual component amplitude evolution of rainfall and riverflow. The raw data was log-transformed before applying UC-DHR, therefore the Yaxis units are log (mm fortnight^{-1})

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REFERENCES

Bonell, M. (2004) Runoff generation in tropical forests. Forests, Water and People in the Humid Tropics. M. Bonell and L. A. Bruijnzeel. Cambridge, Cambridge University Press**:** 925.

Boochabun, K., W. Tych, N. A. Chappell and P. A. Carling (2004) "Statistical modelling of rainfall and river flow in Thailand." *Journal Geological Society of India* **64**: 503-515.

Chappell, N. A., K. Bidin and W. Tych (2001) "Modelling rainfall and canopy controls on net-precipitation beneath selectively-logged tropical forest." *Plant Ecology* **153**: 215-229.

Chappell, N. A., P. McKenna, K. Bidin, *et al.* (1999) "Parsimonious modelling of water and suspended sediment flux from nested catchments affected by selective tropical forestry." *Philosophical Transactions Royal Society London* **B** (354): 1831-1846.

Chappell, N. A., W. Tych, Z. Yusop, *et al.* (2005) Spatially significant effects of selectively tropical forestry on water, nutrient and sediment flows: a modelling-supported review. Forests, Water and People in the Humid Tropics. M. Bonell and L. A. Bruijnzeel, Cambridge University Press.

Hashimoto, S., N. Tanaka, M. Suzuki and A. Inoue (2004) "Soil respiration and soil CO2 concentration in a tropical forest, Thailand." *Journal of Forest Research* **9**: 75-79.

Krause, P., D. P. Boyle and F. Base (2005) "Comparison of different efficiency criteria for hydrological model assessment." *Advances in Geosciences* **5**: 89-97.

Lim, H. S., K. Richards and K. Kurji (2004) Runoff response of small forested catchment in the seasonally humid tropics: identification of runoff processes and modelling. Forests and Water in Warm, Humid Asia. R. C. Sidle, M. Tani, A. R. Nik and T. A. Tadese. Uiji**:** 271-274.

McGregor, G. R. and S. Nieuwolt (1998) *Tropical Climatology*, John Wiley and Sons.

Nash, J. E. and J. V. Sutcliffe (1970) "River flow forecasting through conceptual models, Part I - A discussion of principles." *Journal of Hydrology* **10**: 282-290.

Neale, R. and J. Slingo (2003) "The Maritime Continent and its role in the Global Climate: a GCM study." *Journal of Climate* **16**: 834-848.

Ohta, T., K. Suzuki, Y. Kodama and J. Kubota (1999) "Characteristics of the heat balance above the canopies of evergreen and decidous forests during the snowy season." *Hydrological Processes* **13**(14-15): 2382-2394.

Tanaka, K., H. Takizawa, N. Tanaka and I. Kosaka (2003) "Transpiration peak over a hill evergreen forest in Northern Thailand in the late dry season; assessing the seasonal changes in evapotranspiration using a multilayer model." *Journal of Geophysical Research* **108**(D17): 4533.

Young, P. C. (2001) Data-based mechanistic modelling and validation of rainfall-flow processes. Model validation in Hydrological Science. M. G. Anderson. Chichester, Wiley**:** 117-161.

Young, P. C., D. J. Pedregal and W. Tych (1999) "Dynamic Harmonic Regression." *Journal of Forecasting* **18**: 369-394.