University of BRISTOL


# Assessment of Meteorological Variables from MM5 for Reference Evapotranspiration Estimation

***By***

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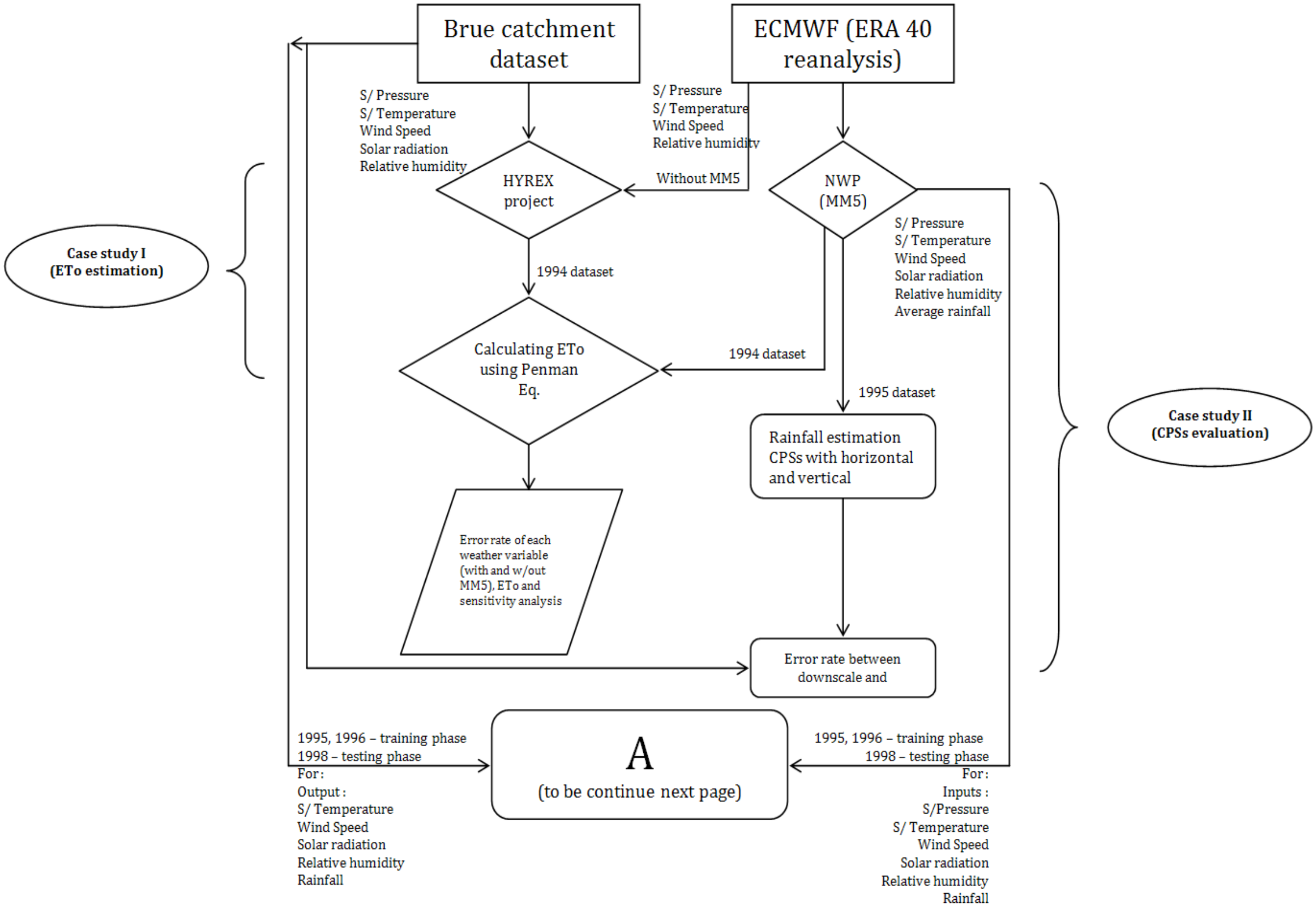
# OVERVIEW

## The methodology adopted to explore in the thesis



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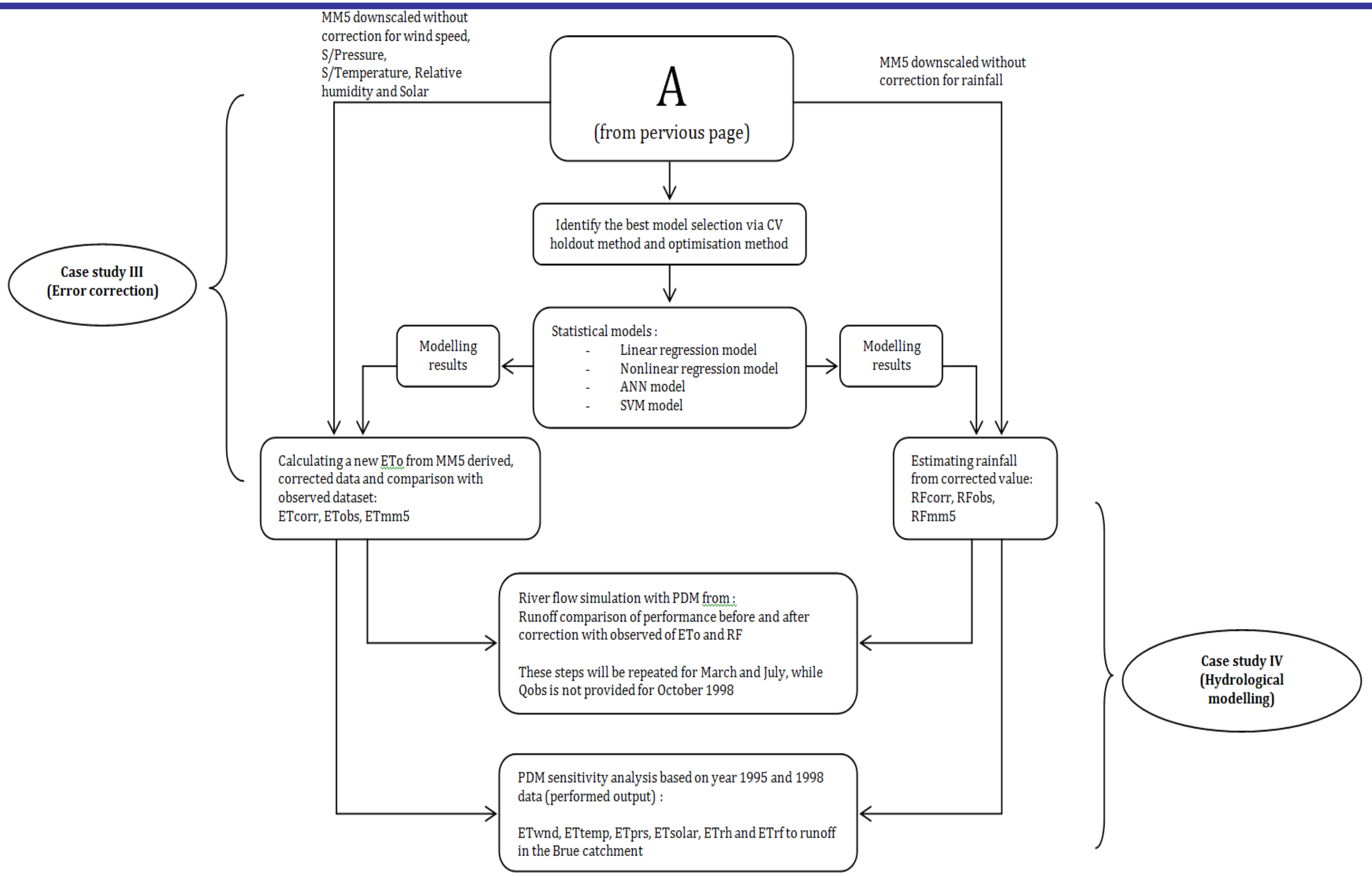


# Outline

- ***INTRODUCTION***
- ***METHODOLOGY***
- ***TEST CASES***
- ***FINDINGS***
- ***DISCUSSION/CONCLUSION***
- ***Q/A***

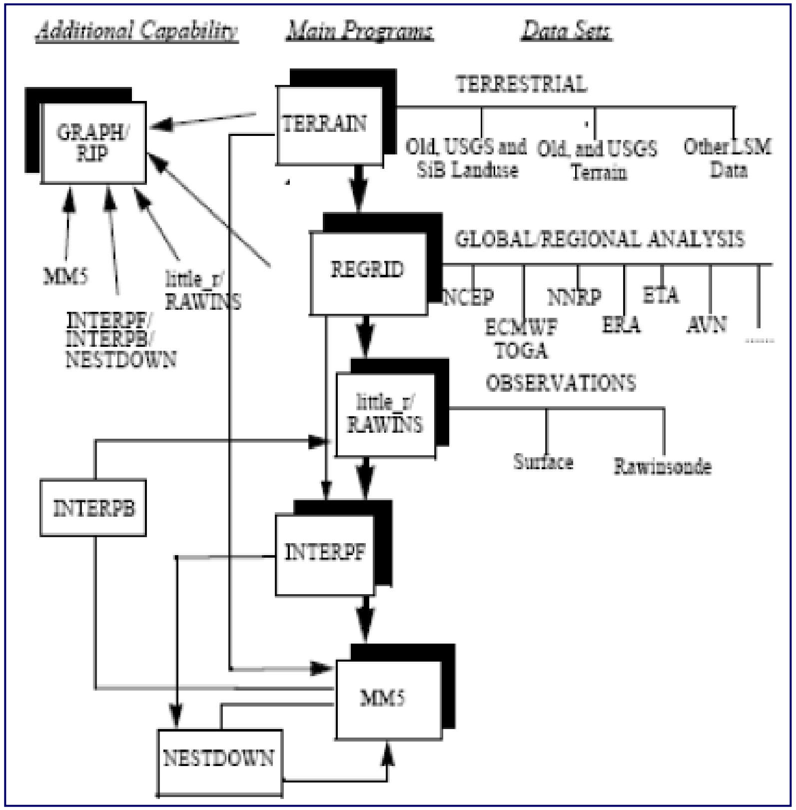
# Introduction

- ***Sustainable water resource management*** **- water availability and quantification of the spatial and temporal changes of hydrological processes;**
- ***Evapotranspiration*** **- major role in the hydrological cycle > agricultural, hydrological, ecological and climatic systems;**
- ***Evapotranspiration*** **- estimated through reference evapotranspiration (i.e., ETo) through many approaches. Doorenbos and Pruitt (1977) made an early attempt and they documented their studies as "FAO-24 Report" - was widely used by many researchers;**
- **The *Food and Agriculture Organization of the United Nations (FAO)* have proposed the Penman–Monteith (FAO-56 PM) method as the standard method;**
- **The PM method requires *a lot of meteorological data*, such as air temperatures, atmospheric pressure, relative humidity, solar radiation and wind speed;**
- **Many published studies point out the major challenges associated with data availability required for the PM method (Shih et al., 1983). For example, *lack of continuous* solar radiation data is quite common, even in developed countries such as the USA and Canada (Remesan et al., 2008);**
- **1) what are *the accuracy* of the downscaled data in comparison with the in-situ measurements? 2) is there an *improvement* between the downscaled data and the original global data? 3) what is the *accuracy of the ETo estimated* from the downscaled data? 4) what are the *impact of individual weather variables* on the ETo estimation?**

# Overview and advantages of NWM （MM5）

- Weather prediction, based on the mathematical solution of the equations governing atmospheric dynamics – wind forecast eq., continuity eq., temperature forecast eq., moisture forecast eq., hydrostatic eq.;
- Proposed by the British scientist Lewis Fry Richardson in his book Weather Prediction by Numerical Process in 1922 and tested by the American meteorologist in 1950;
- MM5, was developed from the 1970s original mesoscale model by the National Center for Atmospheric Research (NCAR), and the Penn. State University;
- Useful for Un-gauged catchment;
- Meteorological variables for water resources management, air quality modelling, flood forecasting, forest fire prediction (Kitwiroon et al. 2003; Chandrasek et al 2003; Coppola et al. 2006; Pasken et al. 2005;, Hoadley et al. 2006) as well as the more traditional weather forecasting and flood operation.

# Overview and advantages of NWM （MM5）




*(Dudhia et al., 2003)*

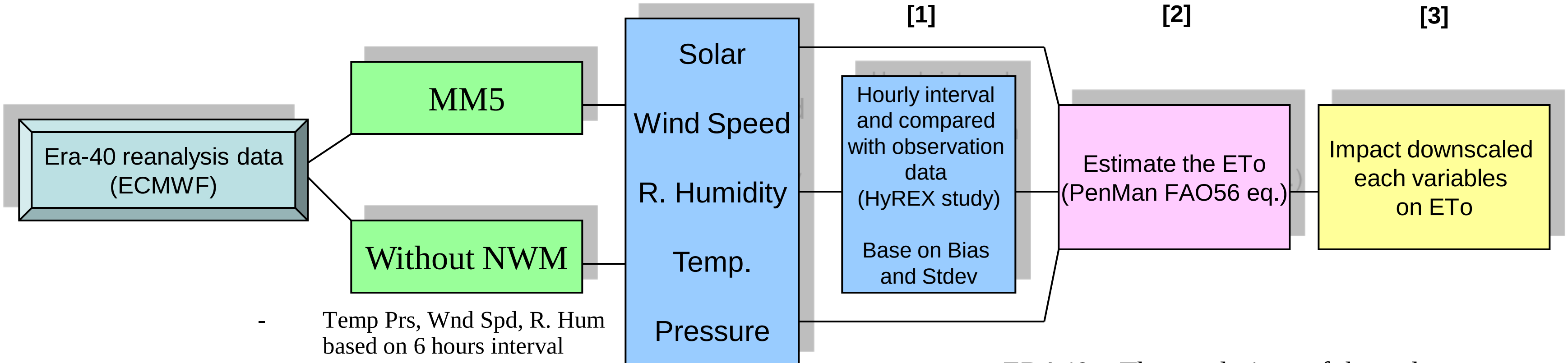
| | Model Type | vertical coordinate system | Domain | Resolution |
|---|---|---|---|---|
| **UKMET** (UK) | Gridpoint | 30 hybrid levels | global and mesoscale | 60 km global 10 km mesoscale |
| **GEM** (Global Enviromental Multiscale -Canada) | Spectral | 58 hybrid sigma Z levels | Global and regional | 15km regional 0.45° lon 0.30° lat global |
| **ECMWF** (European Centre For Medium-Range Weather Forecasts) | Spectral | 60 hybrid sigma levels | Global | 511 wave/26 km |
| **WRF** (Weather Research Forecasting) | Gridpoint | eta or zeta coordinates, | Mesoscale and regional | 10 km |
| **NOGAPS** (Navy Operational Global Atmospheric Prediction System) | Spectral | 30 hybrid sigma-pressure | Global | 239 waves/ 56 km |
| **MM5** Mesoscale Model Fifth Generation | Gridpoint | 42 pure sigma levels | Mesoscale | min res 10km |
| **RUC** Rapid Update Cycle | Gridpoint | 50 hybrid sigma theta levels | Regional | 20 km res |

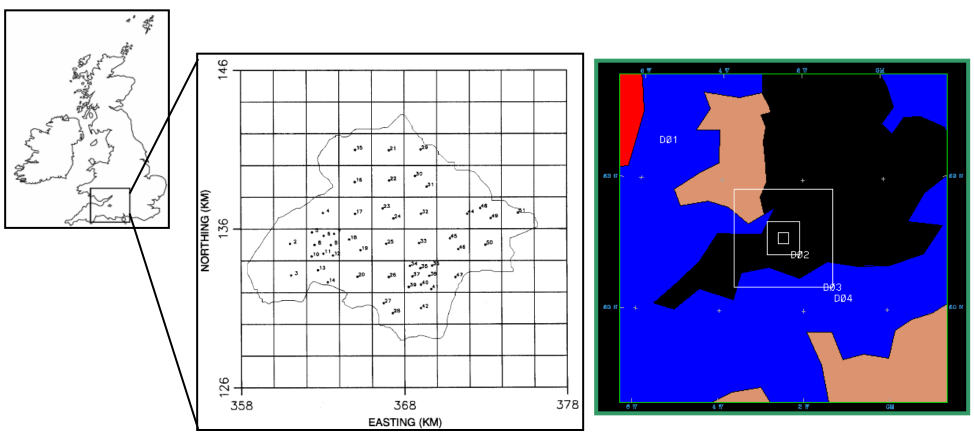
*(Michaela Bray Thesis, 2008)*

# Objectives

- To explored a potential application of downscaled global reanalysis weather data using MM5;
- To downscale the global data down to much finer resolutions in space and time for use in hydrological investigations;
- To compared the ERA-40 reanalysis data with the observation data; Do we need NWM? The accuracy? Impact on ETo estimation?

# Framework




- ERA40 > The resolutions of these data are 1°x1° in space and 6 hours in time;
- Imposed boundary conditions are updated every 6 hours using the ECMWF ERA40 dataset;
- Initial boundary condition from ECMWF;
- Jan 94, Mar 94, Jul 94, Oct 94 to represent cold and warm seasons over Brue catchment;
- grid spacing of 27, 9, 3, 1-km ;
- four domains consist of 21 × 21, 19 × 19, 19 × 19, and 19 × 19 horizontal grids;
- Without NWM > to evaluate the performance of using the MM5 to downscale the ERA40 weather data over the Brue catchment (based on 6 hours interval);

# Penman Eq. (FAO 56 report)

1

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{37}{T_{hr} + 273} u_2 (e^o(T_{hr}))(1 - Rh))}{\Delta + \gamma(1 + 0.34u_2)}$$

where :

| | |
|---|---|
| $R_n$ | = net radiation at the grass surface (MJ $m^{-2}$ $hour^{-1}$), |
| $G$ | = soil heat flux density (MJ $m^{-2}$ $hour^{-1}$), |
| $T_{hr}$ | = mean hourly air temperature (°C), |
| $\Delta$ | = saturation slope vapor pressure curve at Thr (kPa oC-1), |
| $e^o(Thr)$ | = saturation vapor pressure at air temperature Thr (kPa), |
| *ea* | = average hourly actual vapor pressure (kPa), and |
| $u_2$ | = average hourly wind speed (m s-1). |
| *Rh* | = relative humidity |

2

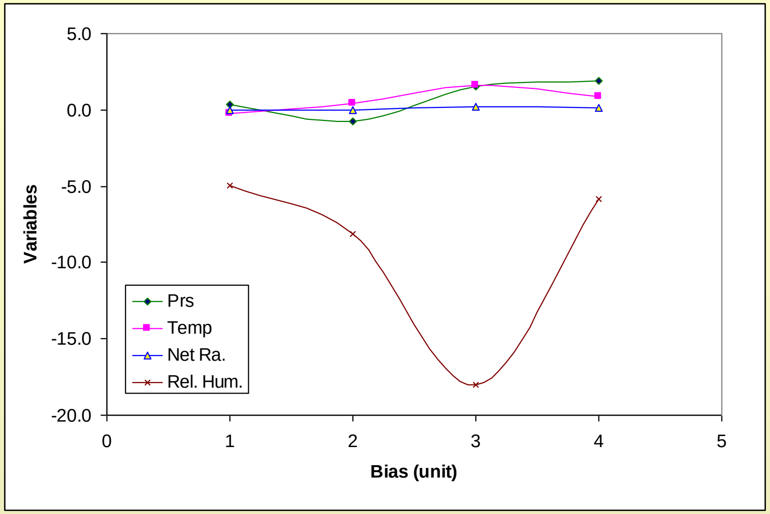
$$MBE = \frac{\sum_{i=1}^{n}(y_i - x_i)}{n}$$

3

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(y_i - x_i - MBE)^2}{n-1}}$$

where *n* is the number of observations; *xi* = observed variable and *yi* = estimated variable.

# Findings




- **This section - comparisons of the MM5 downscaled data against the observed data sets in the Brue catchment;**
- **Wnd - due to the sensitivity of wind to local environment and the greater wind spatial variations in comparison with other weather variables such as pressure and temperature.**

**The statistics of different meteorological variables derived from the mesoscale model (MM5)**

| | | BIAS | SD |
|---|---|---|---|
| Surface pressure (mb and %) | Jan-94 | 0.37 (0.036) | 1.48 (0.15) |
| | Mar-94 | -0.74 (-0.073) | 3.84 (0.38) |
| | Jul-94 | 1.52 (0.15) | 0.79 (0.08) |
| | Oct-94 | 1.88 (0.17) | 1.04 (0.10) |
| Surface temperature ($^{o}$C and %) | Jan-94 | -0.20 (-3.54) | 1.33 (24.1) |
| | Mar-94 | 0.43 (6.01) | 1.63 (22.5) |
| | Jul-94 | 1.64 (9.35) | 2.05 (11.7) |
| | Oct-94 | 0.87 (8.81) | 1.77 (18.0) |
| Net radiation (MJ $m^{-2}$ $hr^{-1}$ and %) balance of incoming solar radiation and outgoing terrestrial radiation | Jan-94 | 0.017 (8.8) | 0.14 (72.4) |
| | Mar-94 | 0.019 (3.7) | 0.25 (50.9) |
| | Jul-94 | 0.19 (22.1) | 0.43 (51.5) |
| | Oct-94 | 0.11 (22.8) | 0.24 (49.5) |
| Relative humidity (% and %) measure of amount of water vapour in atmosphere | Jan-94 | -4.97 (-5.47) | 7.06 (7.8) |
| | Mar-94 | -8.10 (-9.23) | 6.81 (7.8) |
| | Jul-94 | -18.0 (-21.1) | 9.48 (11.1) |
| | Oct-94 | -5.84 (-6.69) | 8.49 (9.73) |
| Wind speed (m/s and %) | Jan-94 | 5.84 (260) | 3.33 (149) |
| | Mar-94 | 5.80 (217) | 2.32 (86.6) |
| | Jul-94 | 3.55 (301) | 1.71 (145) |
| | Oct-94 | 4.95 (418) | 2.29 (194) |

Theoretically, when temperature increases, relative humidity in the atmosphere decreases and the value of ETo increases.

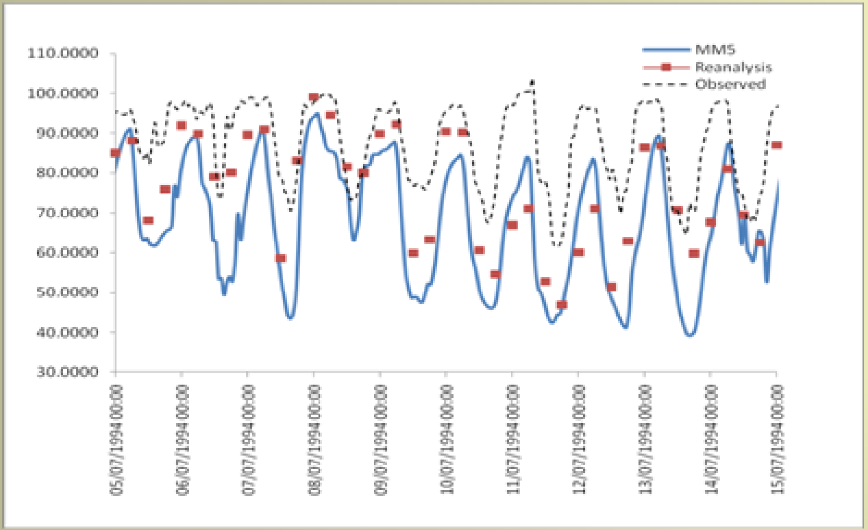
# Findings

- **Next, a comparison is made between the measured data and the original reanalysis data (ERA-40) (i.e., without being downscaled by the MM5);**
- **To ascertain and quantify any benefits of using the MM5 to downscale the ERA-40 data to a finer resolution.**

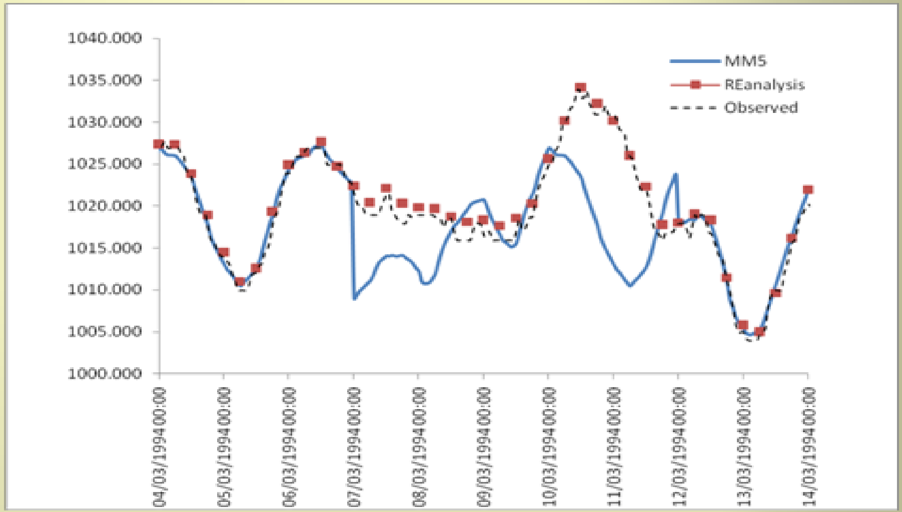
## The comparison between the ERA-40 reanalysis data and the MM5 data

| | | BIAS (%) | | SD (%) | |
|---|---|---|---|---|---|
| | | MM5 | Reanalysis | MM5 | Reanalysis |
| Surface pressure | Jan-94 | 0.04 | 0.08 | 0.15 | 0.11 |
| | Mar-94 | -0.073 | 0.08 | 0.38 | 0.07 |
| | Jul-94 | 0.15 | 0.18 | 0.08 | 0.07 |
| | Oct-94 | 0.19 | 0.22 | 0.1 | 0.1 |
| Surface temperature | Jan-94 | -3.54 | 13.48 | 24.1 | 19.9 |
| | Mar-94 | 6.01 | 7.8 | 22.5 | 14.1 |
| | Jul-94 | 9.35 ← | 3 | 11.7 | 10.5 |
| | Oct-94 | 8.81 | 8.99 | 18.0 | 14.2 |
| Relative humidity | Jan-94 | -5.47 | -5.55 | 7.8 | 7.6 |
| | Mar-94 | -9.23 | -9.26 | 7.8 | 9.1 |
| | Jul-94 | -21.09 ← | -13.61 | 11.1 | 10.5 |
| | Oct-94 | -6.69 | -8.2 | 9.7 | 10.9 |
| Wind speed | Jan-94 | 260 | 216 | 148 | 121 |
| | Mar-94 | 217 | 202 | 87 | 98 |
| | Jul-94 | 301 | 273 | 145 | 151 |
| | Oct-94 | 419 | 332 | 194 | 160 |

# Findings



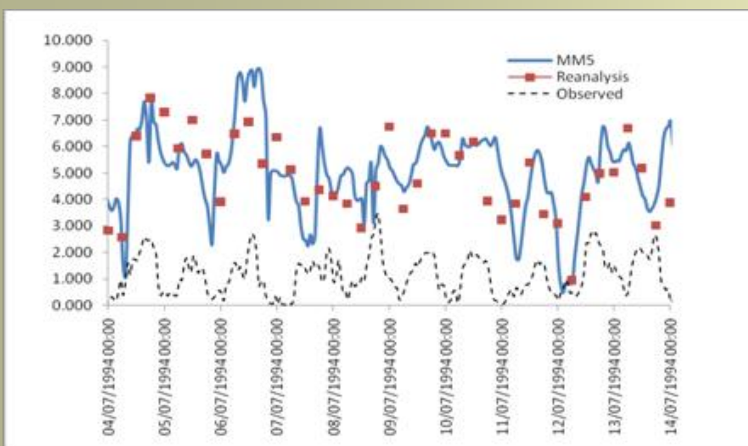

Ten day time series of relative humidity
between the reanalysis, MM5 and the observed



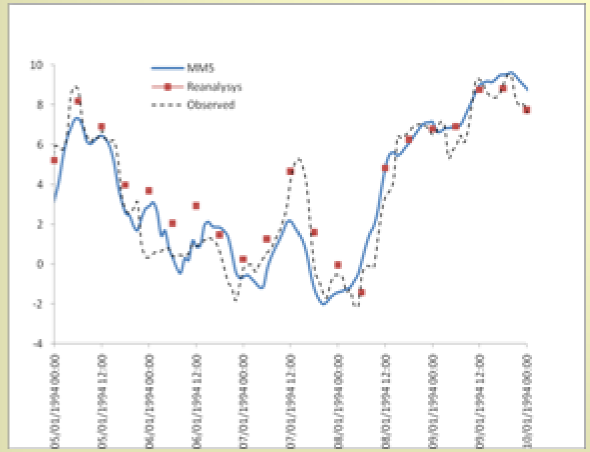

Ten day time series of surface pressure
between the reanalysis, MM5 and the observed

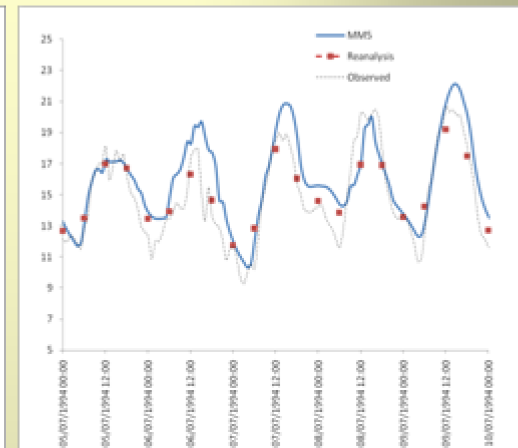
- **Reanalysis - lower than the observed ones which are in a similar pattern to the MM5 downscaled values;**
- **The MM5 downscaled relative humidity values are better in bias**

# Findings




Ten day time series of wind speed
between the reanalysis, MM5 and the observed




Ten day time series of surface temperature
between the reanalysis, MM5 and the observed (left: winter; right: summer)

- Time series plots for 5 days in winter and summer - MM5's overestimation in summer and underestimation in winter;
- The reanalysis data are in very good agreement in winter with higher temperature; but
- Tend to overestimate the low temperature;
- In the summer, the reanalysis data miss both high and low temperature, but do well with the average temperature.

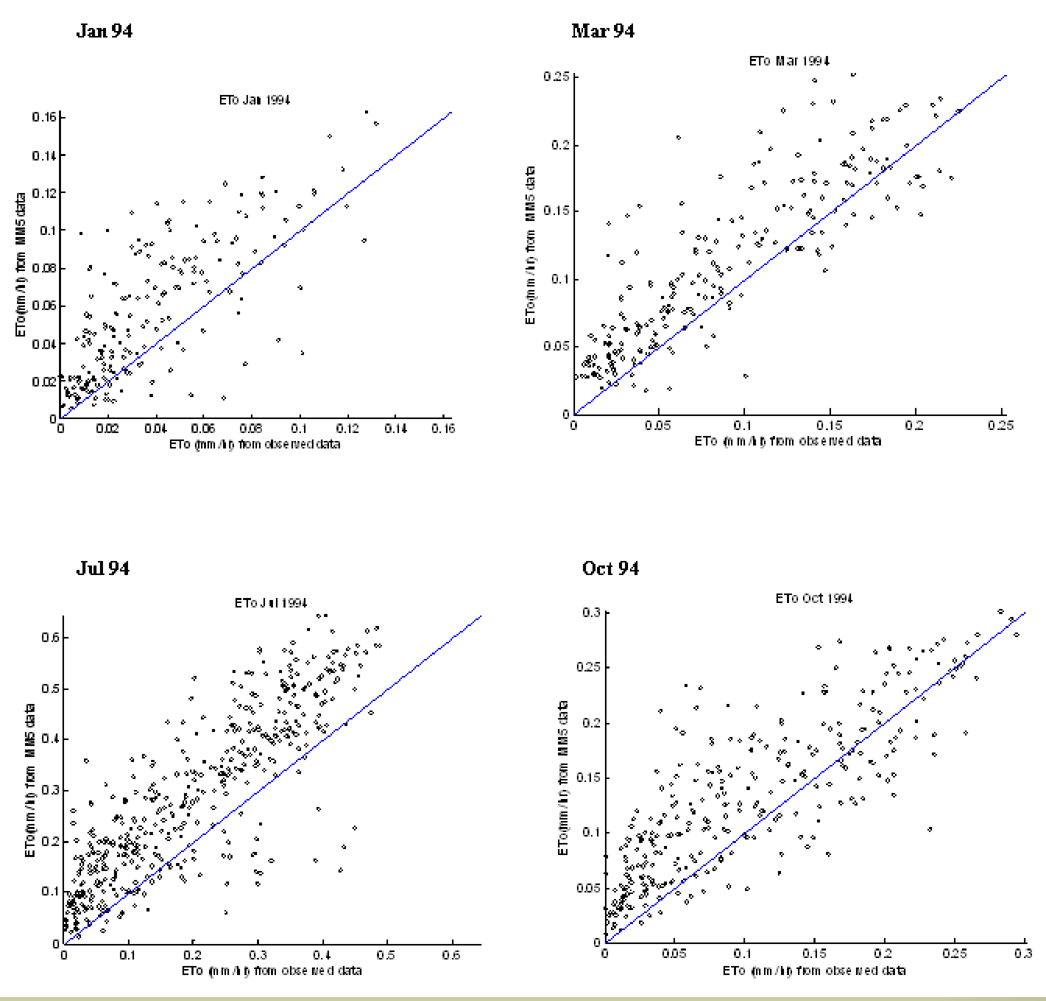
# Findings

## The results of the ETo derived from MM5

| | BIAS (mm/hr and %) | SD (mm/hr and %) |
|---|---|---|
| Jan | 0.018 (46%) | 0.024 (64%) |
| Mar | 0.023 (27%) | 0.032 (37%) |
| July | 0.088 (44%) | 0.085 (43%) |
| Oct | 0.029 (29%) | 0.044 (43%) |

**FAO56 PM ETo is calculated :**

- **Firstly using the meteorological variables downscaled by MM5;**
- **Secondly by using the observed data measured on the Brue catchment;**
- **The ETo derived from the observed data is used as the benchmark (i.e., ground truth);**
- **The overestimation is worst in summer (0.088mm/hr) and least in winter (0.018mm/hr);**
- **The absolute bias in summer is the greatest, its relative bias is smaller than winter due to its large ETo.**



# Findings

## MM5 downscaled data impact on ETo

- How important these variables contribute to the ETo result ???;
- Finally the sensitivity of the different downscaled weather variables on ETo is carried out;
- The MM5 downscaled pressures have a minimum impact on ETo - no need to put any further effort in improving the atmospheric pressure accuracy;
- Surface air temperature and wind play a minor role in contributing to the ETo discrepancy;
- Net radiation and relative humidity are the most important weather variables among the downscaled data;
- Impacts vary between cold and warm seasons.
- Cold period (winter and spring), relative humidity plays a dominant role;
- Warm period (summer and autumn), net radiation has the most important impact.

| | | ETo (%) |
|---|---|---|
| Surface pressure (mb and %) | Jan-94 | -0.02 |
| | Mar-94 | 0.03 |
| | Jul-94 | -0.04 |
| | Oct-94 | -0.07 |
| Surface temperature (°C and %) | Jan-94 | -2.6 |
| | Mar-94 | -1.1 |
| | Jul-94 | 1.6 |
| | Oct-94 | -0.5 |
| Net radiation (MJ $m^{-2}$ $hr^{-1}$ and %) | Jan-94 | 6.4 |
| | Mar-94 | 2.8 |
| | **Jul-94** | **18.2** |
| | **Oct-94** | **17.2** |
| Relative humidity (% and %) | **Jan-94** | **20.2** |
| | **Mar-94** | **17.4** |
| | Jul-94 | 12.0 |
| | Oct-94 | 3.6 |
| Wind speed (m/s and %) | Jan-94 | 10.1 |
| | Mar-94 | -1.0 |
| | Jul-94 | -0.5 |
| | Oct-94 | 6.6 |

# Result discussions

- This study explored a performance of downscaled global ERA40 reanalysis data using and without the MM5;
- It is not always possible to get access to in-situ weather measurements, especially for ungauged catchments;
- Measurements of other weather variables such as solar radiation, wind speed, surface temperature, surface pressure and relative humidity are usually missing;
- Atmospheric pressure can be estimated very accurately from the downscaled data (with less than 0.2% error);
- Wind speed is the worst weather variable to derive (with a huge discrepancy of around 300%;
- Air temperature is quite reasonable (< 10%). The net radiation and relative humidity have about 10~20% error;
- In comparison with the original reanalysis data, the downscaled data are generally better except wind speed;
- The reanalysis data only have 6 hour interval and without solar radiation, it is not practical to use the reanalysis data for ETo estimation;
- The ETo estimation from the downscaled data has about 30%~40% error compared with the estimation from the observed weather variables;

# Result discussions

- **Errors are quite large for practical usage; therefore further studies are needed to improve the results by looking at which variables play more influential roles in ETo estimations;**
- **The sensitivity analysis > has shown that the impact of atmospheric pressure is minimal. The air temperature and wind speed play a minor role. The most important weather variables are net radiation and relative humidity;**
- **Interesting to note that albeit the huge discrepancy in wind speed (around 300%), its impact to evapotranspiration is insignificant;**

- **some interesting patterns have been observed. Clearly, more exploration of the downscaled data should be carried out over several decades so that more reliable data quality assessment could be achieved : 5) how could the result be further improved? 6) will the similar patterns be present at different geographical and climatical conditions? 7) Is there any methodology to overcome the error resulted in this study i.e wind speed.**

# Conclusions

**There are several approaches to improve evapotranspiration estimation from the downscaled data :**

- **[1] using error models developed from a short in-situ measurement or through regionalisation**
- **[2] data assimilation using multiple sources could improve the downscaled data i.e remote sensing**
- **[3] modern artificial intelligence (AI) i.e Artificial Neural Networks or Support Vector Machines could be developed to map the downscaled weather variables to evapotranspiration estimation**
- **[4] parameterisation schemes in MM5 may be useful to explore to find an overall optimal scheme for evapotranspiration estimations**
- **The accumulated experience and knowledge will help hydrologists develop regionalisation schemes so that the suitable data correction algorithms could be readily deployed in practical water resources projects.**

# Future works

**Mathematical model and modern artificial intelligence (AI) i.e nonlinear model or Artificial Neural Networks or Support Vector Machines could be developed to map the downscaled weather variables to evapotranspiration estimation :**

- **Calibrate (2/3) and validate (1/3) in 1994;**
- **Calibrate 1994 and validate 1995; simulate 1996**
- **Calibrate 1994 and 1995; validate 1996**

# Thank you