# Role of Atmospheric Thermodynamics in Estimating Extreme Precipitation

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## INTRODUCTION

Events of extreme precipitation have a huge influence on society. They are associated with flooding, erosion, negative impacts on water infrastructure, transport and safety. Precipitation extremes have increased over the last century (Alexander et al.;2006,Westra et al.,2013), and these changes are outcome of human induced, climate change (Min et al.,2011) However, forecasting extreme precipitation is not easy, as reaction and roles played by unseen climate factors has always been mystery.

It is commonly expected that precipitation extremes will increase as the climate warms (Trenberth *et al* 2003, Pall *et al* 2007, Groisman *et al* 2005, Emori and Brown 2005). The primary reason why precipitation extremes are expected to increase follows from the fact that a warmer atmosphere can 'hold' more moisture. The increase in the moisture-holding capacity of the atmosphere with temperature occurs at a rate given by the Clausius–Clapeyron relation (CCR): approximately 7% per degree temperature rise.

## Research Question

How does atmospheric thermodynamics play role in estimating extreme precipitation?

Does local physiographic parameters needs to considered, while predicting extreme precipitation?

## Objectives

The main objective of the present study is to use attributes of atmospheric thermodynamics, to establish relationship between extreme precipitation and temperature using historical database (1960-2010) for Ontario.

To compare the model output(referred as WIT3 model hereafter) with existing non-stationary model(RTA)

## Data Sources

**Physiographic Parameters**

- Longitude
- Latitude
- Barrier height to the West
- Slope in the north/south direction
- Slope in the east/west direction
- Elevation
- Distance to the nearest Great Lake
- **Source:** Waterloo Multiple Physiographic Parameter Regression (WATMAPPR) model (Seglenieks,2009;Soulis et al.,2015)

**Extreme Annual Precipitation Intensity**

- **Source:** Meteorological Services Canada (MSC)

**Temperature**

- Annual daily maximum temperature (from daily mean temperature data)
- Annual mean temperature (from maximum of monthly mean temperature data)
- **Source:** Environment Canada

## Methodology

Using annual daily maximum temperature values, saturated vapour pressure was calculated using following equation based on a Clausius-Clapeyron relationship:

$$e^* = 0.611 \cdot exp(\frac{17.3 \cdot \theta}{\theta + 237.3}) \qquad (1)$$

where:

$\theta$ = Annual daily maximum temperature (°C), as described in Data Source section and

$e^*$ = saturated vapour pressure (kPa)

The final regression equation, was arrive at, until no parameters remained with p-values greater than 0.05.

The equation is:

$$R_n(\tau) = B_0 + B_1 \cdot \Delta t + B_2 \cdot \bar{\theta} + B_3 \cdot e^* + B_4 \cdot I_1 + B_5 \cdot I_2 + B_6 \cdot I_3 \quad (2)$$

where,

$R_n(\tau)$ = Annual daily maximum precipitation intensity(mm/hr)

The corresponding coefficients are:

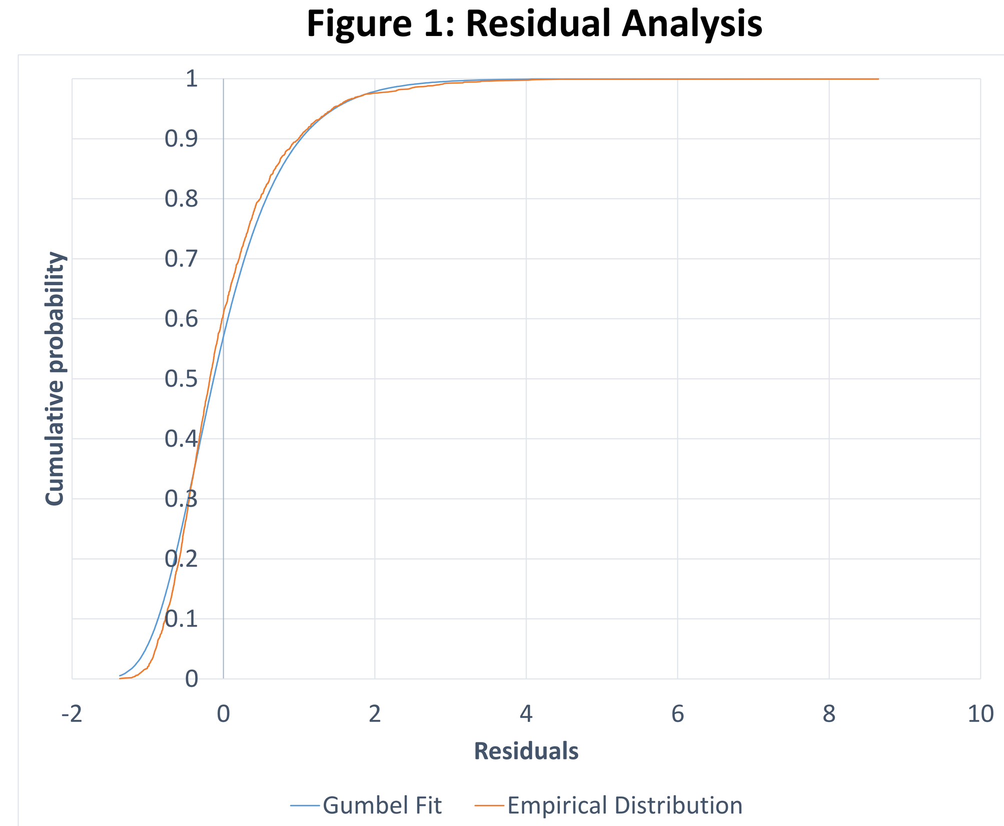
| | Coefficients | Standard Error | t-stat | P-value |
|---|---|---|---|---|
| Intercept | 2.270 | 0.631 | 3.600 | 0.000325 |
| Year-2010($\Delta$t) | 0.00551 | 0.00147 | 3.760 | 0.000175 |
| Mean Temperature ($\bar{\theta}$) | 0.0260 | 0.0135 | 1.922 | 0.0547 |
| Saturated Vapour Pressure(e*) | -0.0705 | 0.0316 | -2.231 | 0.0258 |
| Longitude($I_1$) | -0.0139 | 0.00612 | -2.268 | 0.0234 |
| Latitude($I_2$) | -0.0279 | 0.0123 | -2.274 | 0.0231 |
| Barrier Height to West ($I_3$) | -0.000819 | 0.000401 | -2.044 | 0.0411 |

Based on classical stationary Intensity Duration Frequency theory, as per Hogg etal.,1989, and its modification by Soulis et al.,2015, following modification was adopted for addressing final extreme precipitation quantile :

$$R_n(\tau, T) = B_0 + B_1 \cdot \Delta t + B_2 \cdot \bar{\theta} + B_3 \cdot e^* + B_4 \cdot I_1 + B_5 \cdot I_2 + B_6 \cdot I_3 + K(T) * S(\tau) \quad (3)$$

where,K(T) =Gumbel frequency factor for the return period T (Hogg et al., 1989) and S($\tau$)= Long term standard deviation of extreme rainfall intensity

**Figure 1: Residual Analysis**




Gumbel Distribution Parameters α= -0.35337, β= 0.6122

## Model Output Comparison with Observed Data

For the historical comparison, 56 stations were selected that have a minimum of 20 years of records in total. The stations also have historic temperature and precipitation records that overlap each other by 10 or more years. The average record year for each station was then identified. The results from MOECC, and MTO models were time corrected to the average years for each station for accurate comparisons.

**Figure 2: Stations selected for comparison across Ontario**

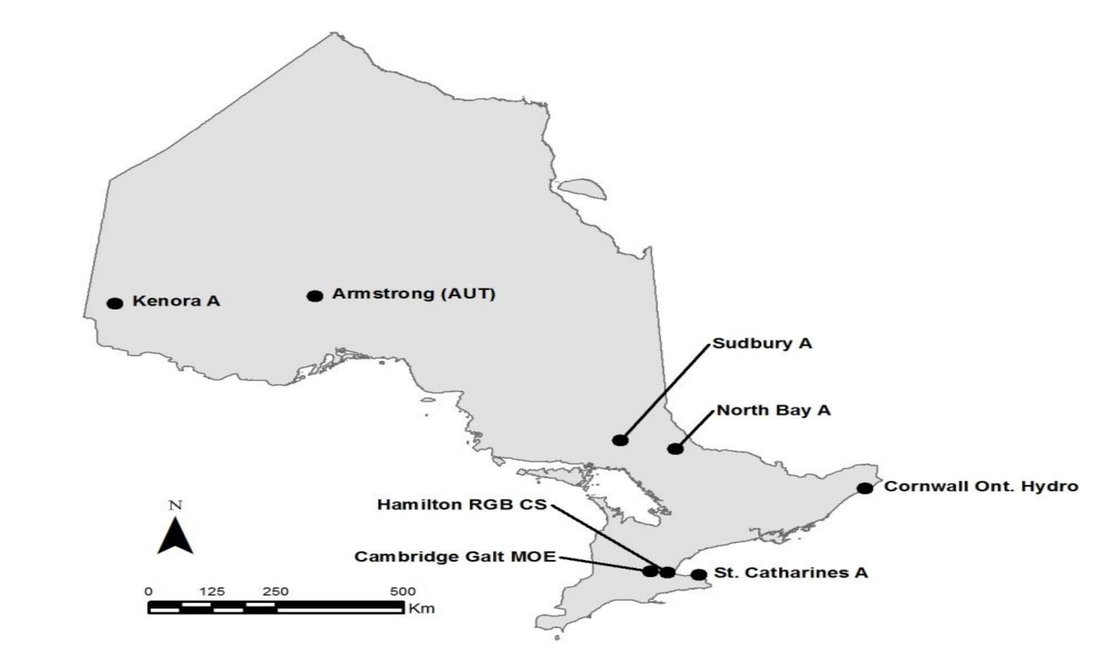



**Figure 3: Comparison of Model Outputs with actual observations (MSC data) for eight stations and study period 1960-2010**

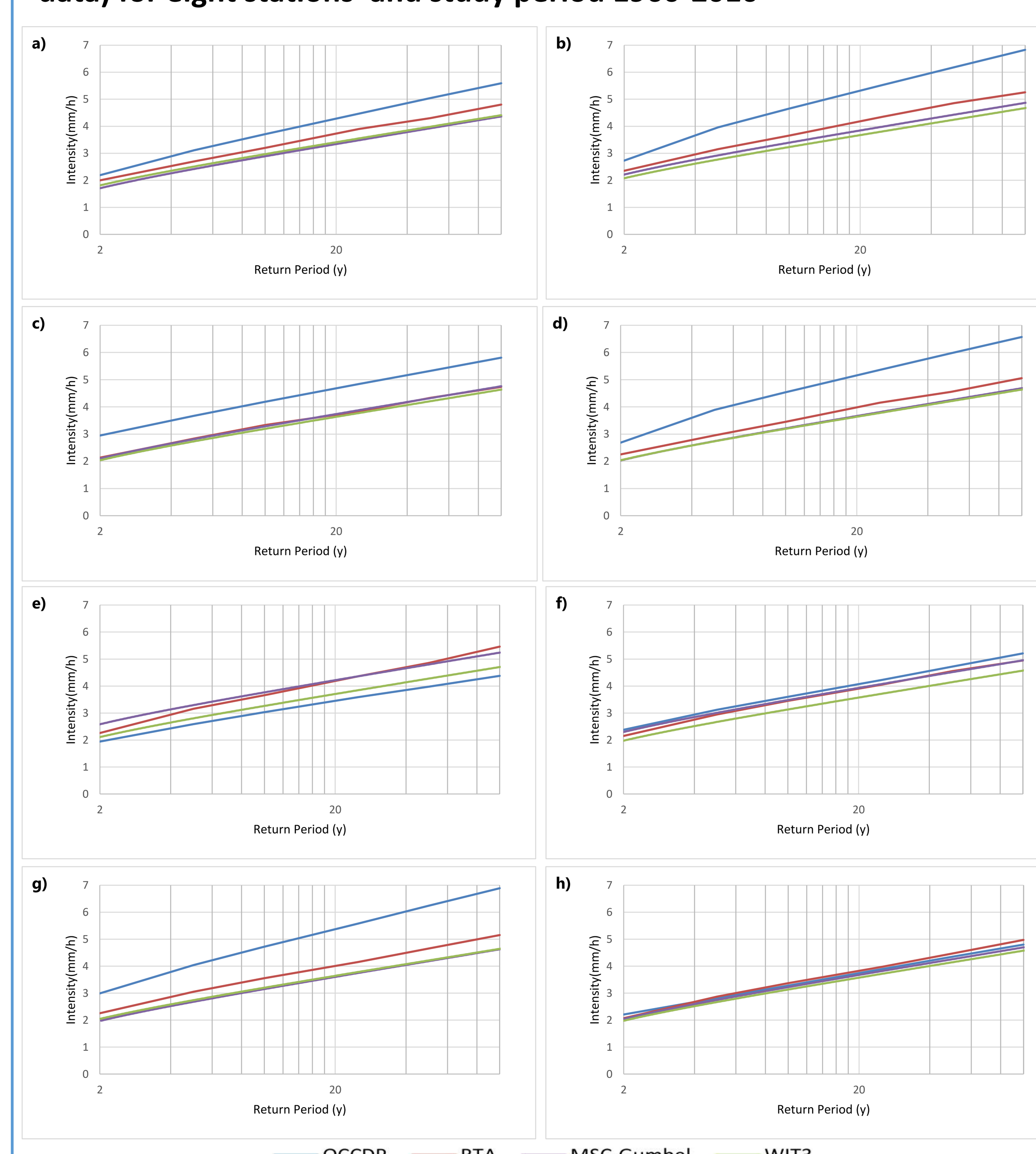



**Table 1: Comparison of Model Outputs with actual observations (MSC data) for 56 stations and study period 1960-2010**

| Return Period (Years) | Mean Difference from MSC ( 24 hour duration) | | Standard Deviation of Difference from MSC | |
|---|---|---|---|---|
| | MOECC | MTO | MOECC | MTO |
| 2 | 0.03 | 0.20 | 0.15 | 0.37 |
| 5 | 0.01 | 0.26 | 0.15 | 0.47 |
| 10 | 0.00 | 0.30 | 0.15 | 0.53 |
| 25 | -0.01 | 0.34 | 0.15 | 0.62 |
| 50 | -0.02 | 0.37 | 0.15 | 0.69 |
| 100 | -0.03 | 0.40 | 0.15 | 0.76 |

## Observations

Authors used MSC 100 year, 24 hr annual maximum rainfall intensity data, fitted to Gumbel distribution (empirical), as a base to compare with MOECC and MTO model output. Authors computed difference between the Gumbel fitted MSC output and respective models.

As can be seen from the table, the MOECC model has largest number of observations near zero. This indicates that the MOECC model has represented the historical data with least discrepancy between actual observations and MOECC generated model output.

The MTO results are close, but tends to overestimate precipitation values and show potential for refinement. The MOECC results are the closest to the empirical MSC results, where it almost perfectly overlaps the Gumbel Distribution of the MSC data.

## Conclusion and Future Scope

Present study combines the atmospheric thermodynamics with temporal trend along with station wise interpolated local physiographic parameters, to forecast extreme precipitation, which has led to a new paradigm that can characterize a rainfall series and be sensitive to environmental attributes, which reflects climate change.

The next part of this research includes forecasting extreme precipitation using MOECC model and extend the future projections using downscaled and bias corrected outputs from Global Climate Models. Authors have also taken into account different Representative Concentration Pathways (RCP) (Climate scenarios)

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