Estimation of Extreme Rainfall in South Africa and Development of Methods to Account for Non-stationary Climate Data

Katelyn Johnson [1,2*] and Jeff Smithers [1,2]

[1]School of Engineering, University of KwaZulu-Natal, South Africa *johnsonk1@ukzn.ac.za
[2]Centre for Water Resources Research, University of KwaZulu-Natal, Pietermaritzburg, South Africa

D81 |EGU2020-3326
WEDNESDAY, 6 MAY 2020, 10:45–12:30

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- Findings

Introduction

- Estimating extreme design rainfall events
  - Needed for design and risk assessment of hydraulic structures
    - Probable Maximum Precipitation
    - Rainfall T > 200 year
- Accounting for non-stationary data
  - Impacts on design rainfalls
    - e.g. due to climate change

Extreme rainfall and flooding in KwaZulu-Natal, South Africa in 2016 and 2017. (ENCA, 2016; SABC, 2017)

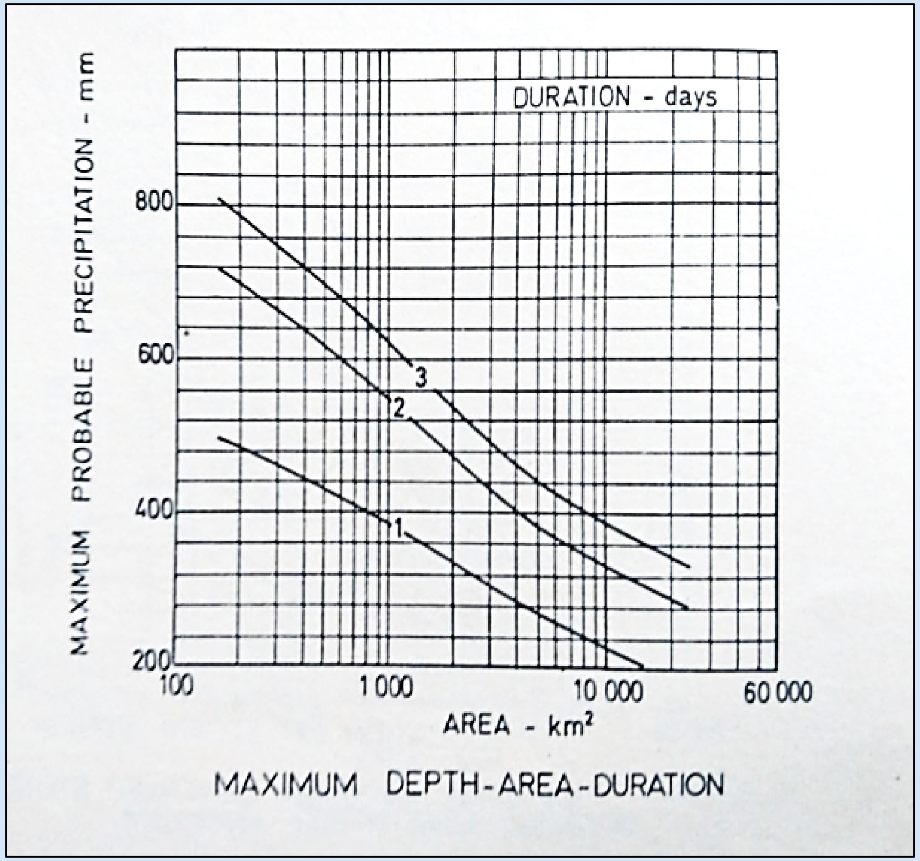
Background - Probable Maximum Precipitation (PMP)

- Greatest depth of precipitation possible for a given location and duration
- However, no allowance made for long term climatic trends
- Used to estimate Probable Maximum Flood needed to design high-hazard hydraulic structures
- Maximise safety and reliability

Shaw (1994); WMO (2009); DWAF (2017)

Background - PMP in South Africa

- Only available guidelines: Hydrological Research Unit (HRU) of the University of Witwatersrand, 1972
- Based on 30 years of rainfall data from over 50 years ago (1932 to 1961)
- Since then many severe storms occurred which exceeded the HRU PMP
- May no longer represent upper limit of extreme rainfall
- May be subject to 25 % error
- Need to be updated



Example of PMP curves (HRU, 1972)

HRU (1972), Görgens *et al.* (2007)

Background - Design Rainfall Estimation in South Africa

- Regional L-moment Algorithm and Scale Invariance (RLMA&SI) approach developed by Smithers and Schulze (2003)
- Produced estimates for T = 2 to 200 years, 5 mins to 7 days
- Nearly 2 decades of new data available since previous estimates
- Extended record lengths may impact design rainfall estimates
- Design of large dams - recommended *T* >200 years
- Need to update and extend

Smithers and Schulze (2000a; 2000b; 2003); Cullis et al. (2007)

Background - Climate Change in South Africa

Increased greenhouse gas emissions

↓

Increased global mean temperatures

↓

Changes in extreme weather events

- Mean annual temperature increased
- Frequency of extreme events increased in parts
- Annual maximum rainfall increasing
- Changes predicted to continue in future

Ndiritu (2005), Midgely (2011), Schulze *et al.* (2011), IPPC (2014), Ziervogel *et al.* (2014)

Background - Climate Change and Non-Stationarity

- Previous studies based on the assumption of a stationary climate – not realistic
- Evidence of climate change and its impacts on extreme events
- Need methods to account for trends in extreme rainfall events in non-stationary environment

Objectives of the Study

- Update PMP estimates
  - Using modernised methods and updated rainfall records

- Update design rainfall estimates
  - Extend to T > 200 years

- Develop and assess the performance of a method to account for the impacts of non-stationary data on extreme design rainfall estimation, including PMP

Methodology - PMP

Selection of extreme rainfall events

Calculation of moisture maximisation ratio

Transposition

Enveloping/ smoothing

PMP

Data

Required

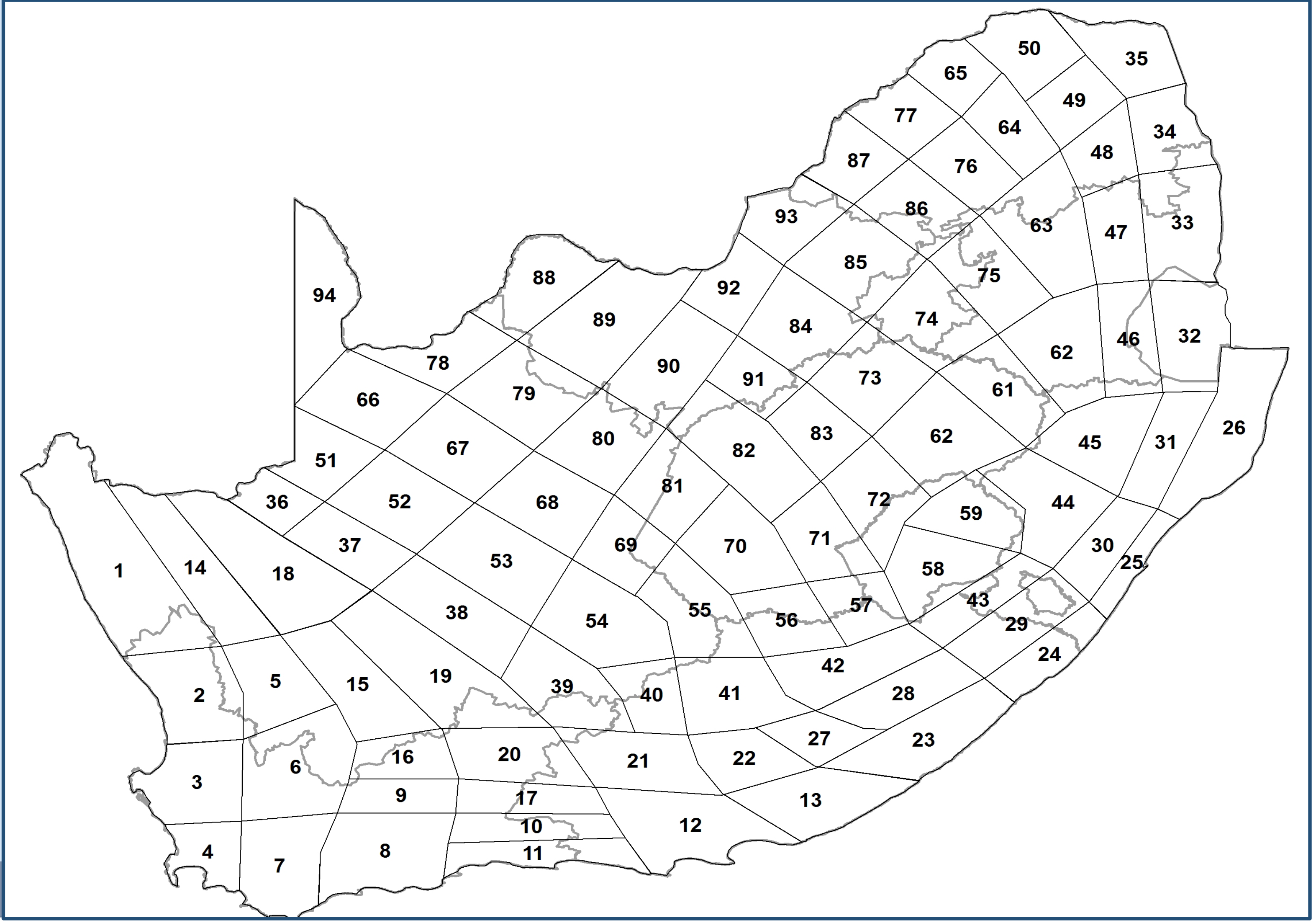
- Daily rainfall
- Dew point temperature (T_d)
  - Required for moisture maximisation of extreme rainfalls
  - Calculated from T and RH data

Available

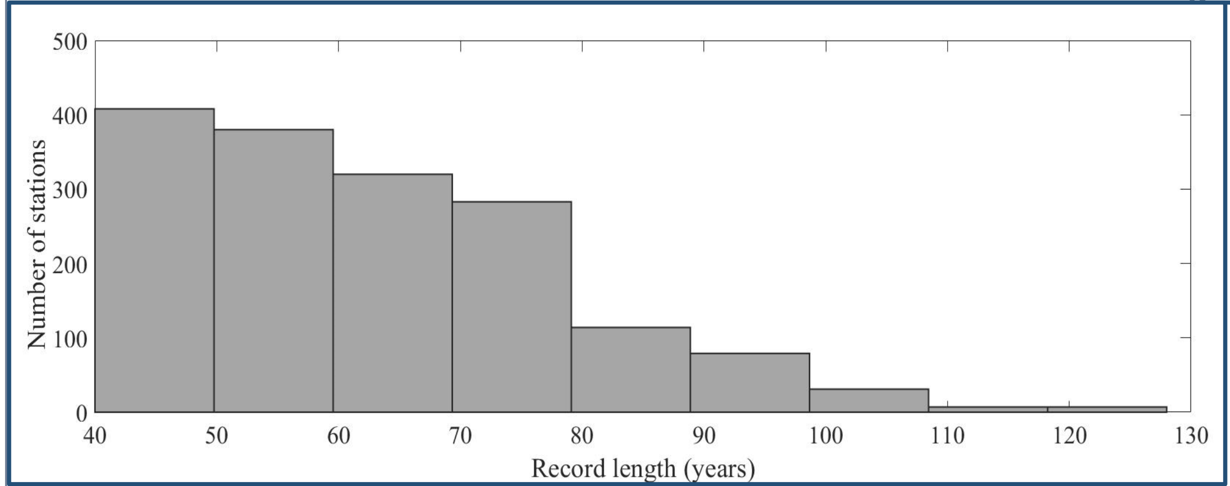
- 1629 stations with > 40 years of record (end dates ranging from 2000 to 2010)
- Temperature (T) and Relative Humidity (RH) data (1950 -2000) from gridded database

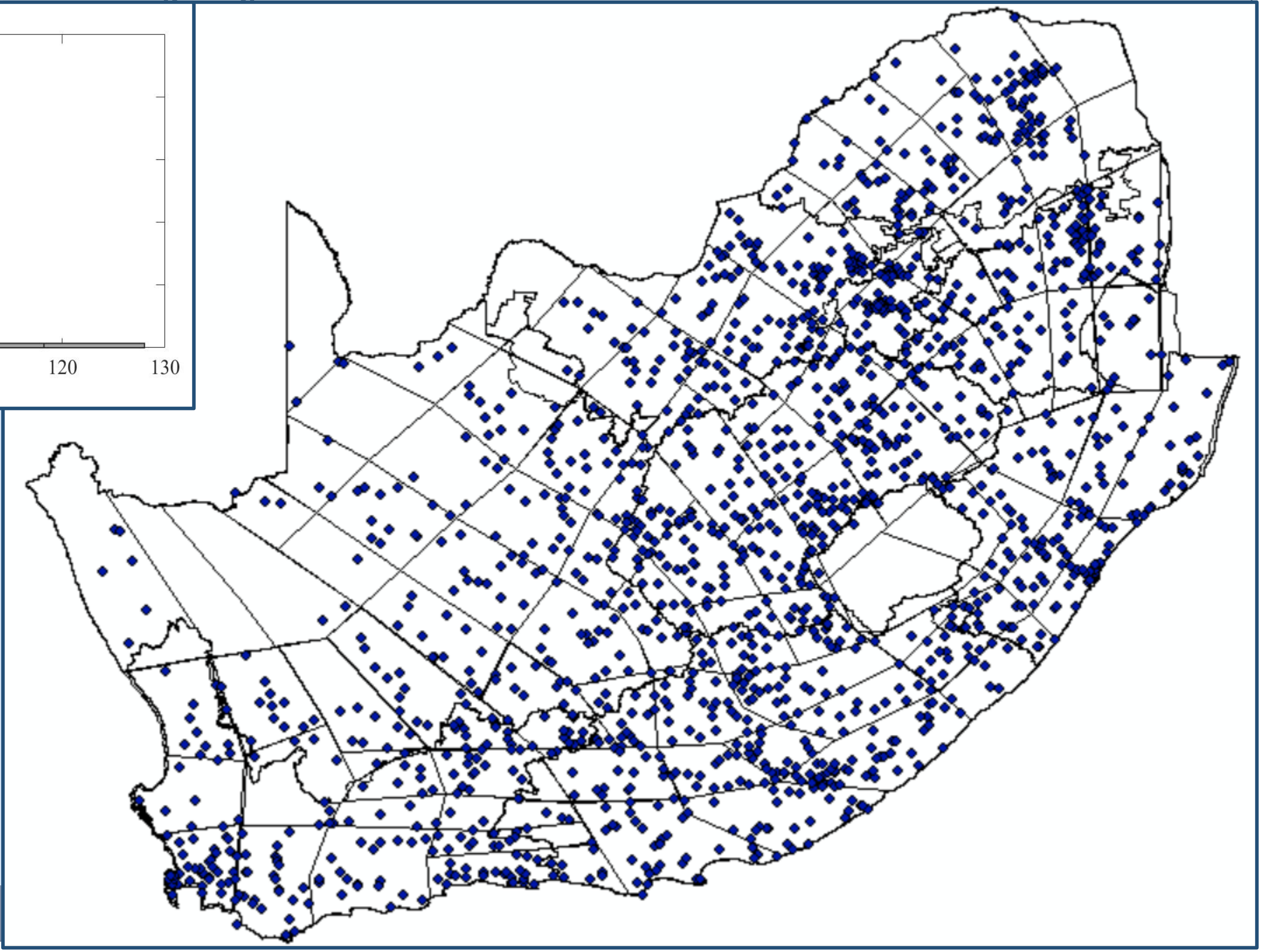
Homogeneous Rainfall Districts

- Homogeneous rainfall districts obtained from the South African Weather Service (SAWS) were used as a basis for this study



Location of Stations & Record Lengths

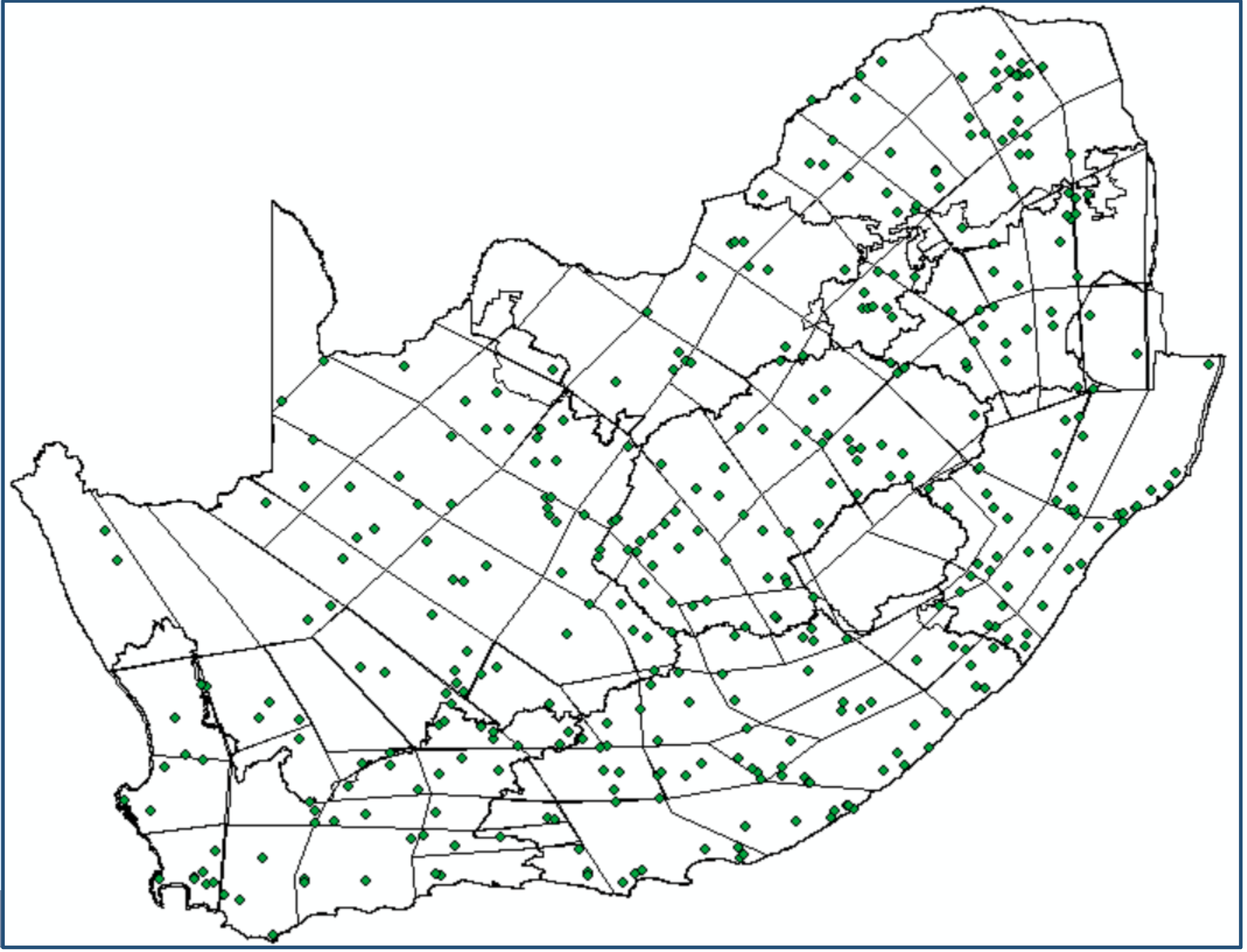




- 1629 stations across the country.
- Some districts have very little to no stations.

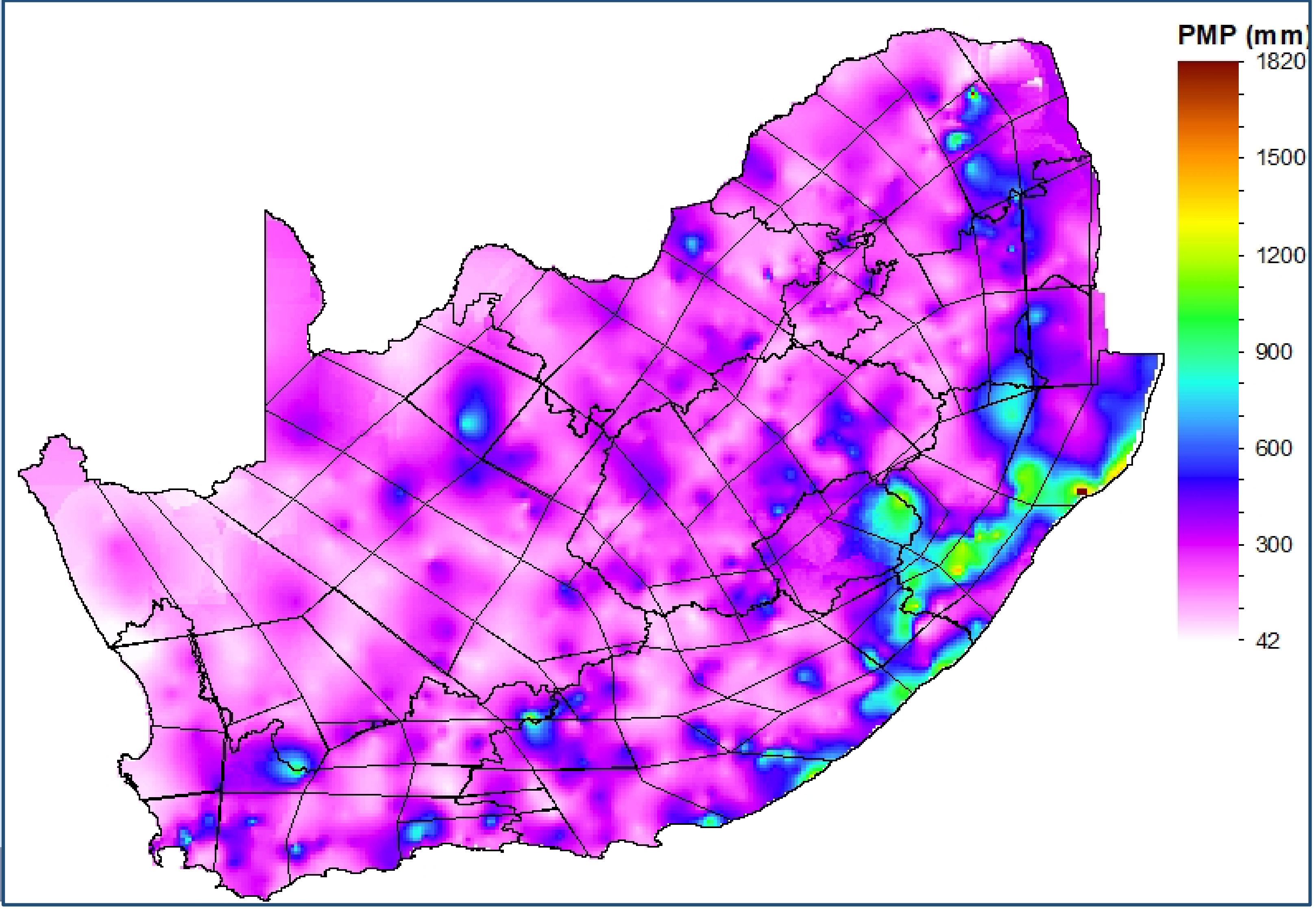
380 Representative Stations

- Selected based on:
  - time period of data available to maximise selected rainfalls
  - dates of storm events
  - magnitudes of events
  - uniqueness of events
- Moisture maximisation ratios determined at the 380 representative stations and transposed to all 1629 stations.

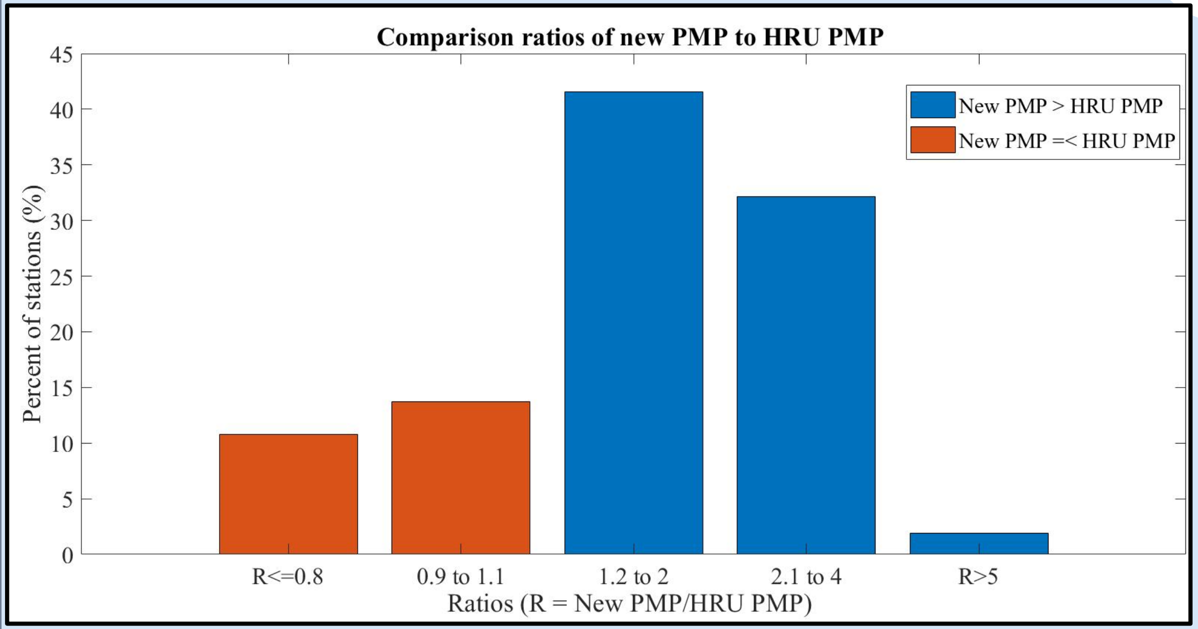


Transposition & Smoothing

- At-site PMPs determined for all stations.
- Transposed to ungauged locations using Multiquadric Radial Basis Functions.
- 1-day PMP estimates on a 5 x 5 km grid for entire country.

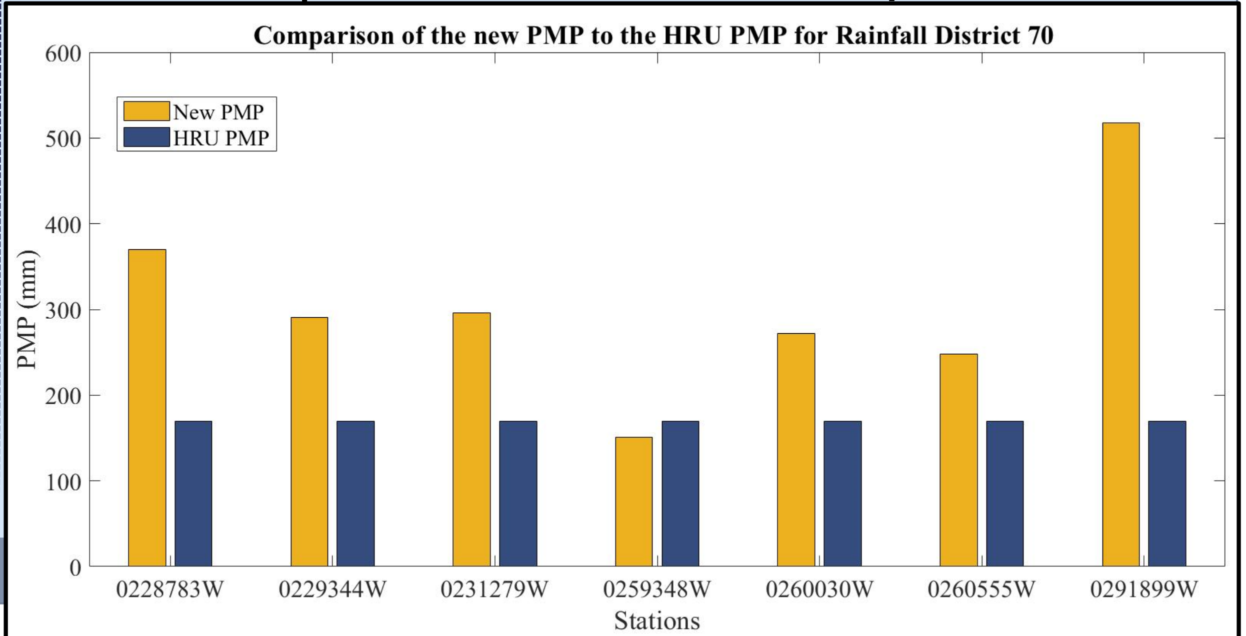


Findings - PMP



- 80% of new PMPs are greater than HRU estimates.
- Most max rainfalls used in this study occurred after HRU (1972) – impact of updated records.

- Blanket HRU values applied throughout region may under- or over-estimate PMPs.
- Possible same storm events used in both studies - new estimates greater.
- Example shown for district 70:



Comparison of HRU (1972) and New Approach in this Study

	HRU (1972)	New SA PMP
Rainfall	30 years (1932 – 1961)	At least 40 years (up to 2000 - 2010)
Selection of extreme rainfall events	170 storms selected country-wide	1629 stations used country-wide and the most extreme rainfall event selected from each station.
Approach	Storm maximisation and transposition	WMO generalised estimation method, storm maximisation and transposition
Homogeneous regions	29	94
Maximisation	No data available. Precipitable water content from surface temperature and pressure derived	Daily T and RH data used to calculate T_d and corresponding precipitable water content obtained from WMO (2009) Table A.1.3
Transposition/ interpolation	Isopercental procedure using percentages of the average MAP to draw isohyetal patterns.	Deterministic models using Multiquadric Radial Basis Functions
Output	DAD curves for various durations applicable at any location in a region	1-day PMP estimates on 5 x 5 km grid

Methodology - High-return Period Rainfall

Selection of extreme value series

Annual Maximum Series

Frequency analysis

LH-moments (Wang, 1997) | Probability distribution (GEV)

Goodness of fit test

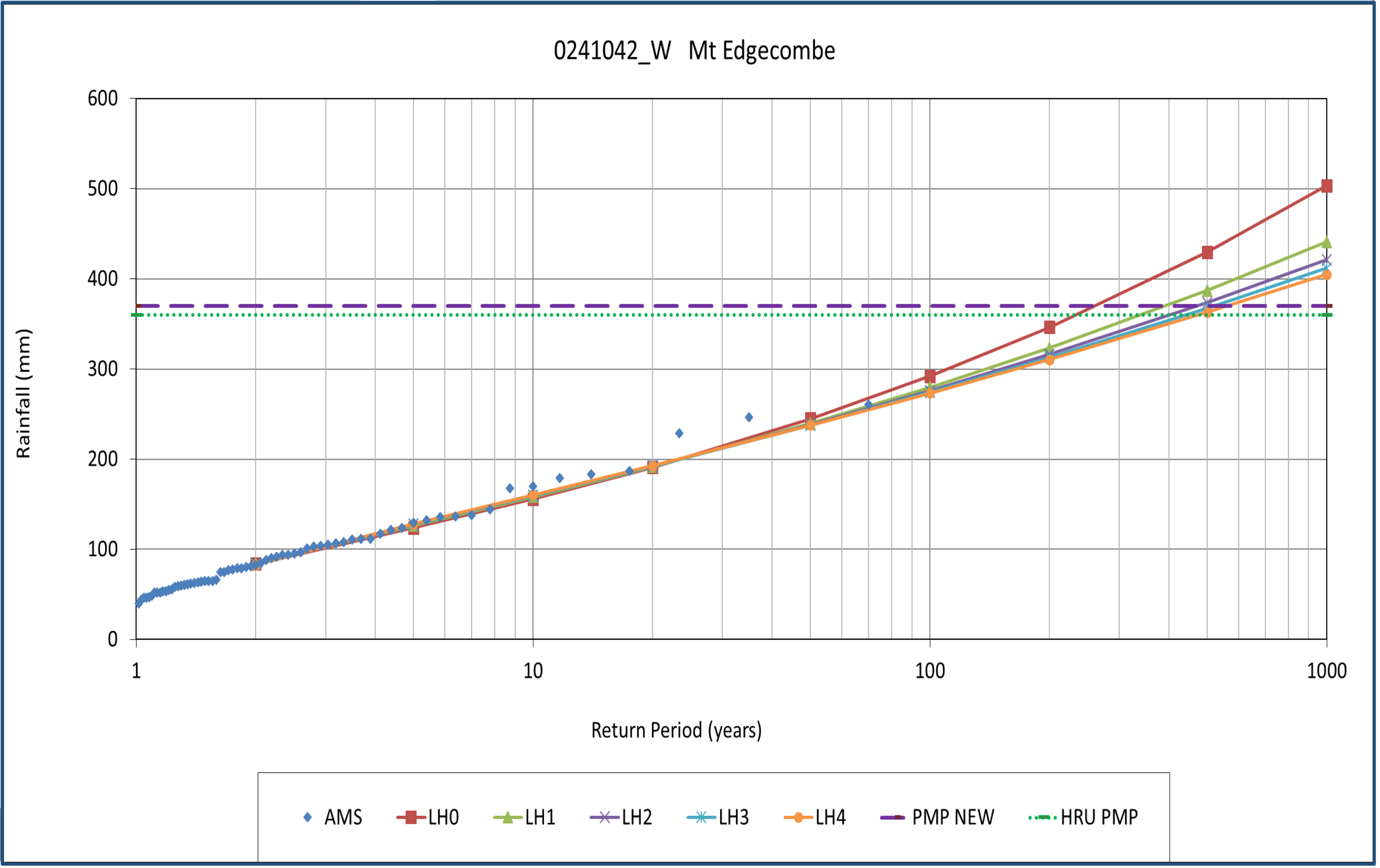
Z-score test (Wang, 1998)

Regionalisation

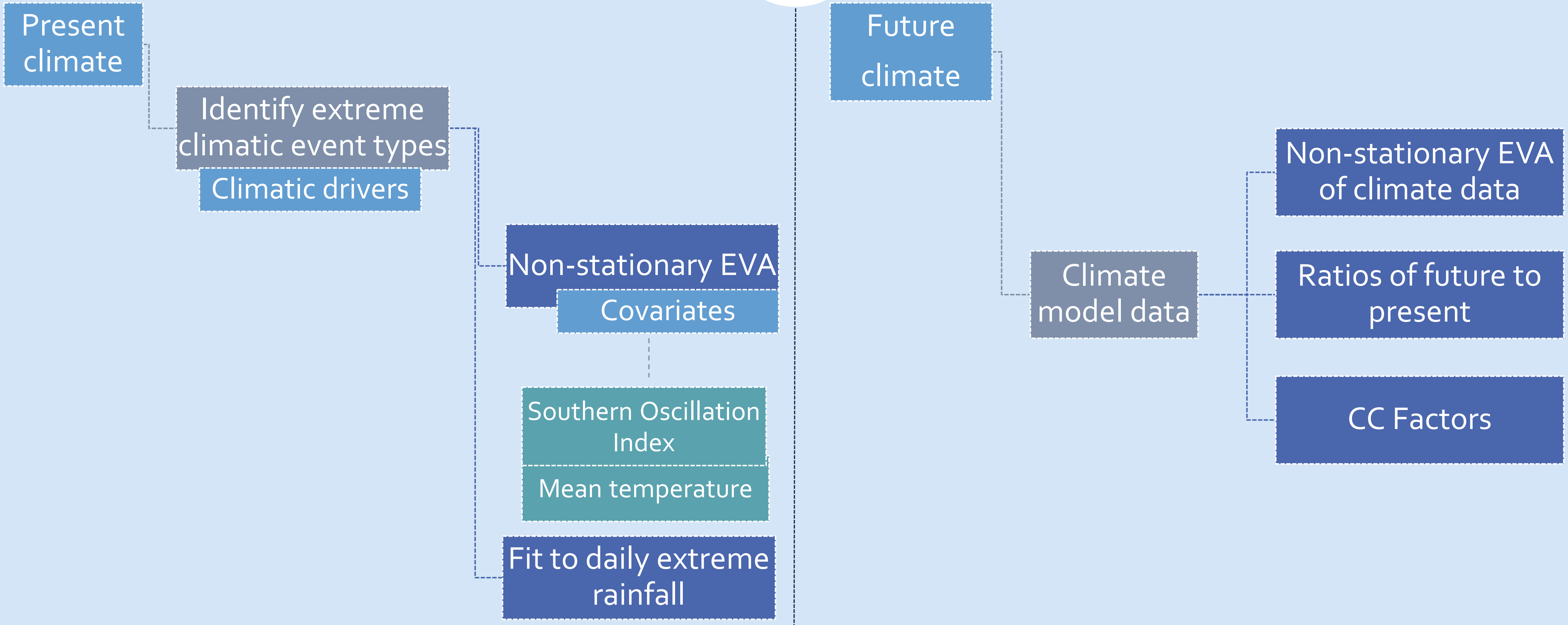
Ungauged locations

Findings – At-site High-return Period Rainfall Estimates

- L-moments tend to give undue favour to outliers -> overestimate extreme rainfalls.
- LH-moments give better estimates in the presence of outliers.
- PMP is the upper limit of rainfall but is often exceeded by high-return period rainfalls.



Methodology - Non-stationarity



Methodology – Considerations for Non-stationary PMP

- Relative Humidity Maximisation (RH = 100%)
  - Dew point temperature = maximum temperature >>> affects moisture maximisation ratio
  - However, this is not a realistic expectation for future climates
- Application of future atmospheric moisture conditions to past observed data
  - Recalculation of PMPs using past extreme events
  - May not be possible to link future climate projections to specific extreme events
- Calculation of PMP using climate model data for future rainfall events
  - May be challenging as climate models do not capture extremes well
- Tracking changes in future dew point temperatures
  - Identifying changes in future atmospheric moisture conditions compared to past conditions associated with extreme rainfalls may indicate impact of future atmospheric conditions on extreme rainfalls

Thank You