Regional SH Westerly Wave Variability and Cape Town's "Day Zero" Drought

Willem Stefaan Conradie[1], Bruce Hewitson[1], Piotr Wolski[1], and Sabina Abba Omar[1]

[1]Climate System Analysis Group, University of Cape Town

November 23, 2022

Abstract

The recent severe "Day Zero" drought (2015-2017) over the winter rainfall zone (WRZ) of South Africa has highlighted low-frequency winter climate variability, possible trends and our generally poor understanding of their mechanisms. We investigate the contribution of dynamic conditions and moisture transport to daily station rainfall events in the WRZ and the relationship between the frequency of such states, seasonal to inter-decadal rainfall variability and hemispheric modes of Westerly Wave variability. Dynamic conditions are assessed using reanalysis data over the South-East Atlantic during the austral winter half-year (AMJJASO) from 1979-2017. A self-organising map (SOM) analysis is performed on 500-hPa geopotential height. Nodes indicating strong troughs and ridges in the Westerly Wave are identified using either rainfall or dynamic (divergence and vorticity) criteria. The two approaches produce similar results; most rainfall (around 80%) occurs on days mapped to trough nodes (35% of days). The trough nodes are subjected to a multi-dimensional SOM analysis to identify conditions leading to variations of rainfall within the original SOM nodes. Nodes showing intense (high divergence and vorticity west of South Africa) troughs extending equatorward of the WRZ (14% of all winter days) account for around 60% of trough rainfall. Cut-off lows (COLs) are independently identified as closed, cold-cored lows at the 500-hPa-level and their contribution to precipitation is assessed separately. COLs are detected on approximately 3% of all winter time steps, contributing only about 11% of the total rainfall, although they account for almost all heavy rainfall events not associated with intense troughs. During the Day Zero drought, the frequency of almost all trough nodes decreased, especially in the shoulder seasons, while ridge nodes occurred 1.5-2 times more frequently and persisted for longer, especially in late autumn. Average rainfall per trough node was lower and COL frequency reduced. The only SOM nodes showing significant trend over 1979-2017 are ridge nodes associated with large anticyclonic vorticity anomalies south of the WRZ. Correlation between the Southern Annular Mode and ridge/trough nodes is weak. We conclude that the Day Zero drought resulted from fewer mobile troughs passing the WRZ in the shoulder seasons, possibly linked to a multi-decadal increase in blocking high frequency.

Posted on 23 Nov 2022 — CC-BY-NC 4 — https://doi.org/10.1002/essoar.10500292.1 — This a preprint and has not been peer reviewed. Data may be preliminary.

A31N-0231:

Regional SH Westerly Wave Variability and Cape Town's "Day Zero" Drought

Stefaan Conradie* Piotr Wolski Bruce Hewitson Sabina Abba Omar Climate System Analysis Group (CSAG), University of Cape Town (UCT)

Background & Introduction

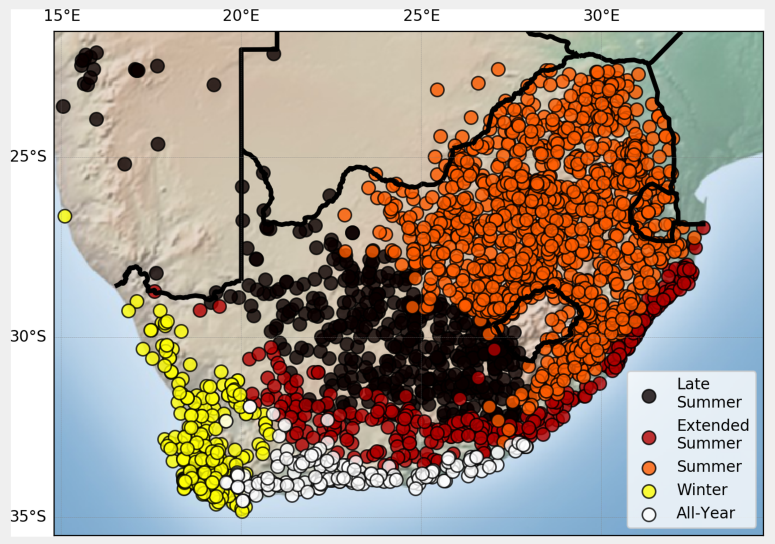

Figure 1:Ward's clustering by seasonality.

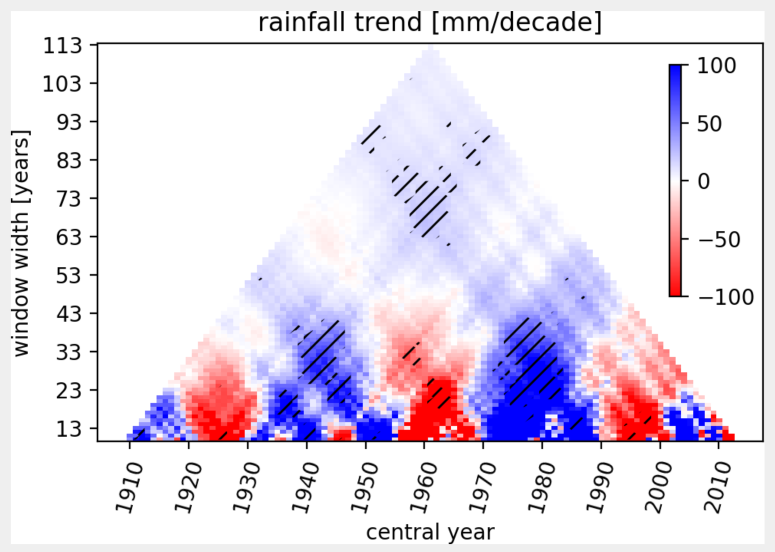

Figure 2:Theil-Sen trends near major dams.

- Southern Africa rainfall seasonality
  - Mostly summer rain
  - Far-SW winter rainfall zone (WRZ) depends on winter frontal rain
- "Day Zero" Drought:
  - Most intense 3-yr drought observed: Spring 2014–Spring 2017 (Wolski, 2018)
  - 2017 driest year on record across WRZ
  - Severe water crisis ⇒ warning of taps running dry (Baudoin et al., 2017)
  - Politically contentious in divided & unequal city, country (Ziervogel, 2018)
  - Related to poleward shift in subtropical highs, moisture transport & ARs in SH & South Atlantic (Sousa et al., 2018)
- Climate change?
  - 3x increase in risk (Otto et al., 2018)
  - Variability overwhelms trend long-term
  - Mechanisms?
- Seasonal prediction: low-skill
  - Weak correlation with major global & hemispheric modes of variability

Data & Methods

- Self-Organising Map (SOM) Analysis of ERA-Interim (Dee et al., 2011) 500-hPa geopotential
  - SOM: artificial neural network (ANN) commonly used for non-linear circulation clustering (Hewitson and Crane, 2002)
  - SE-Atlantic domain: identify 1 trough/ridge affecting WRZ at a time $-55 \leq \phi \leq -25°$; $0 \leq \theta \leq 27°$
  - 6 hourly, AMJJAS 1979-2017
- Cut-Off Lows (COLs)
  - Closed, cold-cored lows at 500hPa
  - COL days considered separately
- SOM node & stations clustering
  - Ward's linkage; Euclidian distance
  - SOM nodes: divergence & geostrophic vorticity near WRZ
  - Stations: contribution of SOM node clusters to AMJJAS rainfall
- Observed station rainfall:
  - **> 98%** coverage 1979-2017
  - Cleaned, date corrected, gap-filled

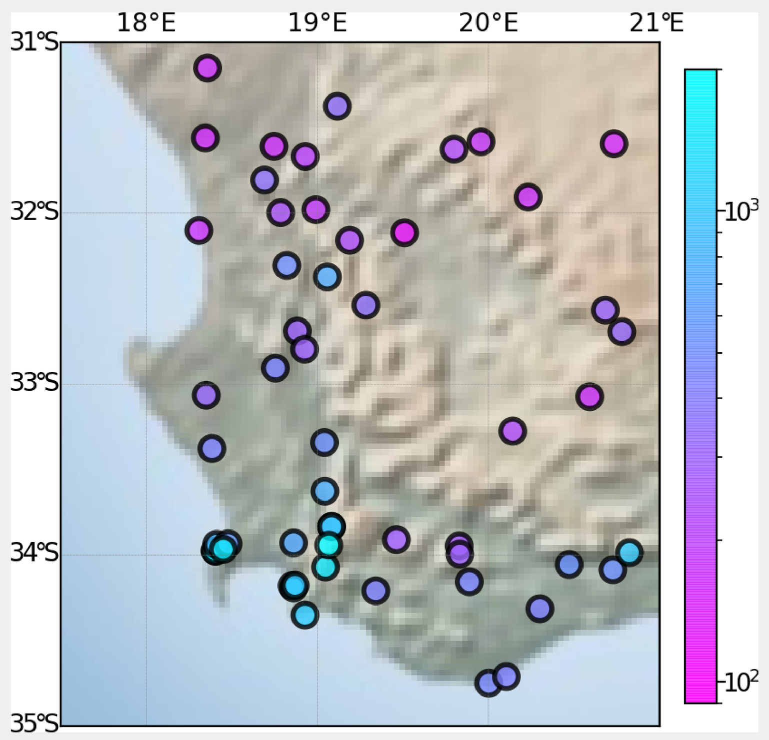

Figure 3:Mean annual station rainfall (mm)

Results: SOM & Station Rainfall

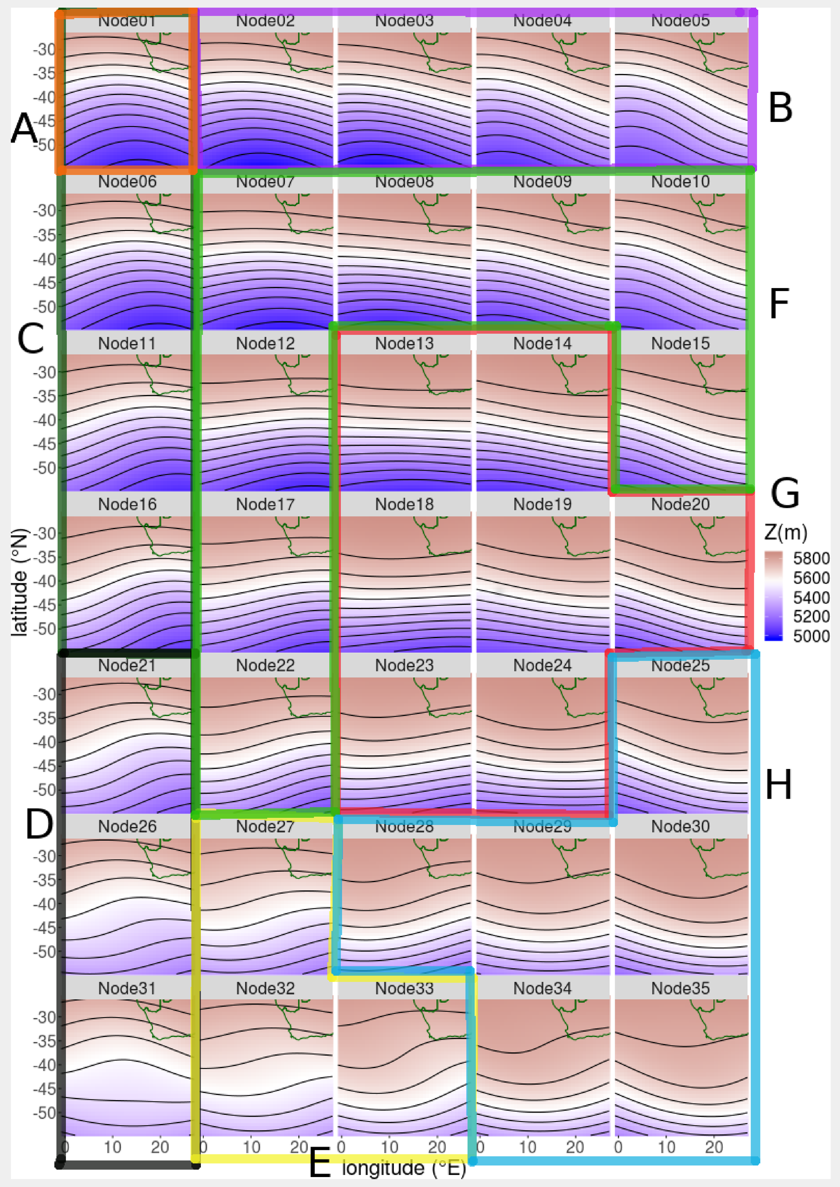

Figure 4:5 × 7 Z500 SOM, with clusters

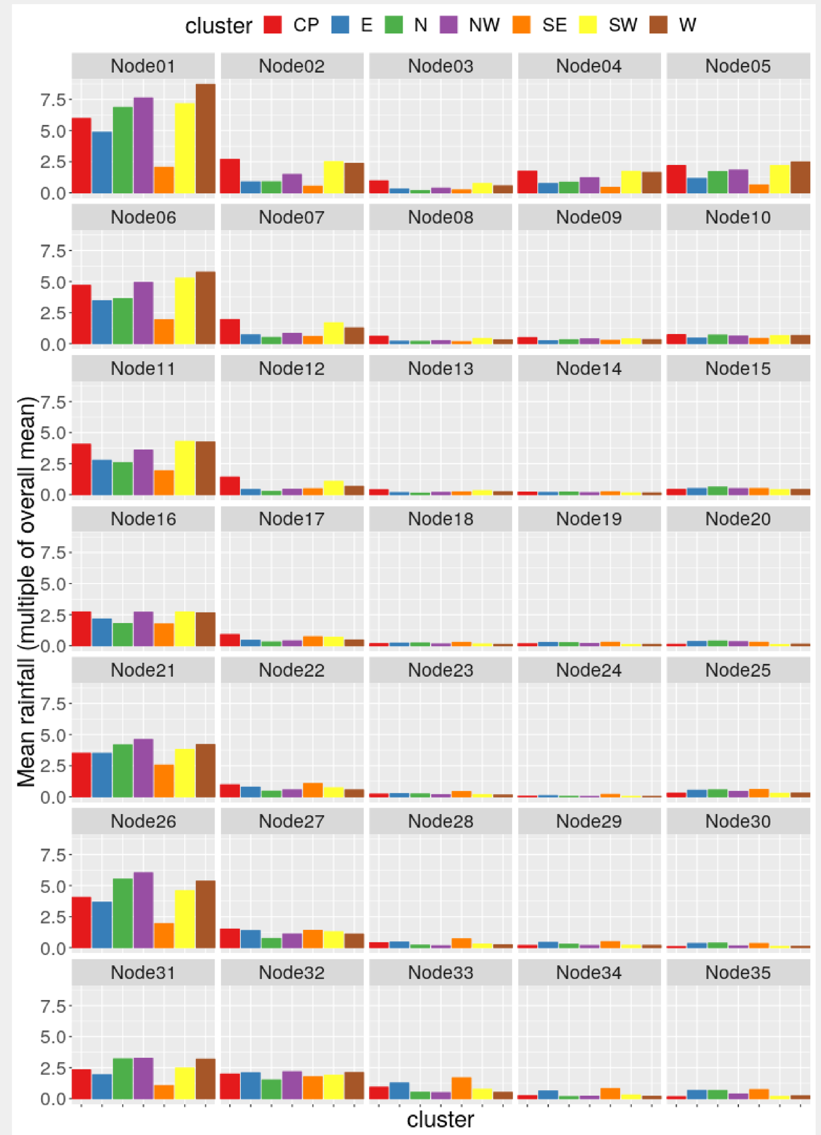

Figure 5:Normalised SOM node mean rainfall

Node Cluster	Freq (%)	Rainfall (% range)
A: Strong trough	3.3	6.2(SE)–18.0(W)
B: NW trough	13.5	6.5(SE)–17.8(CP)
C: S steep trough	8.0	15.6(N)–22.5(SW)
D: Curved trough	8.2	14.2(SE)–24.5(NW)
E: Weak trough	6.8	4.3(N)–12.2(SE)
F: Zonal flow	20.2	5.9(NW)–10.8(CP)
G: Ridge	16.9	1.6(W)–4.7(SE)
H: Strong ridge	20.2	2.3(W)–10.7(SE)
COLs	3	7.3(SW)–18.1(SE)

Table 1:SOM node cluster frequency & contribution to AMJJAS rainfall

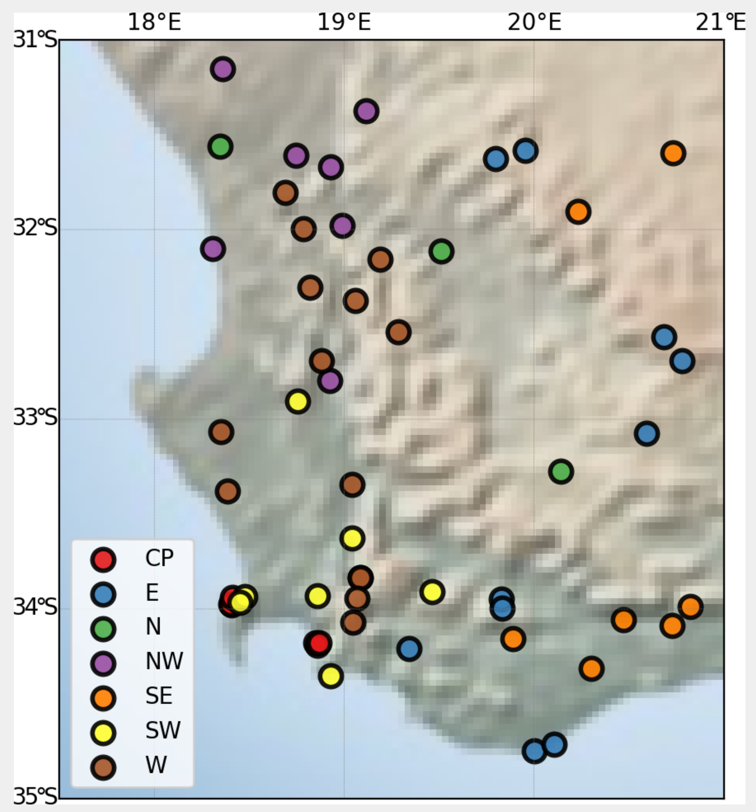

Figure 6:Station clusters obtained

- Troughs (40% frequency) responsible for ≈ **80%** of all AMJJAS rainfall in core WRZ; strongest half bring ≈ **60%** of rain in mnts and NW.
- Contribution from troughs is highest in the W cluster; from COLs is highest in the E& SE; N & NW are most dependent on troughs with large curvature

Results: Circulation & Rainfall Prediction

- Annual SOM node cluster frequency anomalies with mean rainfall patterns for each are used to predict station cluster annual AMJJAS rainfall.
- Each year predicted using all others in turn.
- 2 strongest ridge nodes (34, 35) exhibit blocking behaviour & unprecedented frequency during drought; hence, they are separated in frequency time series

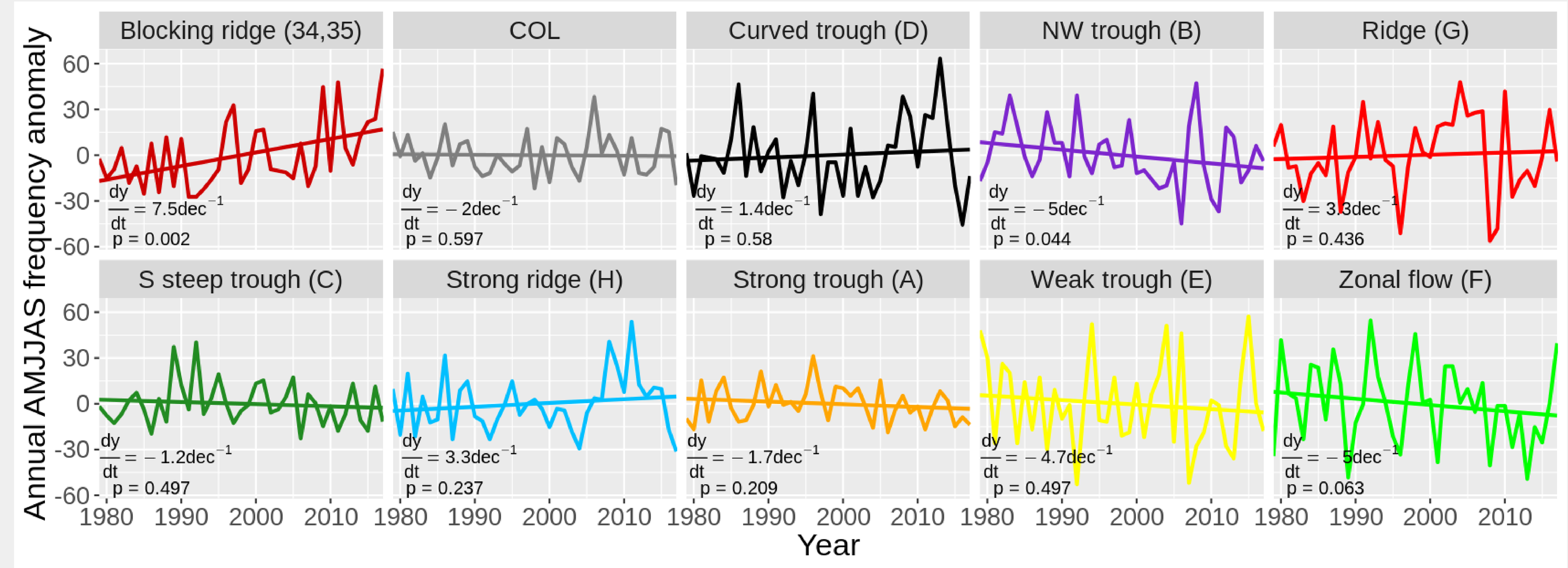

Figure 7:AMJJAS circulation type anomaly 1979-2017 with decadal trend and significance

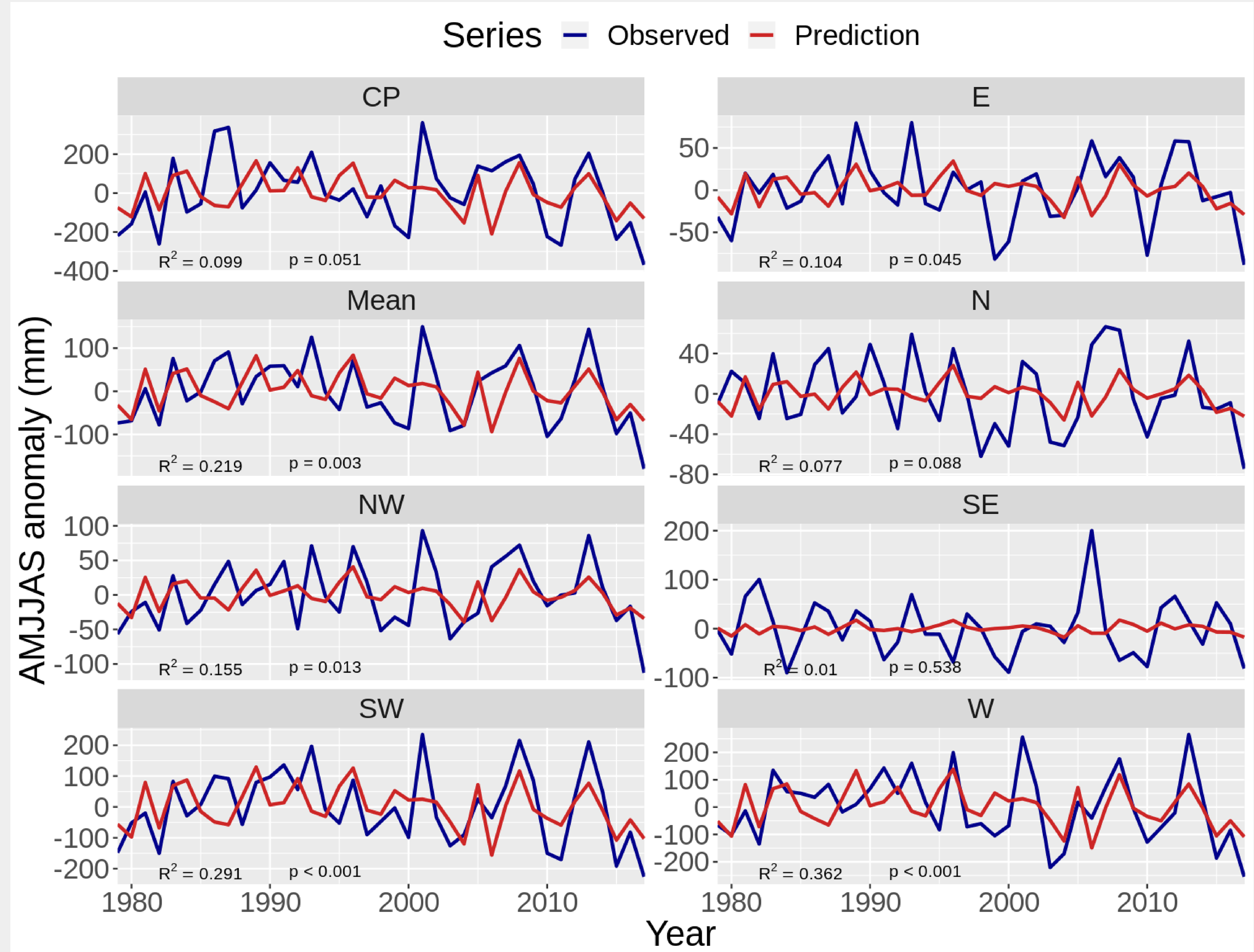

Figure 8:Observed and predicted station cluster mean anomaly 1979-2017

- Prediction best in the W & SW mnts; model explains essentially none of the variability in E & SE

Acknowledgments

- Phillip Mukwenha for assistance with software, hardware and data
- Chris Jack & Pierre-Louis Kloppers for data formatting & cleaning
- Birgit Erni for assistance with gap-filling techniques
- South African Weather Service (SAWS) for providing long-term station records for many locations; City of Cape Town & SA Dept. of Water and Sanitation (DWS), for additional station data
- Financial assistance towards the PhD research project from the SA National Research Foundation (NRF) and CSAG
- CSAG and UCT PGFO for sponsoring attendance at this conference

Conclusion: Circulation Contribution to Drought

- Most rainfall in extended winter associated strong troughs in mid-tropospheric westerlies
- Circulation type frequency variation explains **2−36%** of rainfall variability across WRZ
- Explanatory power greater in recent years (≲ **50%**)
- ≈ **55%** of Day Zero Drought shortfall explained by trough/ridge variability & trend.
- Unprecedented autumn (AM) frequency of most intense ridge node during severe drought year 2017, consistent with increasing trend ($p < 0.01$) over 39 yrs

References

Baudoin, M.-A., C. Vogel, K. Nortje, and M. Naik, 2017: Living with drought in South Africa: lessons learnt from the recent El Niño drought period. *International Journal of Disaster Risk Reduction*, **23**, 128–137, doi:10.1016/j.ijdrr.2017.05.005.

Dee, D. P., and Coauthors, 2011: The ERA-Interim reanalysis: configuration and performance of the data assimilation system. *Quart. J. Roy. Meteor. Soc.*, **137 (656)**, 553–597, doi:10.1002/qj.828.

Hewitson, B. C., and R. G. Crane, 2002: Self-organizing maps: Applications to synoptic climatology. *Clim. Research*, **22 (1)**, 13–26, doi:10.3354/cr022013.

Otto, F. E. L., and Coauthors, 2018: The role of climate change in the 2015-2017 drought in the western cape of south africa. *Submitted to Environmental Research Letters*.

Sousa, P. M., R. Blamey, C. Reason, A. M. Ramos, and R. M. Trigo, 2018: The Day Zero Cape Town drought and the poleward migration of moisture corridors. *Environmental Research Letters*, doi:10.1088/1748-9326/aaebc7.

Wolski, P., 2018: How severe is Cape Town's Day Zero drought? *Significance*, **15 (2)**, 24–27, doi:10.1111/j.1740-9713.2018.01127.x.

Ziervogel, G., 2018: Climate adaptation and water scarcity in southern africa. *Current History*, **117 (799)**, 181.

*Corresponding author (Stefaan Conradie) e-mail: stefaan@csag.uct.ac.za