

Supplementary Material

The Cape Town "Day Zero" drought and Hadley Cell Expansion

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Supplementary Table 1. List of the SAWS weather stations used in this study.

	SAWS Station Name	Latitude (°)	Longitude (°)	Altitude (m)	Start Date	End date	Missing days ²
1979-2017 Cape Town Catchment Cluster¹	BETTYS BAY	-34.35	18.93	34	1979/1/1	12/31/17	261
	STEENBRAS II	-34.19	18.86	375	1979/1/1	12/31/17	88
	SIMONSTOWN	-34.18	18.42	30	1979/1/1	12/31/17	238
	STEENBRAS III	-34.18	18.87	390	1979/1/1	12/31/17	128
	RONDEVLEI	-34.06	18.5	8	1979/1/1	12/31/17	263
	RUSTFONTEIN	-34.03	19.19	348	1979/1/1	12/31/17	361
	MOLTENO	-33.94	18.41	93	1979/1/1	12/31/17	203
	STELLENBOSCH	-33.93	18.86	109	1979/1/1	12/31/17	45
	STETTYNSKLOOF	-33.83	19.26	451	1979/1/1	12/31/17	163
	WARMBOKVELD	-33.35	19.34	491	1979/1/1	12/31/17	258
	VRUGBAAR [†]	-33.63	19.04	175	1979/1/1	12/31/17	43
	BOKVELDSKLOOF	-33.19	19.33	1035	1979/1/1	12/31/17	128
	REMHOOGTE	-33.18	19.15	371	1979/1/1	12/31/17	640
Centennial Cluster of Records Surrounding Cape Town	SA ASTRONOM. OBSERVATORY	-33.93	18.48	15	1841/01/01	12/31/17	1571
	TULBAGH	-33.28	19.14	163	1877/10/01	12/31/17	415
	PIKETBERG-SAPD	-32.91	18.75	230	1879/05/01	12/31/17	215
	ROBBEN ISLAND	-33.81	18.37	25	1890/03/01	12/31/17	1597
	VRUGBAAR [†]	-33.63	19.04	175	1904/11/01	12/31/17	43
	ALGERIA - BOS	-32.37	19.06	505	1908/06/01	12/31/17	389

¹ Many of these stations start pre-1979

² Number of days missing for the periods used in the text

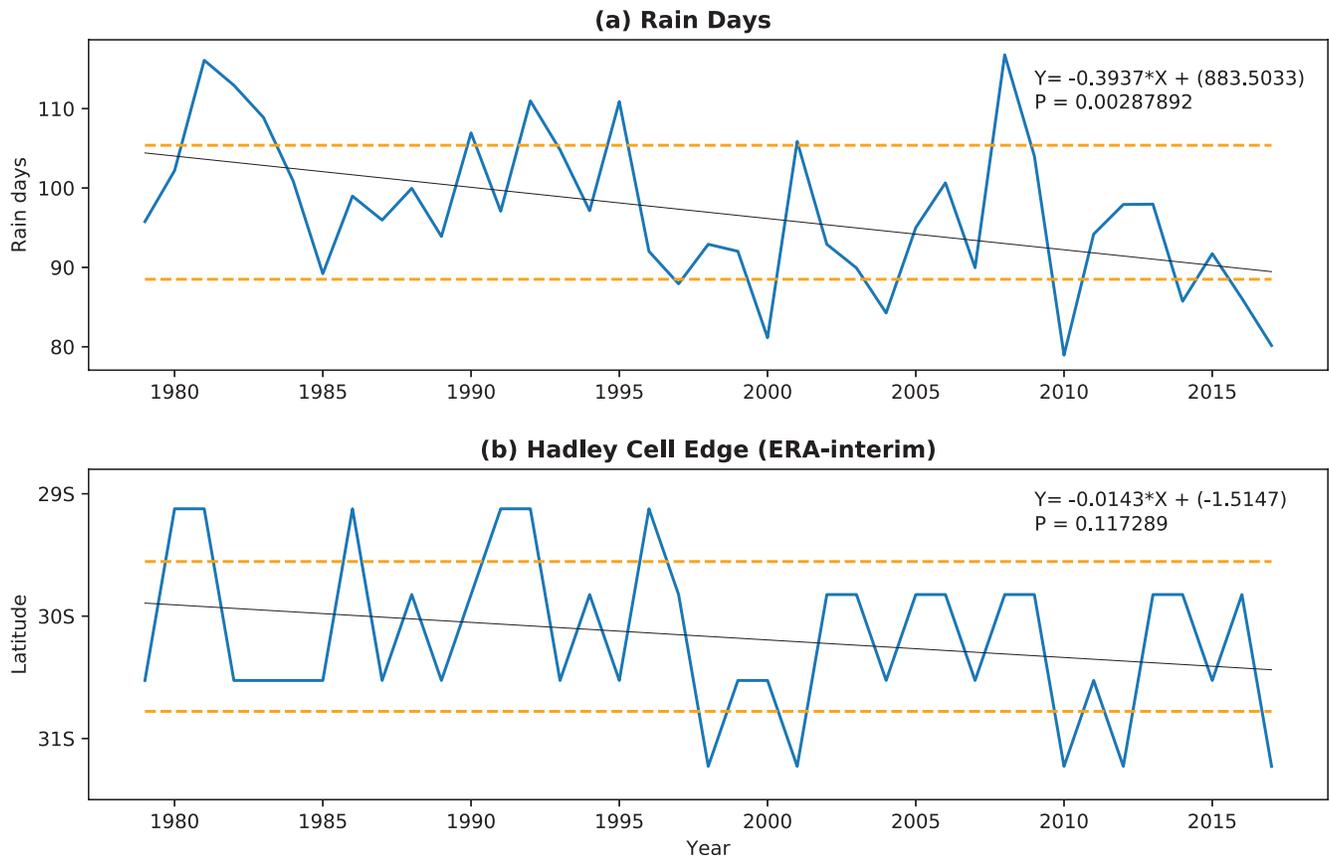
[†] Same station in both subsets

Supplementary Table 2. Trends in Rainfall, Rainfall Days and Rainfall Intensity. Trends are calculated by taking average values over the year if annual, or season if AMJJAS, and then taking the trend across these average values. Units are therefore mm/day/yr or mm/day/yr for rainfall and rainfall intensity and days/yr/yr or days/season/yr for rainfall days.

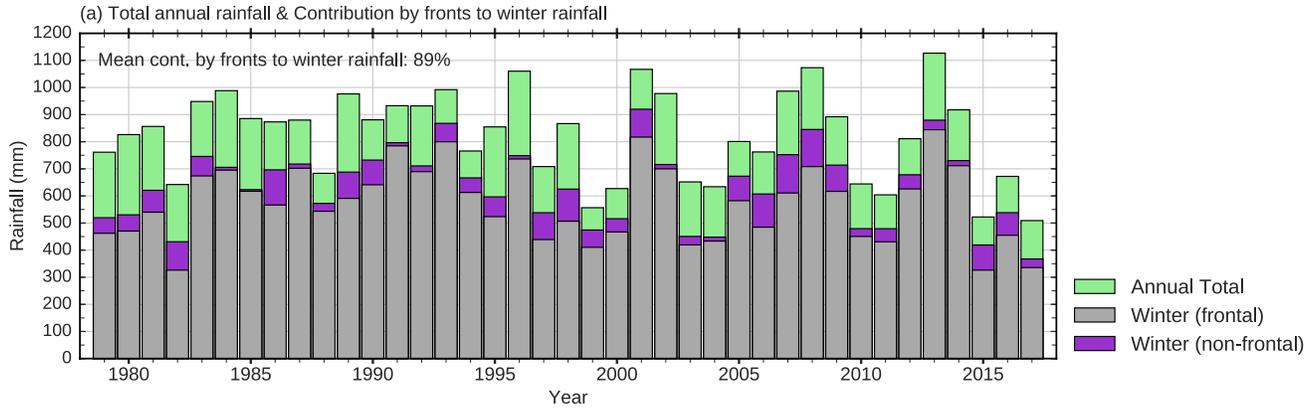
Station Data	Rainfall	Rainfall Days	Rainfall Intensity
Centennial Cluster (Annual) 1909-2017	No trend Slope: 0.001 Intercept: -1.012 95% confidence: (-0.001, 0.003)	<i>Decreasing trend</i> Slope: -0.305 Intercept: 729.955 95% confidence: (-0.39, -0.24)	<i>Increasing trend</i> Slope: 0.015 Intercept: -25.42 95% confidence: (0.009, 0.021)
Centennial Cluster (AMJJAS) 1909-2017	No trend Slope: 0.0025 Intercept: -2.48 95% confidence: (-0.001, 0.006)	<i>Decreasing trend</i> Slope: -0.148 Intercept: 373.815 95% confidence: (-0.21, -0.09)	<i>Increasing trend</i> Slope: 0.02 Intercept: -26.34 95% confidence: (0.009, 0.023)
Catchment Cluster (Annual) 1979-2017	No trend Slope: -0.006 Intercept: 13.93 95% confidence: (-0.022, 0.007)	<i>Decreasing trend</i> Slope: -0.75 Intercept: 1662.5 95% confidence: (-1.08, -0.5)	No trend Slope: 0.007 Intercept: -8.672 95% confidence: (-0.025, 0.038)
Catchment Cluster (AMJJAS) 1979-2017	No trend Slope: -0.002 Intercept: 7.649 95% confidence: (-0.031, 0.023)	<i>Decreasing trend</i> Slope: -0.4 Intercept: 895.2 95% confidence: (-0.63, -0.16)	No trend Slope: 0.013 Intercept: -18.505 95% confidence: (-0.028, 0.059)
Centennial Cluster (Annual) 1979-2017	No trend Slope: -0.01 Intercept: 16.03 95% confidence: (-0.017, 0.004)	No trend Slope: 0.083 Intercept: -46.5 95% confidence: (-0.28, 0.5)	No trend Slope: -0.026 Intercept: 56.79 95% confidence: (-0.05, -0.01)
Centennial Cluster (AMJJAS) 1979-2017	No trend Slope: -0.0076 Intercept: 17.92 95% confidence: (-0.03, 0.01)	No trend Slope: 0.048 Intercept: -16.14 95% confidence: (-0.2, 0.29)	No trend Slope: -0.016 Intercept: 37.61 95% confidence: (-0.05, 0.02)

Supplementary Table 3. Trends in frontal (defined as rainfall averaged across the day before, day of, and day after a front passes Cape Town) and non-frontal (rainfall on all other days) rainfall and rainfall days.

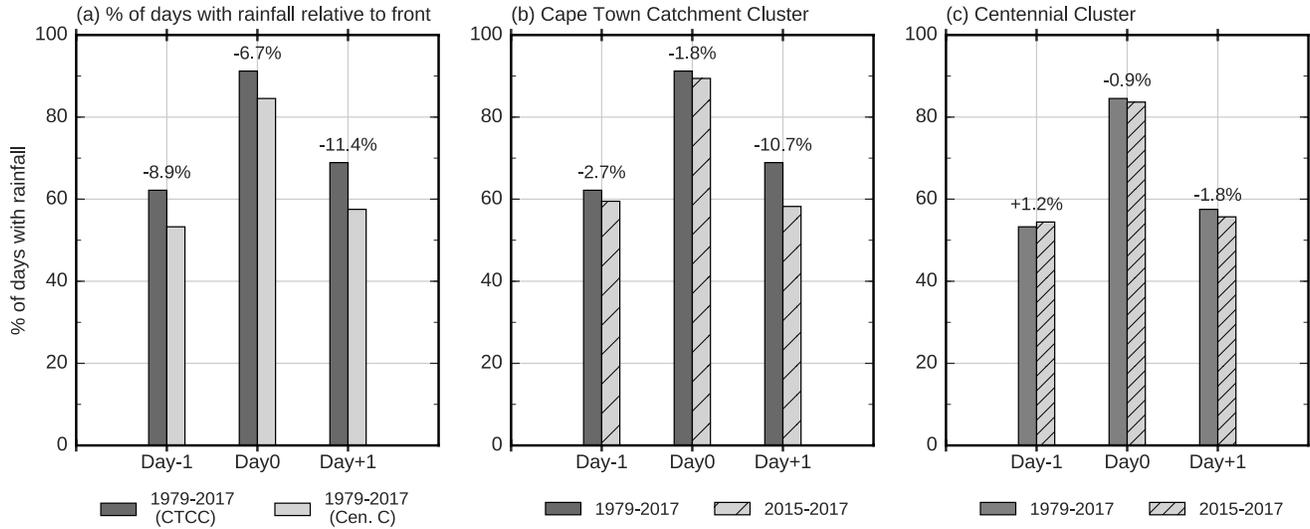
Fontal Analysis	Rainfall	Rainfall Days
Frontal Rainfall (AMJJAS) (Catchment Cluster)	No trend Slope: -1.21 Intercept: 3022.97 90% confidence: (-5.26, 2.51)	<i>Decreasing trend</i> Slope: -0.29 Intercept: 658.65 90% confidence: (-0.5, -0.09)
Non-frontal Rainfall (AMJJAS) (Catchment Cluster)	No trend Slope: 0.3 Intercept: -543.87 90% confidence: (-0.79, 1.38)	No trend Slope: -0.12 Intercept: 265.76 90% confidence: (-0.33, -0.08)
Number of days per season (AMJJAS) identified as having fronts (front days)		No trend Slope: -0.10 Intercept: 246.31 90% confidence: (-0.23 0.0)



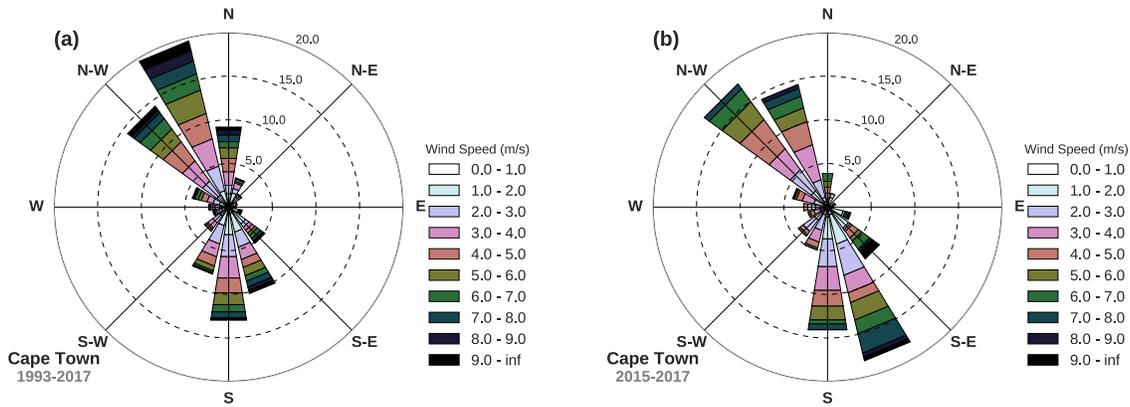
Supplementary Figure 1: Hadley Cell edge and rainfall days. (a) AMJJAS rainfall days. The yellow dashed lines indicate 1σ from the mean calculated using a detrended version of the time series (not shown) to evaluate internal variance once the 40-year trend is removed. Years where the original timeseries (blue line) falls beyond these limits make up the Rainfall Days (Rday) composite (See Methods). (b) As in panel a, except for the Hadley Cell edge, defined as the latitude of maximum zonal-mean sea-level pressure within Era-Interim.



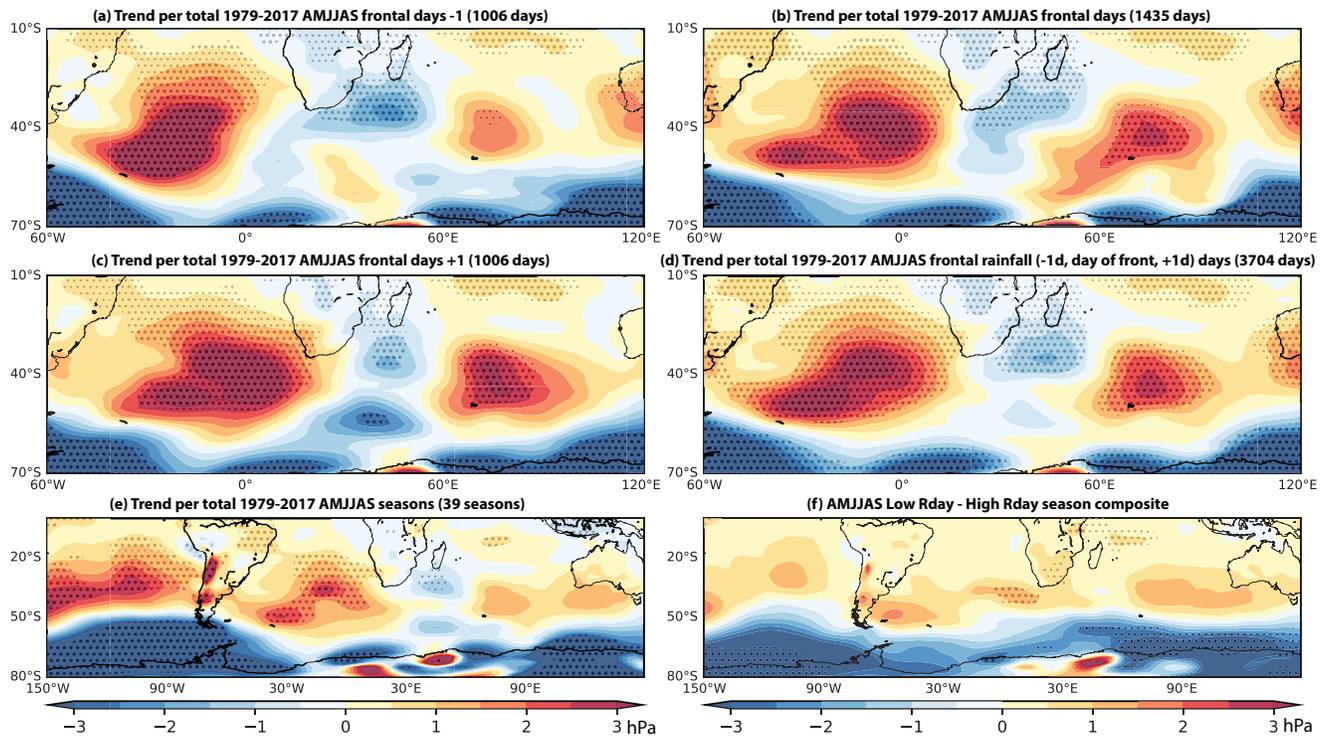
Supplementary Figure 2: Rainfall identified by our methodology as frontal rainfall accounts for 89% of the total winter rainfall. Cumulative annual rainfall calculated using the average of daily rainfall measurements across the Cape Town Catchment Cluster stations. The relative contribution of winter (AMJJAS) frontal, winter non-frontal and summer (ONDJFM) rainfall to the annual total is shown.



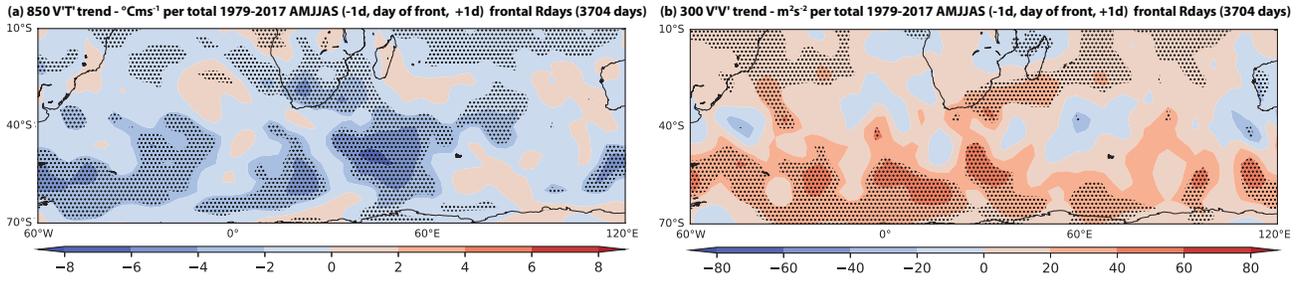
Supplementary Figure 3: Evidence that there is more orographic enhancement of frontal rainfall within the Cape Town Catchment Cluster relative to the Centennial Cluster and hence a large decrease in post-frontal rainfall days during the 2015-2017 drought. (a) The percentage of days identified as pre-frontal (the day before a frontal day), frontal (having at least one front) and post-frontal (the day after a frontal day) that experienced rainfall for the Cape Town Catchment and Centennial Clusters respectively. Percentage values above each set of bars states the difference between the former and latter. (b & c) As in (a) but compared with 2015-2017 values for (b) the Cape Town Catchment and (c) the Centennial Cluster.



Supplementary Figure 4: Fewer winter days with Northerly to North-westerly winds during the 2015-2017 drought. Wind rose of daily winds during the winter months (AMJJAS) measured at the Cape Town International airport (red star in **Fig. 1b**) for (a) 1993-2017 and (b) 2015-2017 wind data. Data quality concerns, involving movement of the anemometer and instrument change, restrict this dataset to 1993-2017.



Supplementary Figure 5: Same as Fig. 5 but based on NCEP reanalysis and without 850hPa winds superimposed.



Supplementary Figure 6: Local trends in storm track indicators are consistent with Hadley Expansion mechanism. The local trend in (a) the eddy meridional heat flux ($V'T'$), as measured by the covariance of high-pass meridional wind and temperature at 850hPa, and (b) the variance of high-pass meridional wind ($V'V'$) at 300 hPa, for all three days associated with a frontal passage (includes one day prior to and one day after as in Fig. 4d and Extended Data Fig. 4d). Trends are per the total frontal rainfall days totaling 3704 days during AMJJAS 1979-2017. Note that the negative trends in the meridional heat flux indicate a stronger poleward eddy heat flux while the positive trend in $V'V'$ indicates increased storminess.