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Extremes in South African Rainfall: Mean Characteristics and Seamless Variability Across Multiple Timescales

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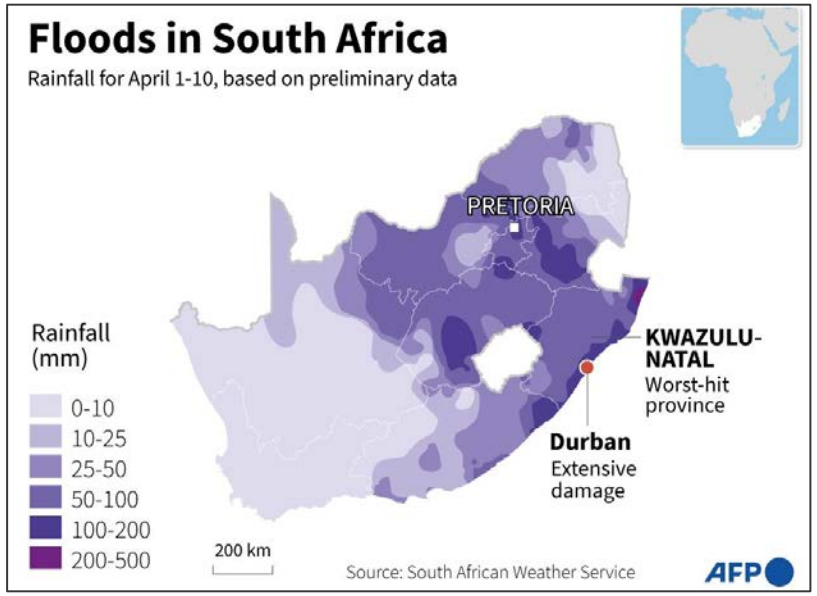
Motivation: A recent heavy rainfall event in South Africa (8 – 12 April 2022)



In a 24-hour period spanning 11–12 April, Virginia Airport recorded 304 mm (12.0 in) of Rainfall

Death toll = 443 (65 still missing)

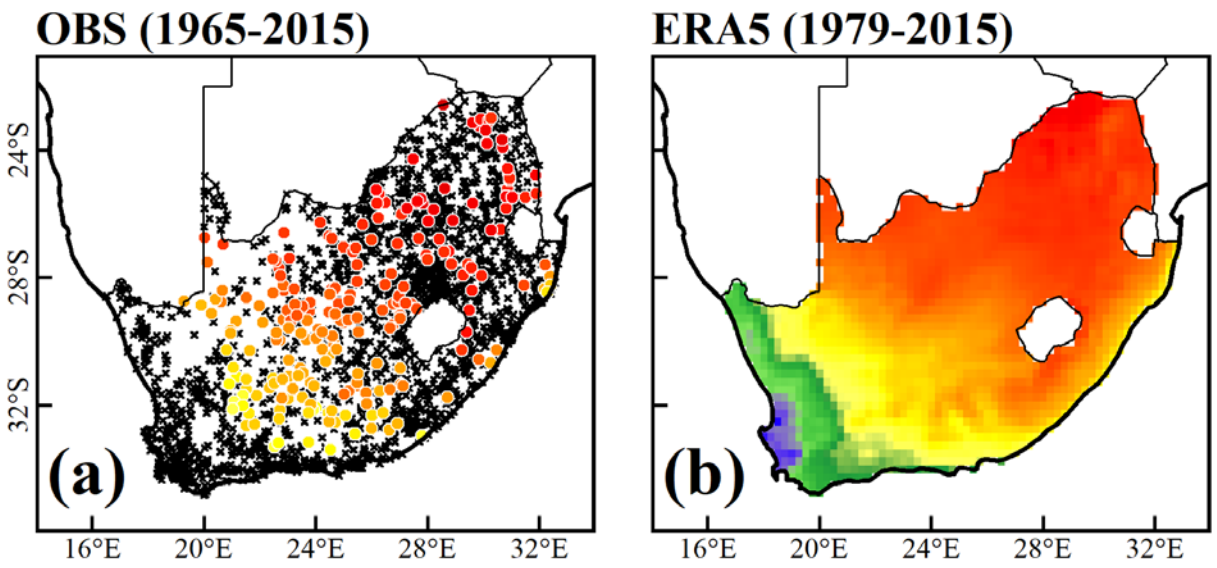
Economic losses = $5.7 billion (early estimate)

Households affected = 13,500

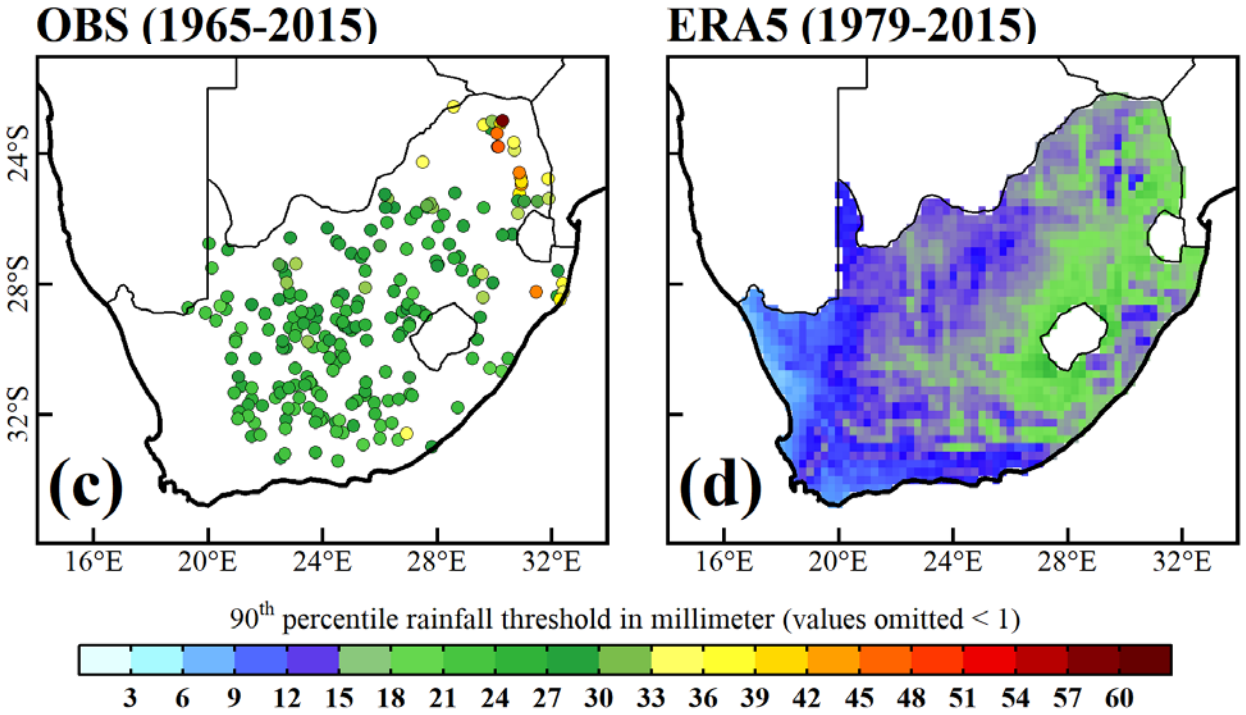
It is one of the deadliest natural disasters in the country in the 21st century after 1987 floods

Study area and Methods

Seasonality test



Local 90th Percentile threshold



- To calculate 90th Percentile (ONDJFM: 1965-2015) for OBS and 1979-2015 for ERA5
- Longer period and extended season ensures robustness of local threshold
- Overall study period: Austral Summer Season (NDJF: 1979-2015)

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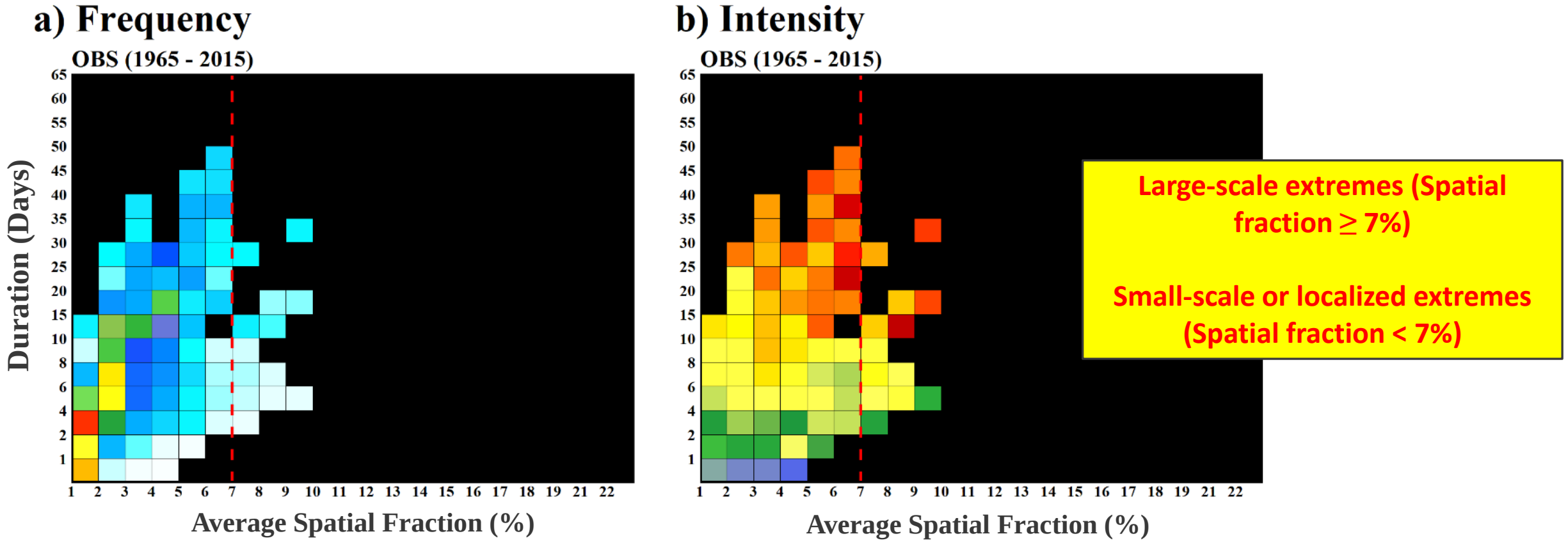
Results: Typology of rainfall extremes

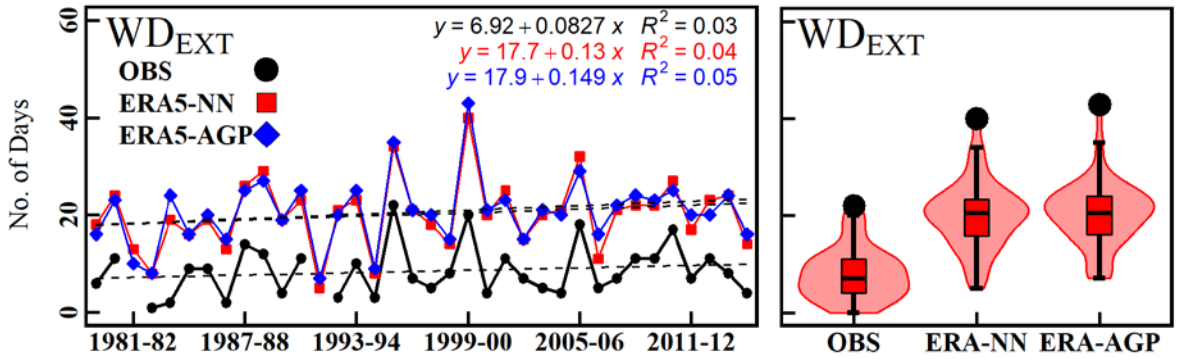


Large-scale extremes (Spatial fraction ≥ 7%)

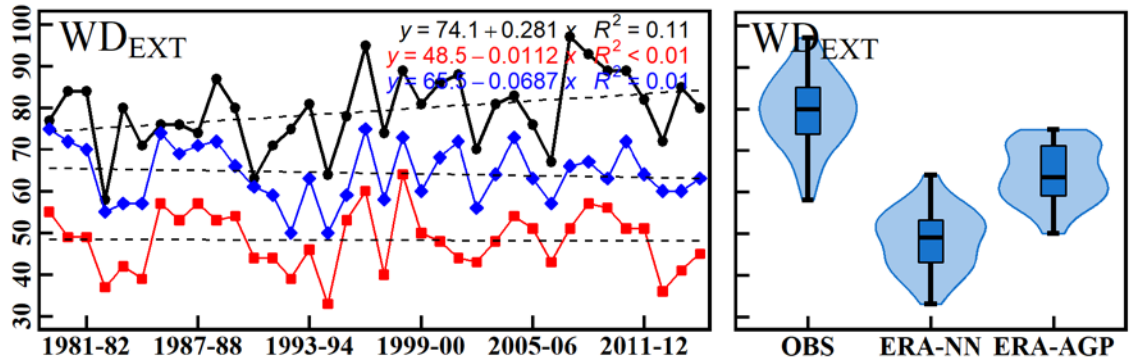
Small-scale or localized extremes (Spatial fraction < 7%)

Results (Mean characteristics)

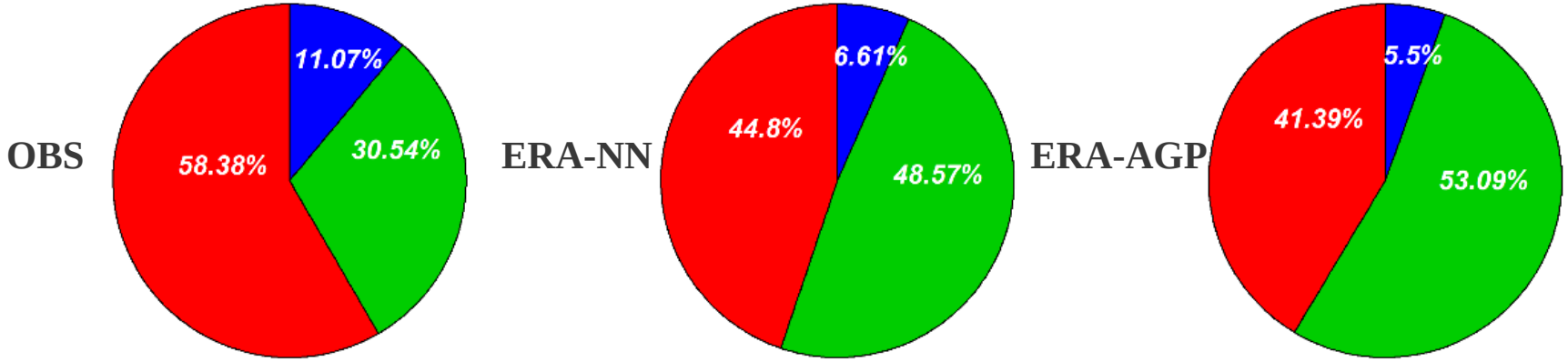
a) ISDs (Large-scale Extremes)

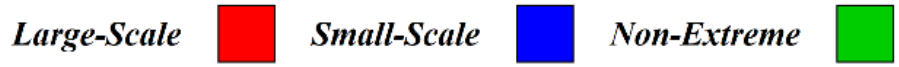


b) ISDs (Small-scale Extremes)



c) Contribution of rainfall during austral summer season (NDJF)





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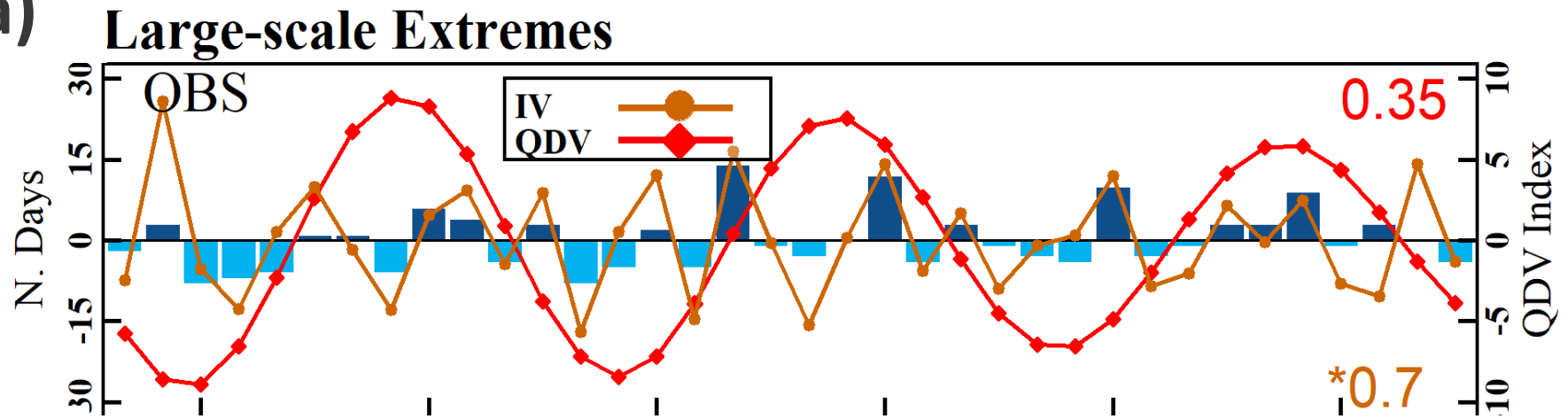
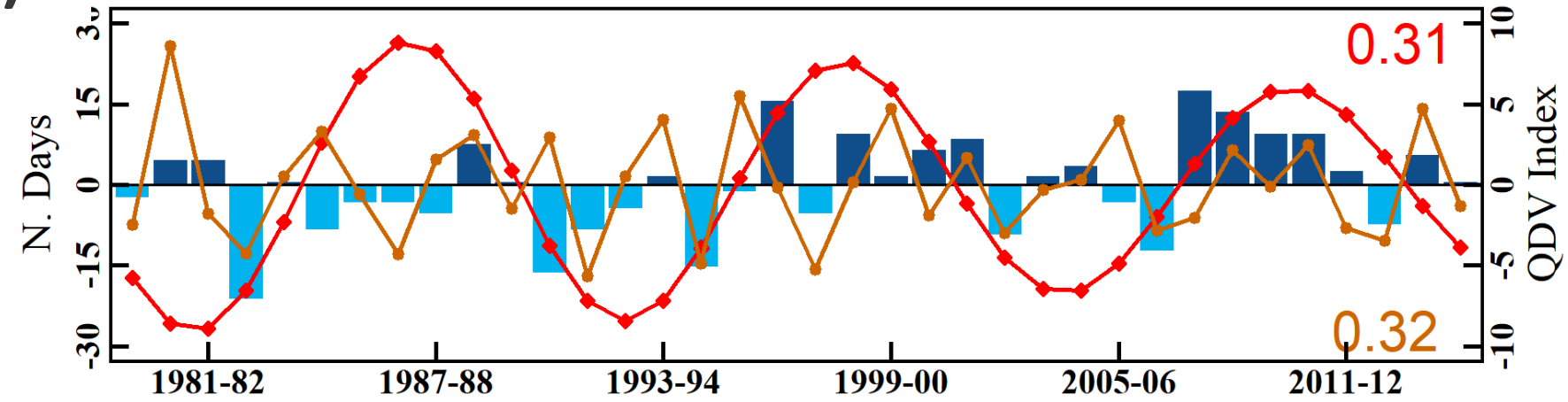
Results: Variability of extremes at low frequency timescales (ENSO and IPO)

a)



b)



The time series of Summer Rainfall Index (SRI) filtered at 2–8 year interannual (IV) and 8–13 year's quasi decadal timescales (QDV) using a *Fast Fourier Transform* filtering (Dieppois et al 2016). The filtered SRI displays different periodicities, where IV and QDV were found to be primarily associated with ENSO and the Interdecadal Pacific Oscillation, respectively.

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Risk assessment at low-frequency timescales

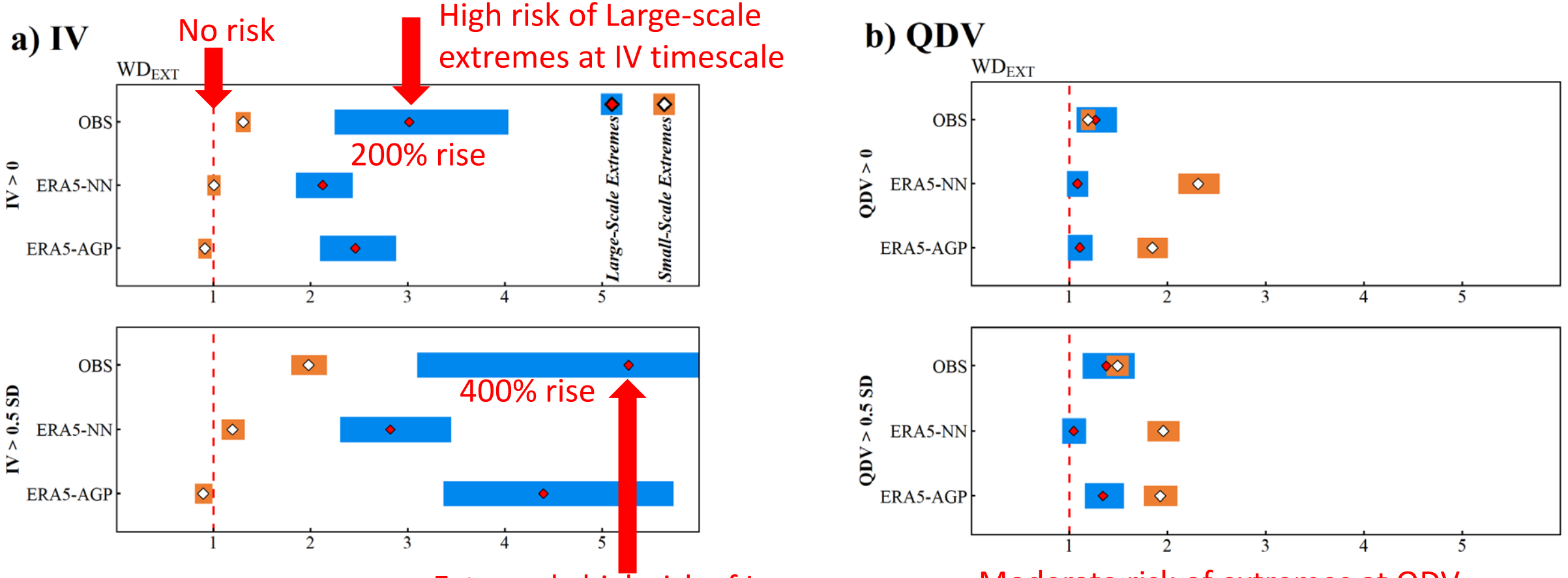
Risk Ratio RR is defined as the ratio of the probability of an ISD under a factual scenario (P_F), to that probability under a counterfactual scenario (P_{CF}) (cf. Paciorek *et al.*, 2018) and is given by the following equation:

$$RR = \frac{P_F}{P_{CF}} = \frac{\left[\frac{a}{(a+b)}\right]_{IV\,|QDV}}{\left[\frac{x}{(x+\ y)}\right]_{IV\ |\ QDV}}$$

where a (b) is the sum of a given ISD (i.e., number of wet days or total rainfall) when it lies in its positive (negative) phase of anomaly, simultaneously when IV or QDV is in the positive phase of the anomaly, representing PF scenario. Similarly, x (y) is the sum of a given ISD (i.e., number of wet days or total rainfall) when it lies in its positive (negative) phase of anomaly, simultaneously when the IV or QDV is in the negative phase of the anomaly, representing PCF scenario.

RR is computed at normal and Strong opposite phases of SRI (±0.5 SD)

Cont...

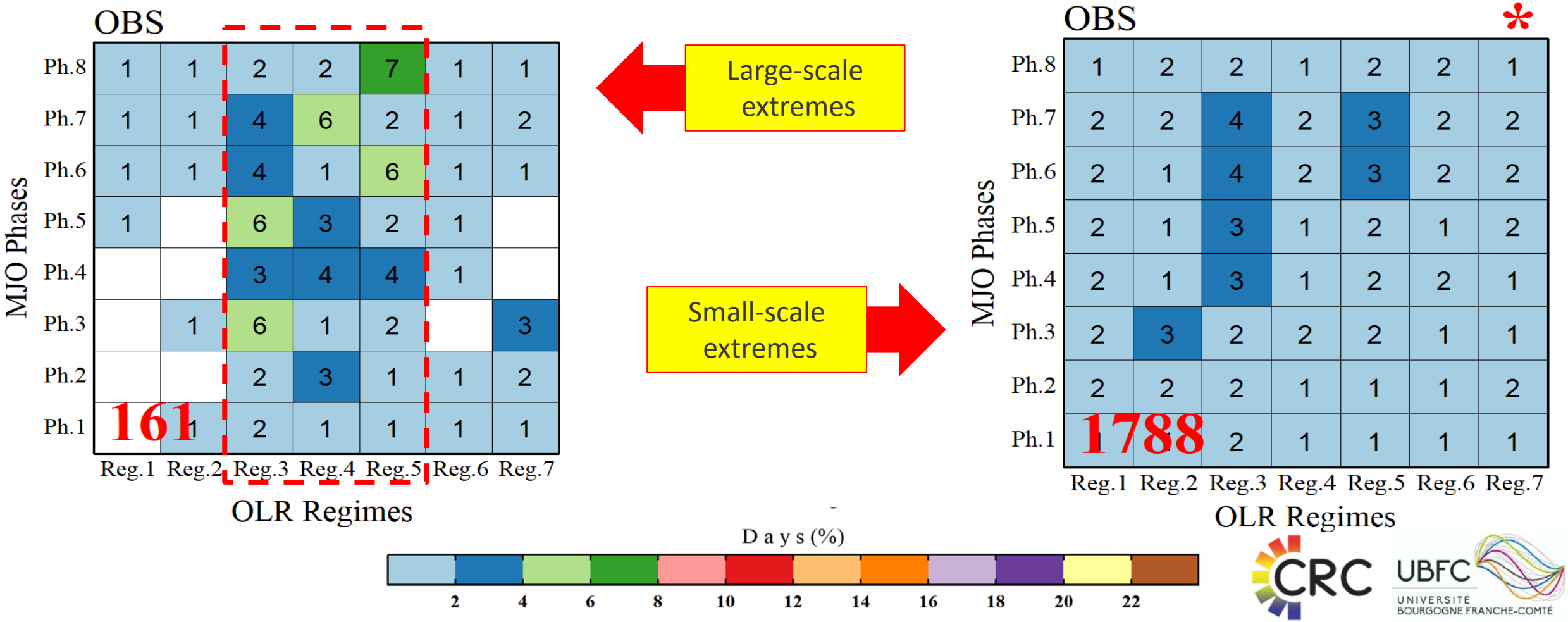


Plain language summary!

For instance, observed data show an average of 8 days.season^{-1} associated with large-scale extremes, but the risk of such extreme wet days can exceed 24 days when IV in its strong positive phase, which tends to coincide to strong La Niña events.

Results: Variability of extremes at high-frequency timescales (Frequency)

At high-frequencies, extremes are associated with synoptic-scale variability related to seven convective regimes of Tropical Temperate Troughs (TTTs: 3–7 days; Fauchareau et al. 2009) and eight phases related to intraseasonal variability of the Madden-Julien Oscillation (MJO: 30–60 days; Wheeler and Hendon 2004).

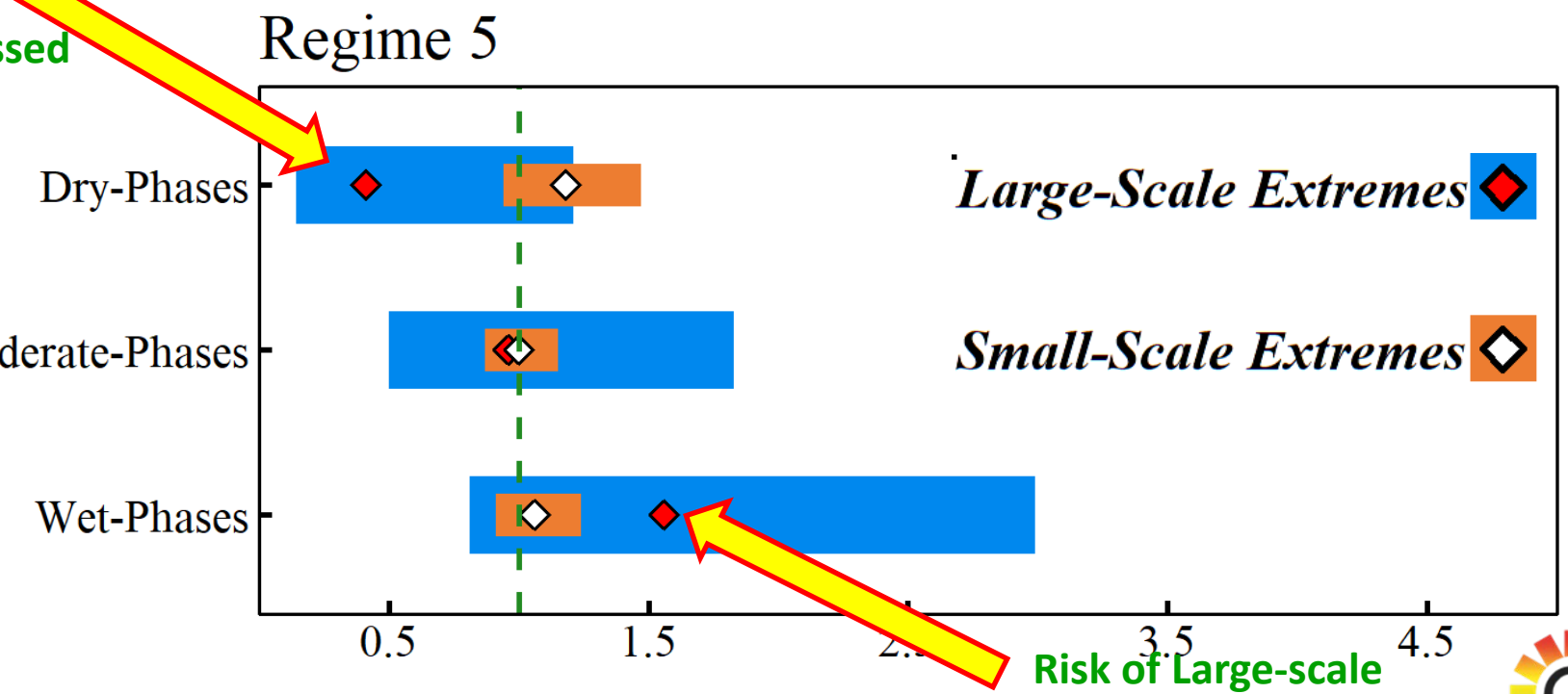


Risk assessment at high-frequency timescales

$$RR = \frac{P_F}{P_{CF}} = \frac{\left[\frac{a}{(a+b)}\right]_{Regime\ and\ Phase\ of\ interest}}{\left[\frac{x}{(x+\ y)}\right]_{Regime\ and\ Phase\ of\ interest}}$$

where *a* (*b*) is the sum of extreme (non-extreme) days when MJO > 1. Similarly, the *x* (*y*) is the sum of extreme (non-extreme) days when MJO < 1.

Risk of Large-scale extremes suppressed



MJO Phases 1-2

MJO Phases 3-5

MJO Phases 6-8

Risk of Large-scale extremes enhanced

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Summary and Conclusions

- The results demonstrate that using 7% of spatial fraction simultaneously exceeding the local threshold of the 90th percentile produces remarkable results in characterizing rainfall extremes into large- and small-scale extremes.
- Austral summer total rainfall is found to be primarily shaped by large-scale extremes.
- We also find that during small-scale events the extreme conditions are found sporadic over the region contrasting with large-scale events for which extreme conditions are found over a larger and coherent region.
- At the low-frequency timescale, the frequency of large-scale extremes strongly varies when IV timescale lies in positive phase while modulation in total rainfall associated with large-scale extremes are mainly related to the QDV timescale.
- At the high-frequency timescale, the synoptic-scale variability associated with TTT events is related to large-scale extremes as nearly 75% of such events occurring during regimes 3 to 5 whereas small-scale extremes are found equiprobable during all TTT synoptic regimes.
- The probability of large-scale extremes in TTT regime 5 is significantly enhanced during MJO phases 6 to 8 while it is suppressed during phases 1 to 2.

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Consume less to save the planet !!!

Thank you so much for your attention

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Graphical Abstract

Extremes in South African Rainfall: Mean Characteristics and Seamless Variability Across Multiple Timescales

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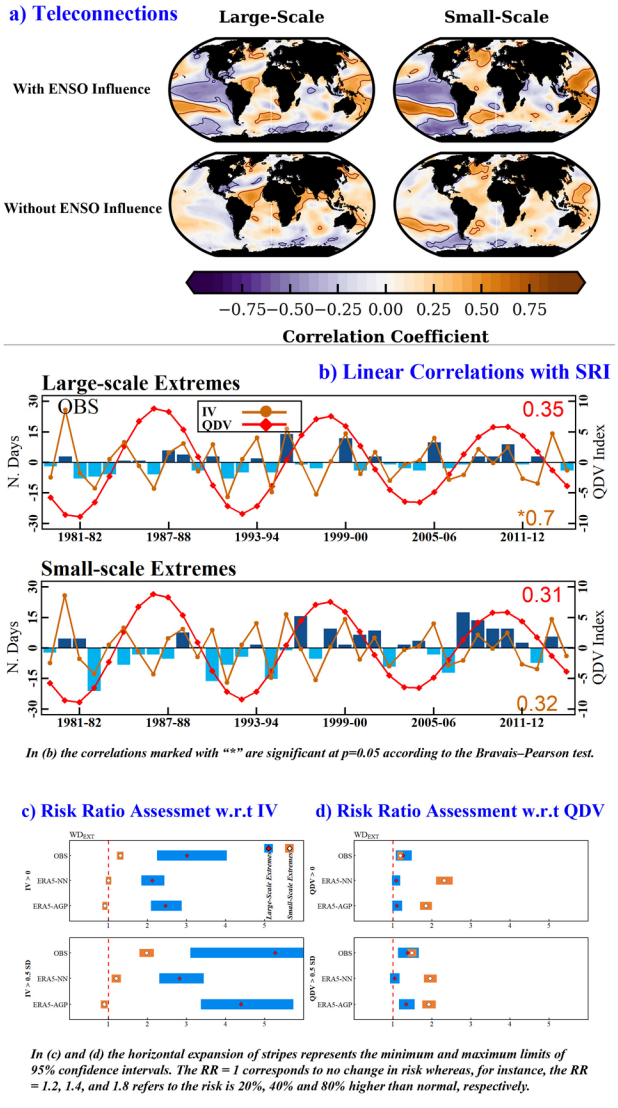
3Nansen Tutu Center for Marine Environmental Research, Department of Oceanography, University of Cape Town, South Africa

1. Variability of rainfall extremes at low-frequency timescales

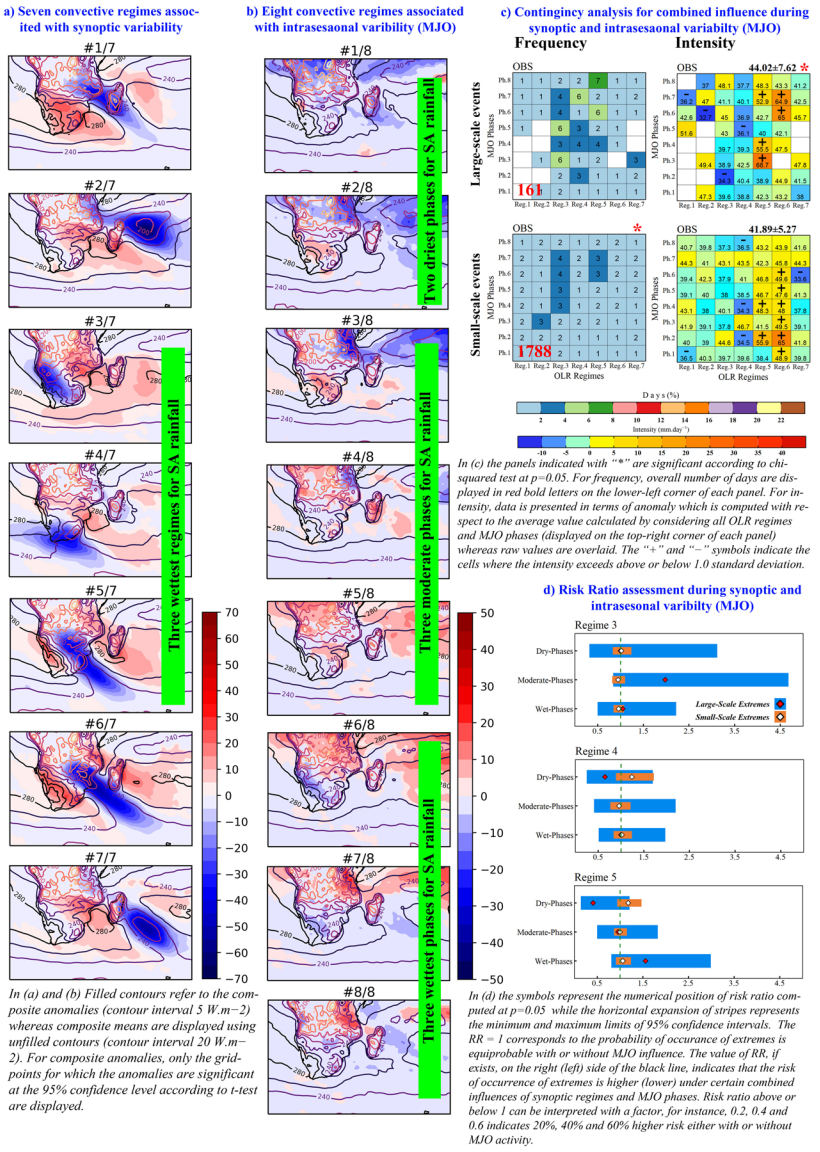


In (b) the correlations marked with "" are significant at p=0.05 according to the Bravais–Pearson test.*

In (c) and (d) the horizontal expansion of stripes represents the minimum and maximum limits of 95% confidence intervals. The RR = 1 corresponds to no change in risk whereas, for instance, the RR = 1.2, 1.4, and 1.8 refers to the risk is 20%, 40% and 80% higher than normal, respectively.

Figure 1. The correlation to global SST fields with the frequency of large- and small-scale extreme in the austral summer (a). The set of two panels in top row (bottom row) refers to the correlation to global SST with (without) ENSO influence. Anomalies of ISDs (blue bars), SRI at IV timescale (brown line) and SRI at QDV timescale (red line) are presented for wet days associated with large- and small-scale extremes (b). Estimated risk ratio computed for wet days associated with large-scale (blue stripes with red symbols) and small-scale extremes (brown stripes with white symbols) with respect to IV (c) and with respect to QDV (d) using OBS, ERA5−NN and ERA5−AGP. First row panels correspond to the RR computed by considering normal phases of IV and QDV. Second row panels correspond to the RR computed by considering strong phases of IV and QDV (i.e. ±0.5 standard deviation).

2. Variability of rainfall extremes at high-frequency timescales



In (c) the panels indicated with "" are significant according to chi-squared test at p=0.05. For frequency, overall number of days are displayed in red bold letters on the lower-left corner of each panel. For intensity, data is presented in terms of anomaly which is computed with respect to the average value calculated by considering all OLR regimes and MJO phases (displayed on the top-right corner of each panel) whereas raw values are overlaid. The "+" and "−" symbols indicate the cells where the intensity exceeds above or below 1.0 standard deviation.*

In (a) and (b) Filled contours refer to the composite anomalies (contour interval 5 W.m−2) whereas composite means are displayed using unfilled contours (contour interval 20 W.m−2). For composite anomalies, only the grid-points for which the anomalies are significant at the 95% confidence level according to t-test are displayed.

In (d) the symbols represent the numerical position of risk ratio computed at p=0.05 while the horizontal expansion of stripes represents the minimum and maximum limits of 95% confidence intervals. The RR = 1 corresponds to the probability of occurance of extremes is equiprobable with or without MJO influence. The value of RR, if exists, on the right (left) side of the black line, indicates that the risk of occurrence of extremes is higher (lower) under certain combined influences of synoptic regimes and MJO phases. Risk ratio above or below 1 can be interpreted with a factor, for instance, 0.2, 0.4 and 0.6 indicates 20%, 40% and 60% higher risk either with or without MJO activity.

Figure 2. Mean daily OLR anomalies illustrating seven convective regimes associated with TTTs (a) and eight phases of the MJO (b) during austral summer season (NDJF) over the period 1979−2015. Concomitance between OLR regimes and MJO phases for the frequency (left panels) and intensity (right panels) during austral summer season (NDJF) over the period 1979−2015, distributed row-wise for large-scale events and for small-scale events (c). For 8 phases of the MJO, only those days were considered where the amplitude exceeded 1 RMM. Estimated risk ratio computed for OBS by considering active and inactive days of the MJO explicitly for regime 3, 4 and 5 by considering dry (1−2), moderate (3−5), and wet (6−8), phases of the MJO (d).

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