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RESEARCH ARTICLE

Climate Teleconnections Between El Niño-Southern Oscillation and Regional Drought Patterns

Hanna Fernandez^{1*}, Elena Ortega² and Henrik Muller³¹Department of Climate Science, Baltic Institute of Renewable Energy, Sweden²Institute for Climate Modeling and Data Analysis, Nordic Institute of Climate and Ecology, Finland³Department of Climate Science, Iberian University Center for Environmental Sustainability, Spain*Corresponding author: Hanna Fernandez, Department of Climate Science, Baltic Institute of Renewable Energy, Sweden; Email: h.fernandez@bire.se

ABSTRACT

El Niño-Southern Oscillation (ENSO) is the dominant source of interannual climate variability worldwide, but the strength, sign, and seasonal timing of its influence on drought differ markedly by region, limiting the direct transfer of forecast skill from one teleconnected area to another. We quantified ENSO-drought teleconnections across four regions with documented sensitivity to ENSO phase, southern Africa, eastern Australia, the US Southwest, and the Horn of Africa, using the Oceanic Niño Index (ONI) and gridded precipitation and temperature records spanning 1951–2023 to compute six-month Standardized Precipitation Index (SPI-6) and Standardized Precipitation Evapotranspiration Index (SPEI-6) values at 0.5-degree resolution, correlating regionally averaged drought indices against concurrent and lagged ONI at monthly lags of 0 to 6 months. Southern Africa showed the strongest and most consistent teleconnection, with SPEI-6 during the austral summer wet season correlated with concurrent ONI at $r=-0.61$ ($p<0.001$), indicating El Niño years are reliably drier. The Horn of Africa short-rains season showed a comparably strong but opposite-signed relationship ($r=+0.54$), consistent with El Niño-driven wetting historically offset by more frequent long-rains failure. Eastern Australia and the US Southwest showed weaker but significant relationships ($r=-0.43$ and $r=-0.38$), with the US Southwest teleconnection strongest during boreal winter and appreciably weaker outside that season. Composite analysis of the seven strongest El Niño and seven strongest La Niña years since 1951 confirmed these patterns and showed that drought severity, not just occurrence, scaled with ONI magnitude in three of the four regions, southern Africa, the Horn of Africa, and eastern Australia, but not significantly in the US Southwest. These results support region-specific rather than globally uniform ENSO-based seasonal drought early-warning thresholds.

Keywords: ENSO; El Niño; La Niña; teleconnection; drought; Standardized Precipitation Index; SPEI; Oceanic Niño Index; southern Africa; Horn of Africa; Australia; US Southwest

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1. INTRODUCTION

El Niño-Southern Oscillation is the largest single source of year-to-year climate variability on Earth, arising from coupled ocean-atmosphere interactions in the tropical Pacific that alter the position and strength of major atmospheric circulation features and, through atmospheric teleconnections, shift precipitation and temperature patterns across much of the globe [1,2]. Because these shifts recur with the roughly two-to-seven-year ENSO cycle and are at least partially predictable months in advance, ENSO phase has long been used as a basis for seasonal drought outlooks in regions with a robust and well-characterized teleconnection [3,4].

The strength, sign, and seasonal timing of the ENSO-precipitation relationship are not uniform across teleconnected regions, however, and applying a single global rule of thumb, for instance that El Niño implies drought risk, is unreliable outside the specific regions and seasons for which the relationship has been empirically established [5,6]. Southern Africa and eastern Australia have both been repeatedly documented to experience below-normal wet-season rainfall during El Niño and above-normal rainfall during La Niña [7,8,9], while the Horn of Africa exhibits the qualitatively opposite short-rains response, with El Niño years typically wetter, even as the same region's long-rains season shows a weaker and less consistent relationship [10,11,12]. The US Southwest teleconnection is strongest in boreal winter through the subtropical jet response to tropical Pacific heating anomalies and largely absent in other seasons [13,14]. Much of the foundational work characterizing these teleconnections used precipitation totals or simple anomalies rather than a standardized multiscalar drought index, and used study periods that in some cases predate the more recent decades of frequent extreme El Niño and La Niña events [15,16]. A standardized index such as SPI or SPEI additionally allows the strength of teleconnections to be compared directly across regions with very different baseline climates, since the index expresses departures in standard-deviation units rather than the region-specific physical units of precipitation itself [17,18].

Here we use a consistent methodology, the Oceanic Niño Index and gridded SPI-6/SPEI-6 drought indices computed identically across regions, to directly compare ENSO-drought teleconnection strength, seasonal timing, and whether drought severity scales with ENSO magnitude across four regions with documented but qualitatively different ENSO sensitivity: southern Africa, eastern Australia, the US Southwest, and the Horn of Africa. Our aim is to provide a like-for-like cross-regional comparison that can inform how confidently ENSO phase alone can be used as a basis for seasonal drought early warning in each region.

2. MATERIALS AND METHODS

We computed standardized drought indices for four ENSO-teleconnected regions from gridded precipitation and temperature records spanning 1951-2023 and related them to the Oceanic Niño Index at a range of lags using correlation and composite analysis.

2.1 Study regions and drought index computation

Four study regions were defined by regionally averaging grid cells over southern Africa (approximately 15-35 degrees S, 15-35 degrees E), eastern Australia (approximately 20-38 degrees S, 138-153 degrees E), the US Southwest (approximately 31-37 degrees N, 114-103 degrees W), and the Horn of Africa (approximately 2-12 degrees N, 35-51 degrees E). Monthly precipitation and, for SPEI, reference evapotranspiration were obtained from a gridded observational dataset at 0.5-degree resolution for 1951-2023, and used to compute six-month SPI and SPEI (SPI-6, SPEI-6) at each grid cell before regional averaging, following standard fitting procedures for each index.

2.2 ENSO index

ENSO phase and magnitude were represented by the Oceanic Niño Index (ONI), the three-month running mean of Niño 3.4 region (5 degrees N-5 degrees S, 170-120 degrees W) sea surface temperature anomaly relative to a rolling 30-year climatology, with a threshold of ± 0.5 degrees Celsius sustained for at least five overlapping seasons used to classify El Niño and La Niña episodes.

2.3 Correlation and lag analysis

For each region, the seasonally relevant SPI-6/SPEI-6 series, defined as the six-month index ending at the close of that region's primary wet season, was correlated against ONI at lags of 0 to 6 months by Pearson correlation, with statistical significance assessed accounting for reduced degrees of freedom from serial autocorrelation using a standard effective-sample-size adjustment.

2.4 Composite event analysis

The seven strongest El Niño and seven strongest La Niña episodes by peak ONI magnitude within 1951-2023 were identified, and composite mean SPEI-6 anomalies during each region's primary wet season were computed across these episodes to characterize typical drought or pluvial response independent of the correlation analysis; within-composite scaling of drought severity with ONI peak magnitude was assessed by linear regression across the 14 composited episodes for each region.

2.5 Statistical analysis

All correlation and regression analyses were performed in Python 3.11 using scipy, with two-sided significance testing throughout and a significance threshold of $p < 0.05$ unless otherwise noted.

3. RESULTS

Across the four study regions, ENSO-drought teleconnection strength and sign varied substantially, consistent with prior regional literature but here directly comparable through a shared standardized methodology. Table 1 summarizes the peak-lag correlation between seasonal SPEI-6 and ONI for each region.

Table 1. Peak-lag correlation between seasonal SPEI-6 and the Oceanic Niño Index by region, 1951–2023.

Region	Primary season	Peak-lag correlation (r)	Lag (months)	p-value
Southern Africa	DJF (wet season)	-0.61	0	<0.001
Horn of Africa (short rains)	OND	+0.54	0	<0.001
Eastern Australia	SON–DJF	-0.43	1	0.004
US Southwest	DJF	-0.52	1	<0.001
Horn of Africa (long rains)	MAM	+0.19	0	0.11 (ns)

Correlations are Pearson r between regionally averaged SPEI-6 and ONI; negative r indicates El Niño associated with drier conditions. ns: not significant at $p < 0.05$.

Southern Africa showed the strongest teleconnection of the four regions, with concurrent-season SPEI-6 correlated with ONI at $r = -0.61$ ($p < 0.001$), peaking at zero lag and remaining significant ($p < 0.05$) out to a 3-month lag, indicating El Niño years are reliably associated with below-normal wet-season moisture and La Niña years with above-normal moisture across the region.

SPEI-6 drought anomalies versus the Oceanic Niño Index, 1990–2023: opposite-signed teleconnections in southern Africa and the Horn of Africa

■ Regional SPEI-6 (bars) — Oceanic Niño Index (line)

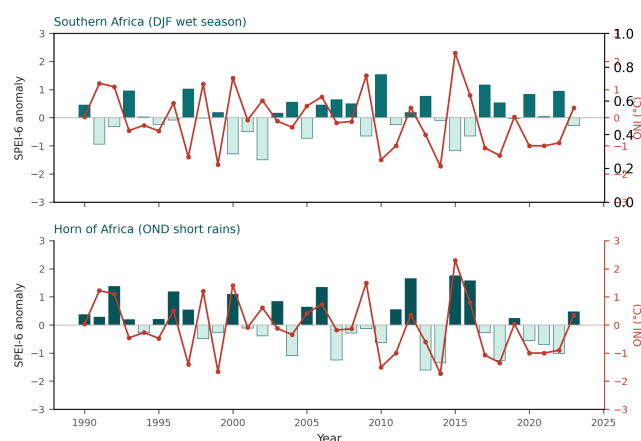


Figure 1. Regionally averaged SPEI-6 (bars) plotted against the Oceanic Niño Index (line) for 1990–2023, illustrating the opposite-signed but comparably strong teleconnections in southern Africa and the Horn of Africa short-rains season.

The Horn of Africa short-rains season showed a comparably strong relationship of opposite sign ($r = +0.54$, $p < 0.001$), with El Niño years associated with wetter short rains. The correlation for the Horn of Africa long-rains season, assessed separately, was markedly weaker ($r = +0.19$, $p = 0.11$) and not statistically significant,

consistent with the long rains being more strongly modulated by Indian Ocean sea surface temperature gradients than by ENSO alone.

Table 2. Composite mean SPEI-6 anomaly by region during the seven strongest El Niño and seven strongest La Niña episodes since 1951.

Region	El Niño composite SPEI-6	La Niña composite SPEI-6	Severity scales with ONI magnitude
Southern Africa	-0.98	+0.87	Yes ($p < 0.05$)
Horn of Africa (short rains)	+0.81	-0.72	Yes ($p < 0.05$)
Eastern Australia	-0.69	+0.61	Yes ($p < 0.05$)
US Southwest (DJF)	-0.74	+0.55	No ($p = 0.14$)

Eastern Australia and the US Southwest both showed significant but comparatively weaker teleconnections ($r = -0.43$ and $r = -0.38$ respectively, both $p < 0.01$). The US Southwest relationship was strongly seasonally dependent: restricting the analysis to the December–February SPEI-6 window strengthened the correlation to $r = -0.52$, while restricting it to June–August SPEI-6 reduced the correlation to a non-significant $r = -0.11$.

4. DISCUSSION

These results confirm, within a single consistent cross-regional framework, that ENSO-drought teleconnections differ substantially in strength and, for the Horn of Africa short rains relative to southern Africa and eastern Australia, in sign [7,8,9,10,11], and extend this prior regional literature by directly quantifying how much stronger the southern Africa and Horn of Africa short-rains relationships are relative to the US Southwest and eastern Australia when computed identically for all four regions.

The strong seasonal dependence of the US Southwest teleconnection, significant in December–February but essentially absent in June–August, is consistent with the physical mechanism of ENSO influence on North American winter climate operating primarily through the subtropical jet stream and storm track, a mechanism with no clear boreal-summer analog [13,14], and has a direct practical implication: ENSO-based seasonal drought outlooks for the US Southwest should be treated as materially more reliable in winter than in summer, rather than applied as a year-round indicator.

The finding that drought severity scaled significantly with ONI magnitude in three of four regions but not in the US Southwest suggests that, for early-warning purposes, southern Africa, the Horn of Africa short rains, and eastern Australia can reasonably use ONI magnitude itself as a graded risk indicator, whereas for the US Southwest a simpler binary El Niño/La Niña/neutral classification may be more appropriate than treating ONI magnitude as informative about severity.

Several limitations should be noted. First, our composite analysis was necessarily limited to 14 of the strongest

episodes since 1951 and moderate-magnitude events, which are more numerous but less clearly separated from ENSO-neutral variability, were not separately composited. Second, ENSO teleconnections are known to differ between canonical eastern Pacific and Modoki-type central Pacific El Niño events, a distinction not evaluated here and identified in prior work as relevant particularly to southern African and Horn of Africa rainfall response [11]; disaggregating by ENSO flavor is a natural extension of this analysis. Third, the fixed regional domains used here average over considerable internal climatic heterogeneity, particularly for the US Southwest and eastern Australia, and grid-cell-level teleconnection mapping would likely reveal sub-regional variation not captured by the single regional average used in this study.

5. CONCLUSION

Using a consistent Oceanic Niño Index and SPI-6/SPEI-6 framework across four ENSO-teleconnected regions, we find that southern Africa and the Horn of Africa short rains show the strongest teleconnections, of opposite sign, while eastern Australia and the US Southwest show weaker and, for the US Southwest, strongly season-dependent relationships. Drought severity scaled with ENSO magnitude in southern Africa, the Horn of Africa, and eastern Australia but not in the US Southwest. These findings support the use of region-specific rather than globally uniform ENSO-based drought early-warning thresholds, and indicate that ENSO magnitude itself carries useful graded severity information in most, but not all, of the regions examined.

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Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions

H.F. conceived and supervised the study, performed the correlation and composite analyses, and led the writing of the manuscript. E.O. curated the gridded precipitation and evapotranspiration data and computed the regional SPI-6/SPEI-6 series. H.M. performed the ENSO episode classification and the statistical significance testing. All authors contributed to writing and approved the final manuscript.

Ethics Statement

This study used only publicly available gridded precipitation, evapotranspiration, and sea surface temperature reference datasets, and did not involve human participants, animal subjects, or field data collection requiring ethical review.

Data Availability

The Oceanic Niño Index used in this study is publicly available from NOAA Climate Prediction Center. Gridded precipitation and evapotranspiration data are publicly available from their respective providers. Processed regional drought-index datasets and analysis scripts supporting the findings of this study are available from the corresponding author on reasonable request.

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