MODULATION OF ENSO TELECONNECTIONS BY THE INDIAN OCEAN DIPOLE OVER SOUTH AMERICA DURING AUSTRAL SPRING

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1. INTRODUCTION

The El Niño–Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD) are key modes of tropical variability with strong impacts across the Southern Hemisphere. Although ENSO is known to influence South American precipitation and temperature anomalies during austral spring (SON), the role of the IOD in modulating these patterns has received less attention. This study investigates how the IOD modulates the atmospheric circulation and surface climate response in South America to ENSO during SON.

2. DATA AND METHODOLOGY

The analysis uses ERA5 reanalysis data for 1940–2020, including geopotential height at 750 hPa and 200 hPa, GPCC precipitation, and CRU TS v4.05 temperature datasets. ENSO and IOD events are identified using the Oceanic Niño Index (ONI) and Dipole Mode Index (DMI), respectively. In addition, a large ensemble of CFSv2 model outputs is used to assess robustness and sampling uncertainty, following methodologies from Kumar and Chen (2017) and Andrian et al. (2024). Partial linear regression is used to isolate the signal of ENSO and IOD on regional climate anomalies. The regressions are computed with and without including the influence of one pattern onto the other (i.e. full ENSO regression includes the influence that IOD might have on ENSO whereas ENSO-based regression excludes this potential influence). Composite analyses are computed to evaluate individual and simultaneous events of the two large-scale climate patterns, with statistical significance tested using a Monte Carlo approach. The signal-to-noise ratio (SNR) is estimated from the ensemble to assess the intra-event variability and to explore nonlinear responses. Puro events are those in which the influence of one of the modes was removed (i.e. pure ENSO events do not include the influence of IOD and vice versa).

3. RESULTS

The regression analysis reveals that both ENSO and IOD exert significant influences on South American climate during SON. The full regression patterns for ENSO and IOD display notable similarities, likely due to the high correlation between their respective indices. ENSO-associated anomalies show the expected behavior: increased precipitation over southeastern South America (SESA) and central Chile, with reduced precipitation over northern South America. Temperature anomalies show warming over tropical western South America and eastern Brazil, and cooling over Patagonia. However, when the IOD signal is removed, the intensity and spatial coverage of the ENSO-associated anomalies diminish, particularly the precipitation anomaly dipole, and the warming pattern over eastern Brazil disappears. On the other hand, the IOD-based regression exhibits a strong anticyclonic circulation anomaly centered around 20°S–50°W, that is not present in the ENSO-based regression. The circulation anomaly seems to modulate the meridional extent of ENSO's precipitation influence by constraining positive rainfall anomalies around 20°S and inhibiting their northward extension into tropical regions. When the ENSO signal is removed the circulation retains its structure, and temperature anomalies, especially warming over central South America, become even more intense and statistically significant, suggesting an important standalone role for the IOD in this region.

Composites further support the regression findings and highlight nonlinearities. Pure El Niño events (Fig. 1a) depicts the well-documented ENSO signal, while pure positive IOD events (Fig. 1b) show an anticyclonic anomaly at midlatitudes and a marked dipole in precipitation over Brazil and SESA. Their co-occurrence (Fig. 1c) produces stronger and more confined positive precipitation anomalies in SESA and enhanced warming in central South America. The constructive interference reflects the reinforcing nature of both circulation anomalies and their associated surface climate anomalies. Conversely, the composites for the negative phases, La Niña and negative IOD, are more variable. Pure La Niña events (Fig. 1d) are associated with a weak, largely non-significant signal in circulation and rainfall anomalies, while temperature anomalies are only notable in central regions. Negative IOD events (Fig. 1e) do not display a simple reverse of those for the positive phase. While the precipitation anomalies mainly reverse signs, the temperature anomalies are weak. The combined La Niña–negative IOD events (Fig. 1f) show a disrupted and inconsistent response: negative rainfall anomalies are enhanced over SESA, but significance is low, and warming is discernible over Patagonia. The CFSv2 model simulations are largely consistent with the observed composite distributions for the positive phases of both large-scale climate patterns. For both El Niño and positive IOD events, the simulated precipitation and temperature anomalies reproduce the observed dipoles, circulation centers, and regional impacts. The combined El Niño–IOD+ cases show enhanced intensity and greater statistical coherence, confirming the modulating effect of the IOD. In the negative phase, the model again captures the ENSO signal reasonably well. However, as in the observational dataset, composites for negative IOD and La Niña are weaker and more spatially variable. A key finding from the model is that the combination of La Niña and negative IOD tends to produce results more consistent with the negative IOD pattern—suggesting that in these cases, IOD dominates the joint response. This is particularly clear in temperature anomalies over Patagonia and precipitation reductions over central Argentina

4. CONCLUSIONS

The IOD plays a key role in modulating ENSO-related climate anomalies in South America in SON. Positive IOD events tend to reinforce El Niño signals, while the influence of negative IODs in La Niña signals is less consistent. The magnitude of both large-scale climate patterns strongly conditions the sign and intensity of the resulting regional anomalies, emphasizing the need for joint monitoring and prediction of ENSO and IOD in climate services. Regional differences, particularly in N-SESA and Patagonia, highlight the importance of understanding IOD–ENSO combined influence for improving seasonal forecasts.

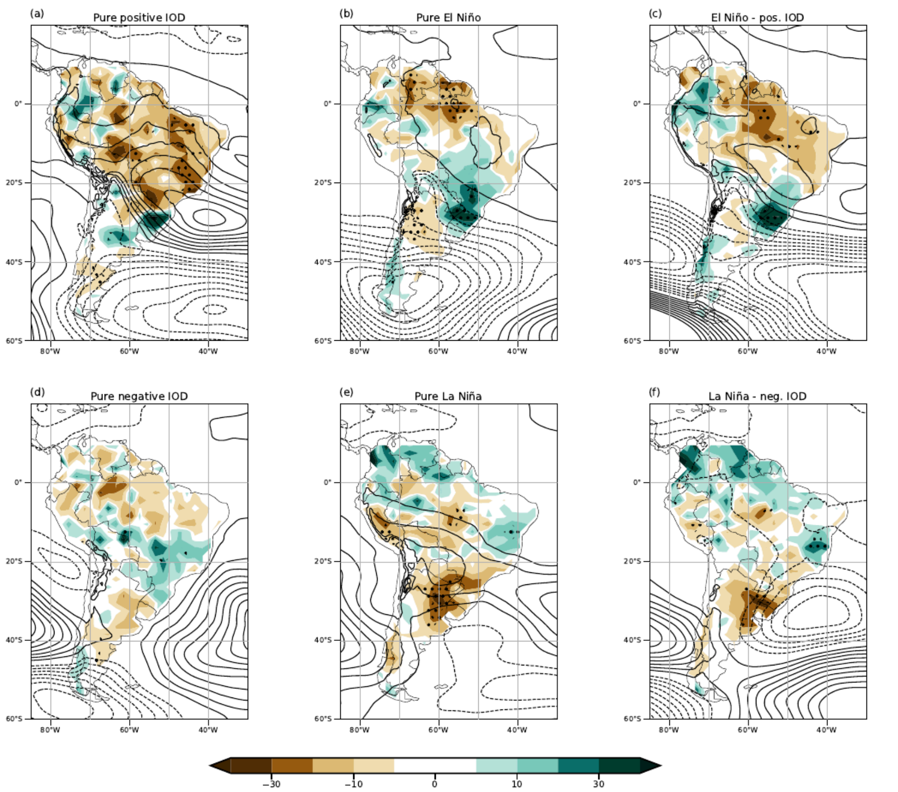

Figura 1: Composites of geopotential height anomalies at 750hPa (m, lines) and precipitation(mm/day, shading) for positive (top) and negative (bottom) events of IOD (left), ENSO (middle), and simultaneous ENSO-IOD (right). Dotted regions indicate 95% statistical significance with a Monte Carlo test.

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