



CGIAR DIGITAL TRANSFORMATION ACCELERATOR • IWMI •  
SEASONAL BRIEFING

# El Niño impacts in the Limpopo River Basin

A very strong El Niño is forecast. This briefing sets out the September 2026–February 2027 seasonal outlook for the basin and what the historical record implies for the 2026/27 growing season and its maize crop.

TYPE **Briefing** AREA **Limpopo Basin** FORECAST ISSUE **September 2026**

CONFIDENCE **Moderate** C3S DATA **FINAL • 8 MODELS**

---

KEY FINDINGS

- A **very strong El Niño** is forecast. On **RONI**, NOAA's standard ENSO index since 2026, which removes the background tropical-ocean warming, the event classifies as very strong ( $\approx +2.8$  at the November reference month). The model's physical **Niño 3.4 SST-anomaly** forecast is **2.78 °C** for the Sep–Feb mean (80% range 2.45–3.12 °C), MOS-recalibrated from the equal-weight mean of all 8 systems (563 members total); the range is the cross-validated calibration error, not the raw member spread.
- **Markedly above-average temperatures** are predicted across the basin from October 2026 to February 2027 (up to +2.1 °C; September near normal at -0.2 °C), with near-unanimous agreement between models from November.
- **Rainfall tilts driest toward November**, when up to 100% of the basin **area** carries a below-normal signal (spatial extent, not a probability).
- Historically, El Niño JFM seasons in the basin are **drier, hotter and more evaporative** (-11.6% rainfall, +0.7 °C, +5 hot days, +34 mm ET<sub>0</sub>) and are associated with **lower maize yields** in South Africa and Zimbabwe (a weaker, non-significant tendency in Mozambique).

NIÑO 3.4  
FORECAST

**2.78** °C

El Niño · Sep–Feb  
average · 80%  
range 2.45–3.12 °C

BASIN  
TEMPERATURE

**+2.1** °C

peak lead · 100%  
model agreement

NOVEMBER  
RAINFALL  
(BASIN)

**100%**

of basin **area**  
below normal  
(spatial extent, not  
probability)

HISTORIC JFM  
ET<sub>0</sub>

**+34** mm

El Niño composite  
anomaly

# El Niño is here

A sustained warming of the central and eastern equatorial Pacific has crossed the El Niño threshold. 8 C3S seasonal forecast systems place the Niño 3.4 index firmly in El Niño territory through September 2026–February 2027.

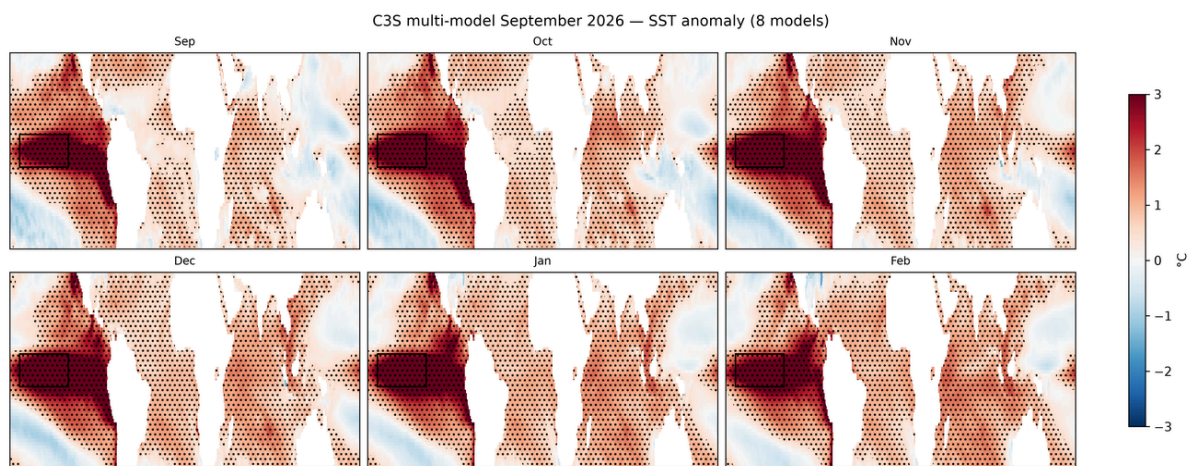


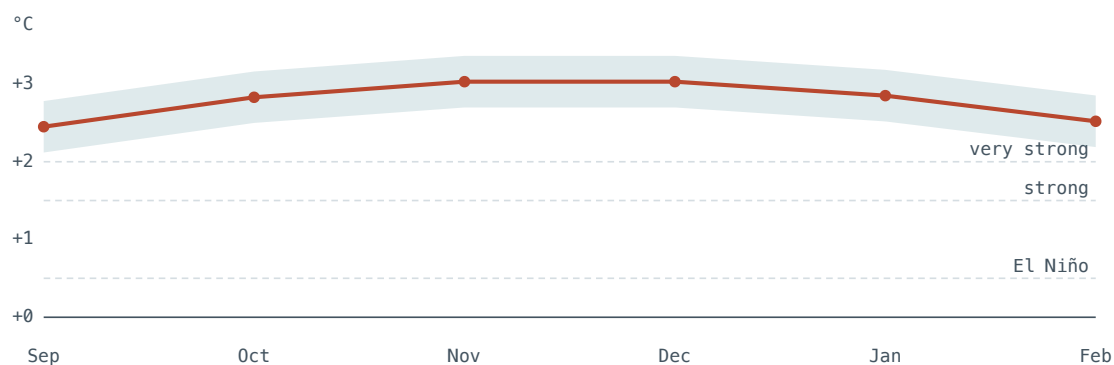
**Figure 1.** Multi-model sea-surface-temperature anomaly forecast (8 systems), September 2026–February 2027. The rectangle marks the Niño 3.4 region (5°N–5°S, 170°W–120°W); stippling shows where the anomaly exceeds 0.5 °C. [Methodology<sup>2</sup>](#)

## FORECAST NIÑO 3.4 • CALIBRATED POINT & 80% INTERVAL



Calibrated multi-model Niño 3.4 (filled marker) with its leave-one-out 80% predictive band; dashed ticks mark the El Niño (+0.5 °C), strong (+1.5) and very-strong (+2.0) thresholds. The hollow marker is the raw model mean before recalibration. [Methodology<sup>2,4</sup>](#)

## FORECAST TRAJECTORY · SEPTEMBER 2026–FEBRUARY 2027



Calibrated Niño 3.4 by target month (line) with the  $\pm$ leave-one-out band, showing whether the event builds or eases through the season. [Methodology<sup>2,4</sup>](#)

## PHASE & STRENGTH PROBABILITIES

|          |                  |
|----------|------------------|
| Phase    | El Niño 100%     |
| Strength | very strong 100% |

Share of the 563-member calibrated ensemble in each ENSO phase (ocean = La Niña, grey = Neutral, ember = El Niño) and, for El Niño, split by strength (deeper = stronger; grey = not El Niño). Derived from MOS-calibrated ensemble members. [Methodology<sup>2,4</sup>](#)

## 02 · THE FORECAST

# What to expect: September 2026–February 2027

The basin is predicted to run hot. Temperature anomalies are near-unanimous and consistent across models; the rainfall signal is weaker: up to 100% of the basin **area** tilts below normal toward November (spatial extent, not a probability; seasonal rainfall skill here is low, so read it as a risk flag rather than a confident drought forecast).

## HOW THE BASIN ENTERS THE SEASON · RECENT RAINFALL VS 1991–2020



**2026-06 to 2026-08 rainfall was 138% of the 1991–2020 normal: much above normal (98th percentile, SPI-3-style +2.1).** Basin-mean CHIRPS gauge rainfall over the three months before issue, standardised against the 30-year distribution of the same window (empirical percentile → normal quantile). The season therefore opens on wet ground, which buffers the drought risk implied by the forecast below. [Methodology<sup>9</sup>](#)

**Root-zone soil moisture is at the 97th percentile (very wet, SSI-3 +1.8; 121% of the 1991–2020 normal).** This is the rain-fed water-availability companion to the rainfall index above: ERA5-Land monthly reanalysis, 0–100 cm root zone over 2026-06 to 2026-08, standardised against the same 1991–2020 window. Rain-fed cropping depends on this soil water; irrigated areas depend on the storage buffer below.

[Methodology<sup>14</sup>](#)

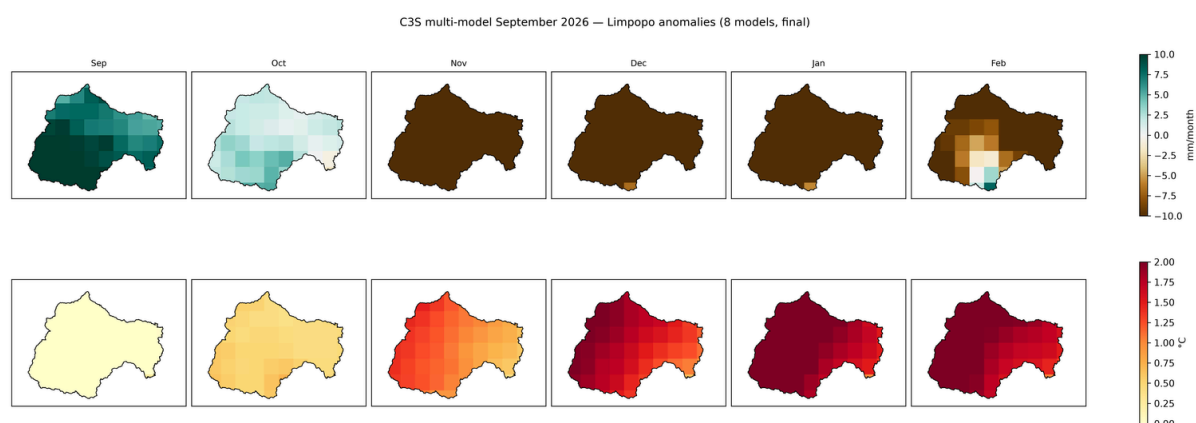
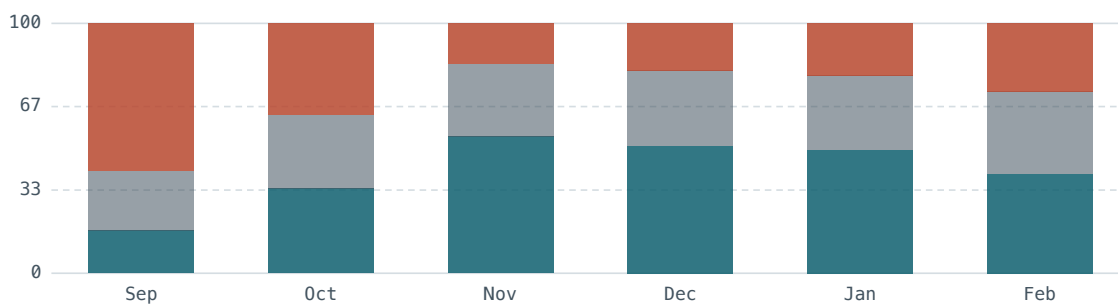


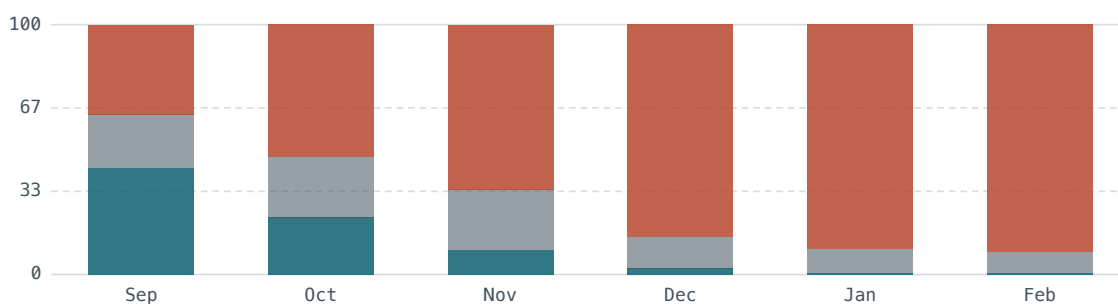
**Figure 2.** Multi-model rainfall (top) and mean-temperature (bottom) anomalies for the Limpopo Basin, September 2026–February 2027, clipped to the catchment. The temperature signal is basin-wide (100% peak model agreement); the basin-mean rainfall deficit runs from November to February and is deepest in December (–24 mm/month). [Methodology<sup>2</sup>](#)

## RAINFALL TERCILE PROBABILITIES · BY MONTH



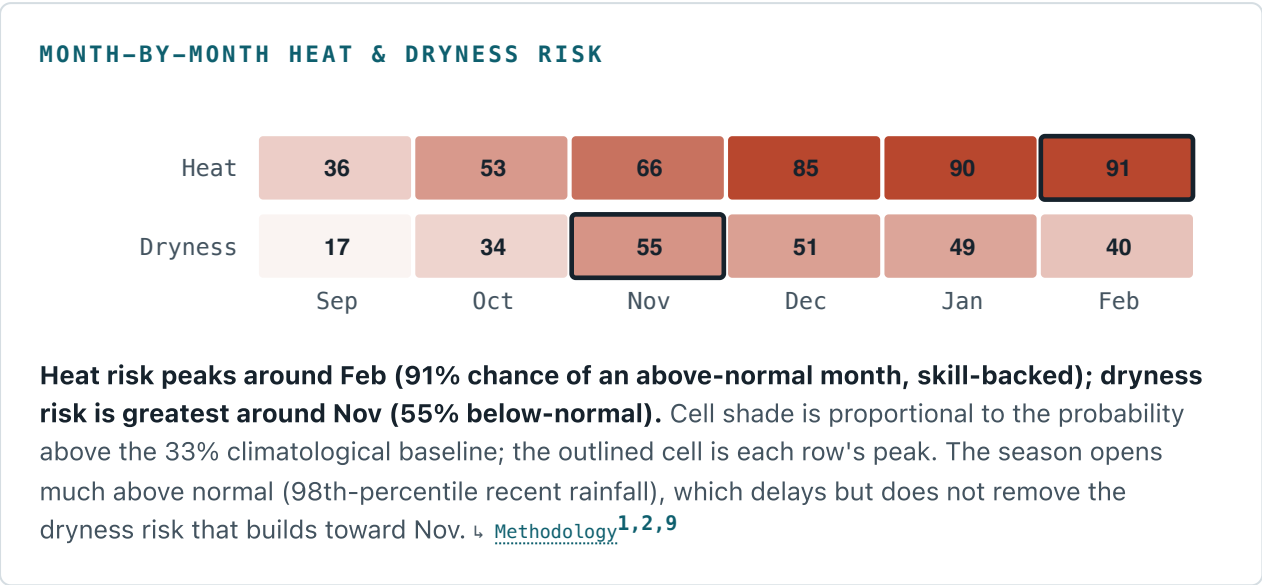
Probability of the below / near / above-normal tercile each month (ocean = below, grey = near, ember = above; dashed guides at 33/67% mark equal-odds climatology). Ensemble counted against each model's own 1993-2016 hindcast terciles. **Verified skill** (leave-one-out vs CHIRPS, 24 yr): RPSS +0.03, ROC 0.56 (below) / 0.62 (above). [Methodology](#)<sup>2,9</sup>

## TEMPERATURE TERCILE PROBABILITIES · BY MONTH

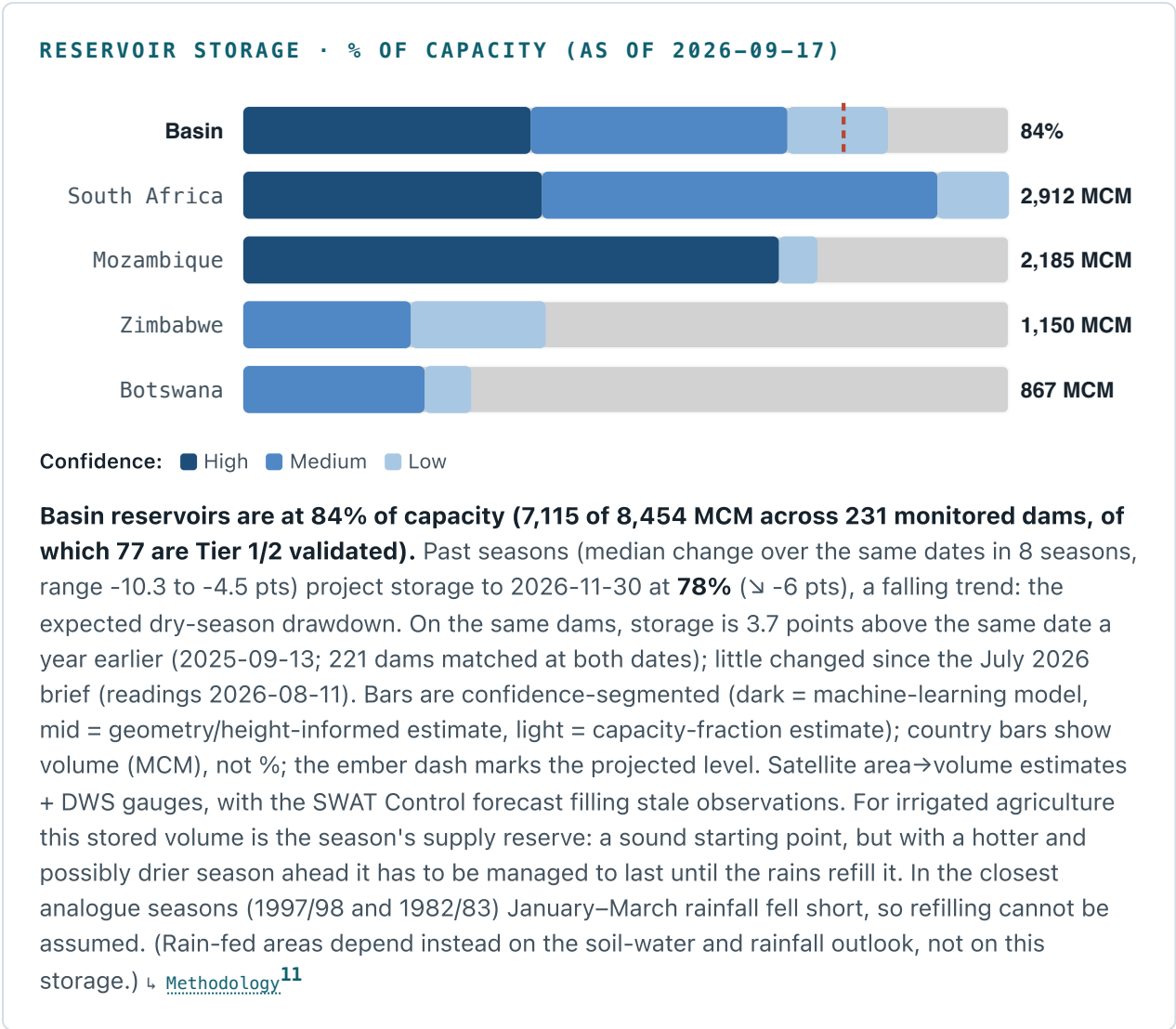


Probability of the below / near / above-normal tercile each month (ocean = below, grey = near, ember = above; dashed guides at 33/67% mark equal-odds climatology). Ensemble counted against each model's own 1993-2016 hindcast terciles. **Verified skill** (leave-one-out vs ERA5, 24 yr): RPSS +0.13, ROC 0.74 (below) / 0.62 (above). [Methodology](#)<sup>1,2</sup>

# Seasonal risk timeline

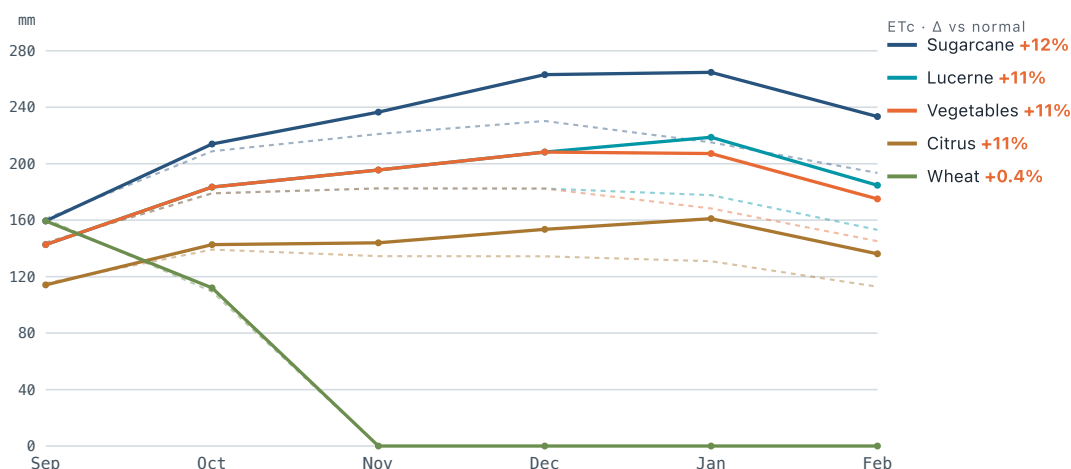


# Water in the basin now: the irrigation-supply reserve



## Crop water demand: the irrigation-demand side

### CROP WATER DEMAND ETC · SEP-FEB · FORECAST VS 1991-2020 NORMAL



Irrigated agriculture is the basin's largest water user, about 52% of total basin water demand (2,551 of 4,881 Mm<sup>3</sup>/yr; LIMCOM Future Water Demand Scenarios Report, 2025), so a warmer season raises how much water crops lose to the atmosphere. The forecast warmth lifts reference  $ET_0$  about +11% above the 1991-2020 normal over Sep–Feb, raising crop water demand ( $ET_c = K_c \times ET_0$ : soil evaporation + plant transpiration) for the main irrigated crops by up to +12% (Sugarcane). Because the rainfall outlook is also drier, the **net** irrigation requirement ( $ET_c$  minus effective rainfall) rises by more than  $ET_c$  alone. This seasonal rise previews the longer-term trajectory: LIMCOM projects basin reference ET to climb roughly 5–10% by 2060 under climate change (LIMCOM Climate Change Analysis for the Limpopo River Basin, 2025). The  $ET_0$  climatology is FAO-56 Penman–Monteith (AgERA5); the  $ET_0$  rise is a **temperature-sensitivity approximation**: the observed basin  $dET_0/dT$  applied to the forecast temperature anomaly, with radiation, humidity and wind held at climatology (fields this pipeline does not ingest), not a full Penman–Monteith recomputation.  $K_c$  curves per crop are FAO-56 (Allen et al. 1998), Table 12, representative and editable. [Methodology](#)<sup>3,5</sup>

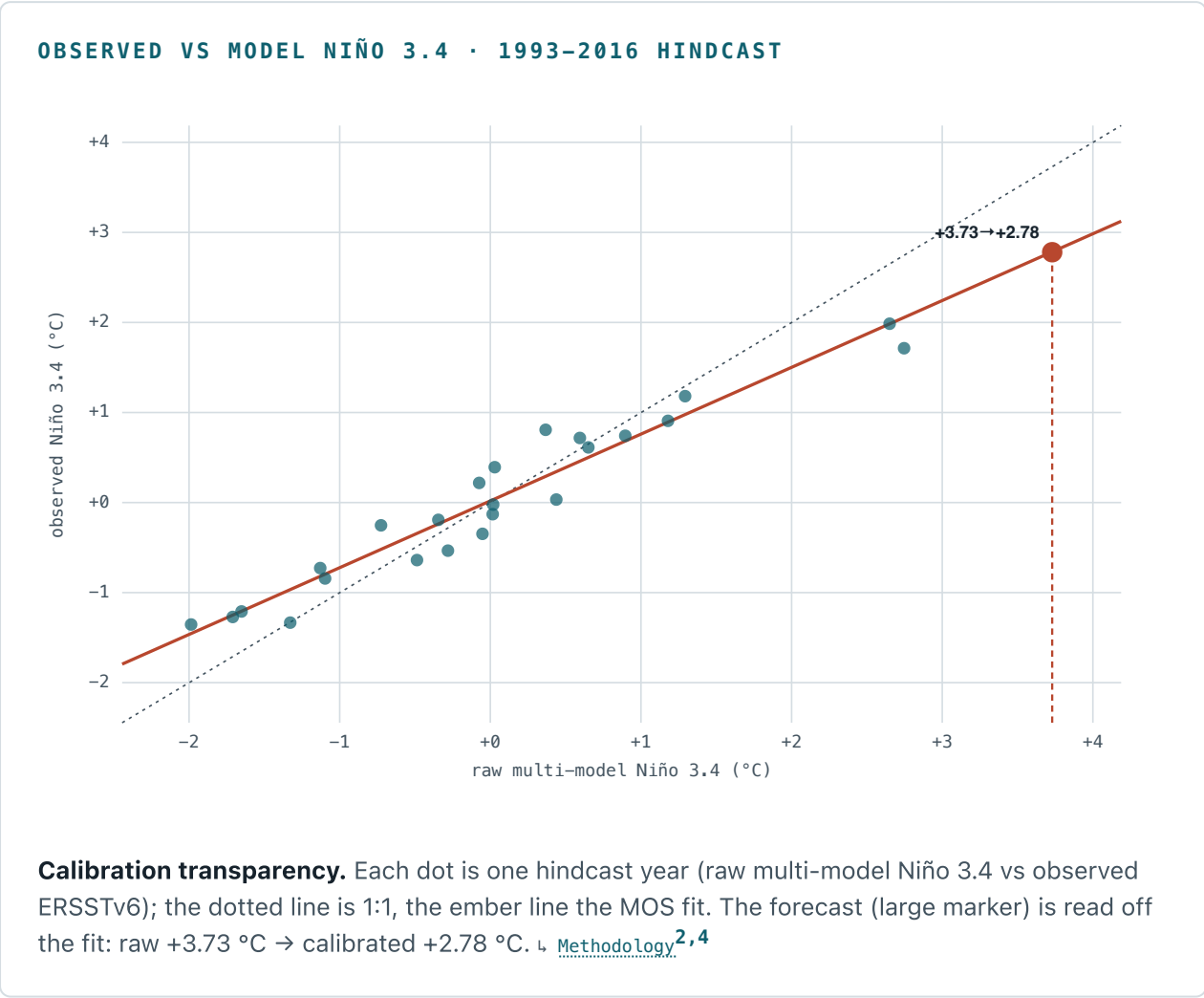
Lower-than-average rainfall at the start of the season can delay planting for rainfed maize, while the accompanying heat raises water demand on emerging seedlings, compounding stress into the 2026/27 season.

### 03 · CALIBRATION & TRANSPARENCY

## How the forecast is bias-corrected

Raw coupled-model Niño 3.4 can mis-scale El Niño amplitude, so the headline index is recalibrated against observations. Over 1993–2016 the multi-model hindcast tracks observed Niño 3.4 with correlation  $r = 0.97$ ; a least-squares fit

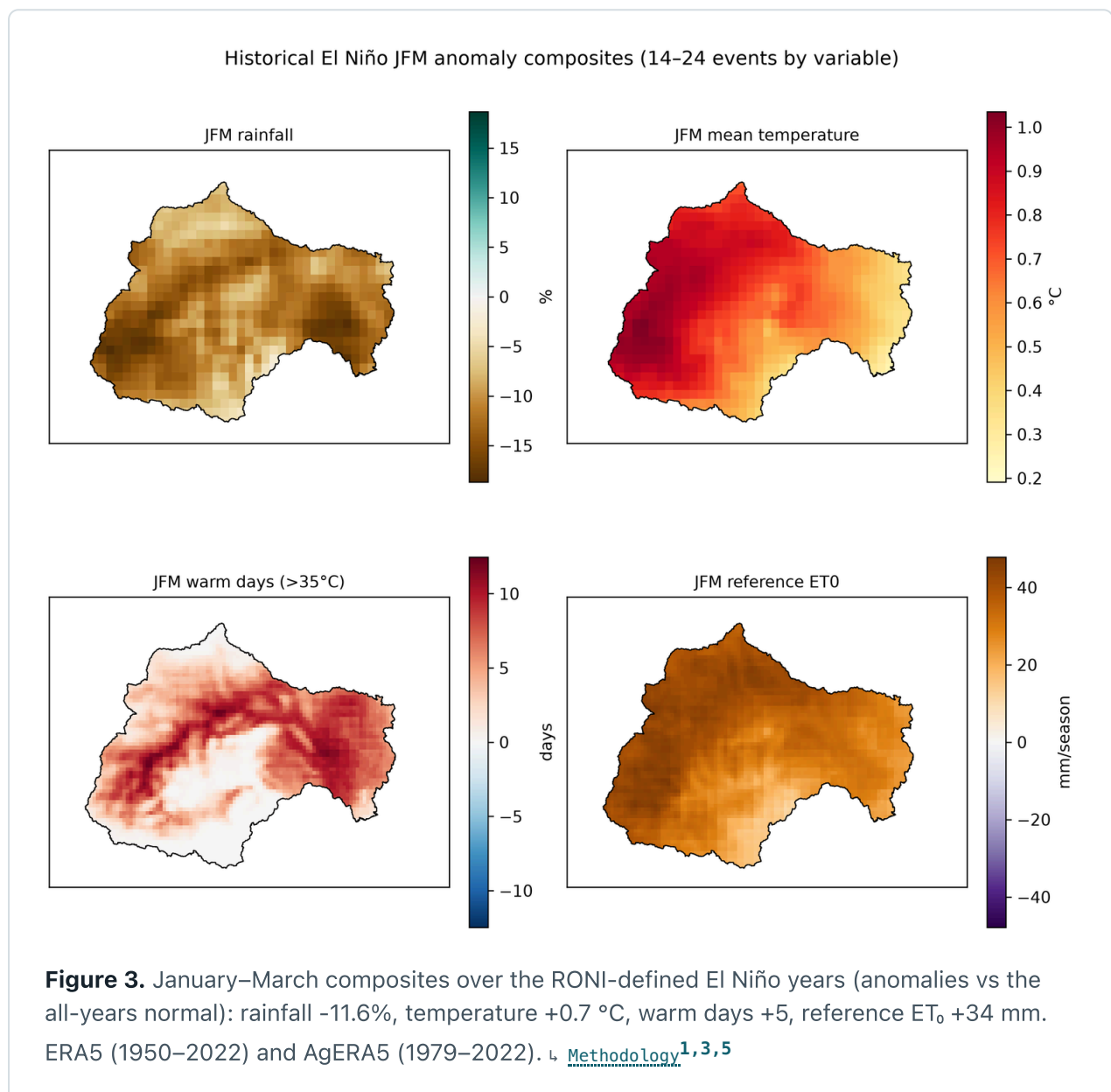
(slope 0.74) maps the raw forecast onto observations, and the leave-one-out RMSE (0.26 °C), not the over-dispersed ensemble spread, sets the uncertainty band.



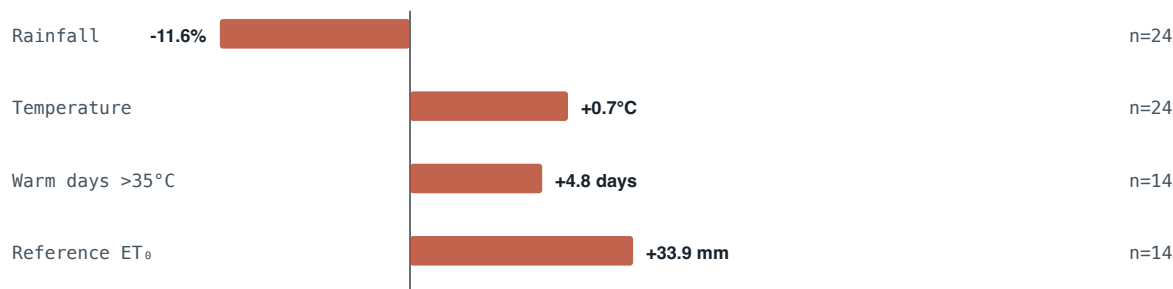
|                                                                      |                                                                                       |
|----------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| <p><b>Correlation (phase skill)</b></p> <p><math>r = 0.97</math></p> | <p><b>MOS slope</b></p> <p><math>b = 0.74</math> · over-amplifying (slope &lt; 1)</p> |
| <p><b>Cross-validated error</b></p> <p>L00 RMSE = 0.26 °C</p>        | <p><b>Training period</b></p> <p>1993–2016 · n = 24 yr</p>                            |

## What past El Niño seasons did to the basin

Over the January–March growing season, historical El Niño years in the basin trend drier, hotter and more evaporative. The temperature, hot-day and evaporative-demand signals are the most consistent; the rainfall signal is drier on average but weaker and more variable; the strength of each link is quantified below.



## AVERAGE EL NIÑO SIGNATURE OVER THE BASIN



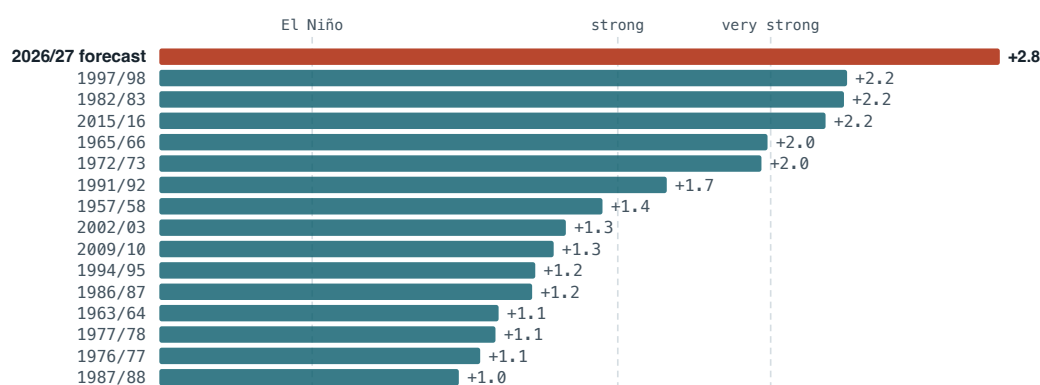
Basin-mean El Niño composite anomaly per variable (bar length normalised within each variable; ember = drier / hotter / more evaporative, ocean = wetter / cooler). n = El Niño years composited.

↳ [Methodology](#) **1,3,5**

## How this compares to past El Niños

### STRONGEST EL NIÑOS ON RECORD · RANKED BY NOVEMBER RONI

On **RONI**, NOAA's standard ENSO index since 2026, which strips out the background tropical-ocean warming, the forecast is a **very strong El Niño** at  $\approx +2.8$ , ranking the strongest El Niño in the record since 1951. Its closest RONI analogues are 1997/98, 1982/83, 2015/16: those seasons ran -10%, -44%, -16% on basin January–March rainfall, with generally lower maize yields (8 of 9 country-seasons below normal). The model's physical Niño 3.4 SST-anomaly forecast (MOS-calibrated, not RONI) is +3.0 °C at its November reference month and +2.78 °C for the Sep–Feb mean. Events are compared on preceding-November RONI (the methodology's predictor month).



The 15 strongest El Niño seasons since 1951 (of 24 with November RONI  $\geq 0.5$ ), ranked; this forecast (ember) sits at #1. The closest analogues and the basin impacts they recorded (RONI primary, the long-series Niño 3.4 shown alongside):

| ANALOGUE SEASON | NOV RONI | NOV NIÑO 3.4 | BASIN JFM RAINFALL | MAIZE YIELD  |
|-----------------|----------|--------------|--------------------|--------------|
| 1997/98         | +2.2     | +2.4         | -10%               | -11% to +8%  |
| 1982/83         | +2.2     | +2.1         | -44%               | -54% to -13% |
| 2015/16         | +2.2     | +2.6         | -16%               | -53% to -16% |

Analogue-season Niño 3.4 is the HadISST long series (1870 onward, base 1981–2010), the reconstruction this briefing's historical record is built on; the forecast is calibrated against the NOAA PSL ERSSTv6 series (base 1981–2010). Same base period, different SST reconstructions. At the seasons listed here the long series runs about 0.4 to 0.7 °C warmer than the series the forecast is calibrated against, so the forecast's own Niño 3.4 should not be read against this column. Ranking and classification use NOAA CPC RONI on both the forecast and the analogue seasons.

Analogues are the observed El Niño seasons closest to this forecast in preceding-November RONI; impacts are the basin January–March outcomes those seasons actually recorded (not a forecast). Maize-yield range spans South Africa, Mozambique and Zimbabwe. [Methodology](#) **1, 6, 16**

## 05 • THE CONSEQUENCE

# Maize yields & basin climate track ENSO

Across the historical record, the association between the preceding-November RONI and maize-yield anomalies is negative in all three riparian countries (statistically clear for South Africa and Zimbabwe, but weaker (not significant at  $p < 0.05$ ) for Mozambique), alongside a hotter, more evaporative basin. None of these links is deterministic; they are statistical associations, and their strength is shown below. **Maize is used here as a proxy for rain-fed cropping only:** the relationship reflects national yields dominated by rain-fed production; irrigated maize is buffered by the stored water shown in the water-resources section, so this signal should be read as the outlook for the rain-fed crop.

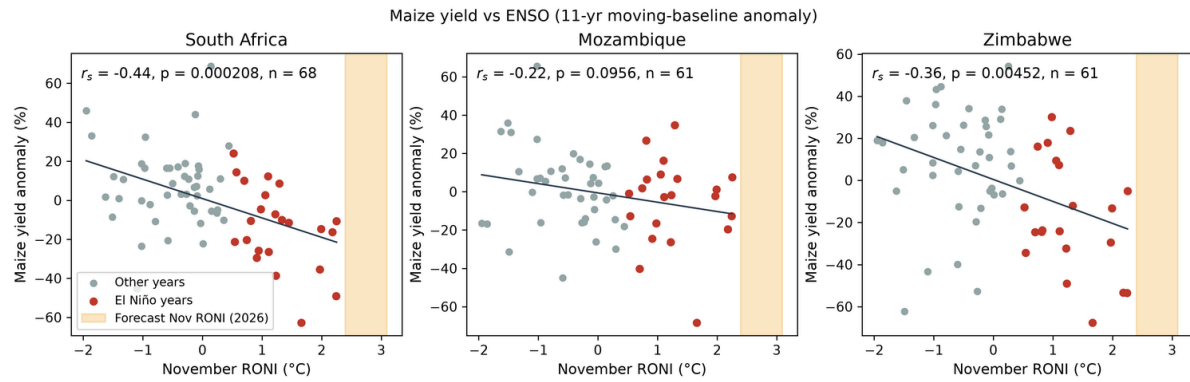


**Figure 4.** National maize-yield anomaly versus the preceding November **RONI** (NOAA CPC, from 1950). Red points are El Niño years; the shaded band is the 2026 forecast range. Maize yields: South Africa long series; Mozambique and Zimbabwe from FAOSTAT. [Methodology](#)<sup>6,7,16</sup>

### South Africa

Spearman **-0.44** ·  
 $p < 0.001$  ·  $n=68$

### Mozambique

Spearman **-0.22** ·  
 $p = 0.096$  ·  $n=61$

### Zimbabwe

Spearman **-0.36** ·  
 $p = 0.005$  ·  $n=61$

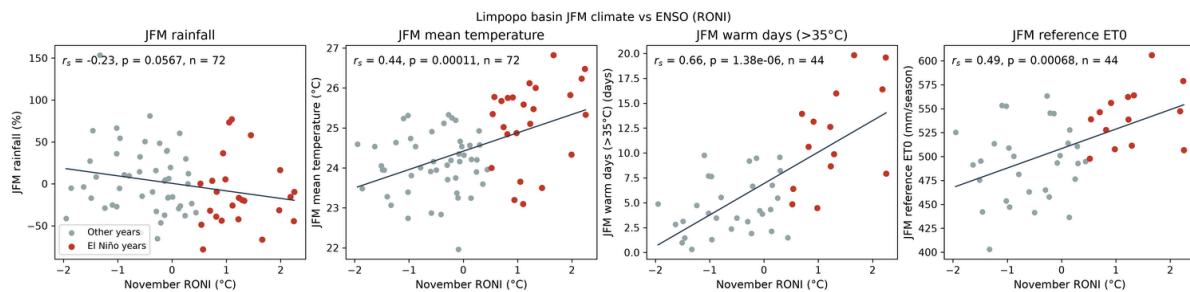
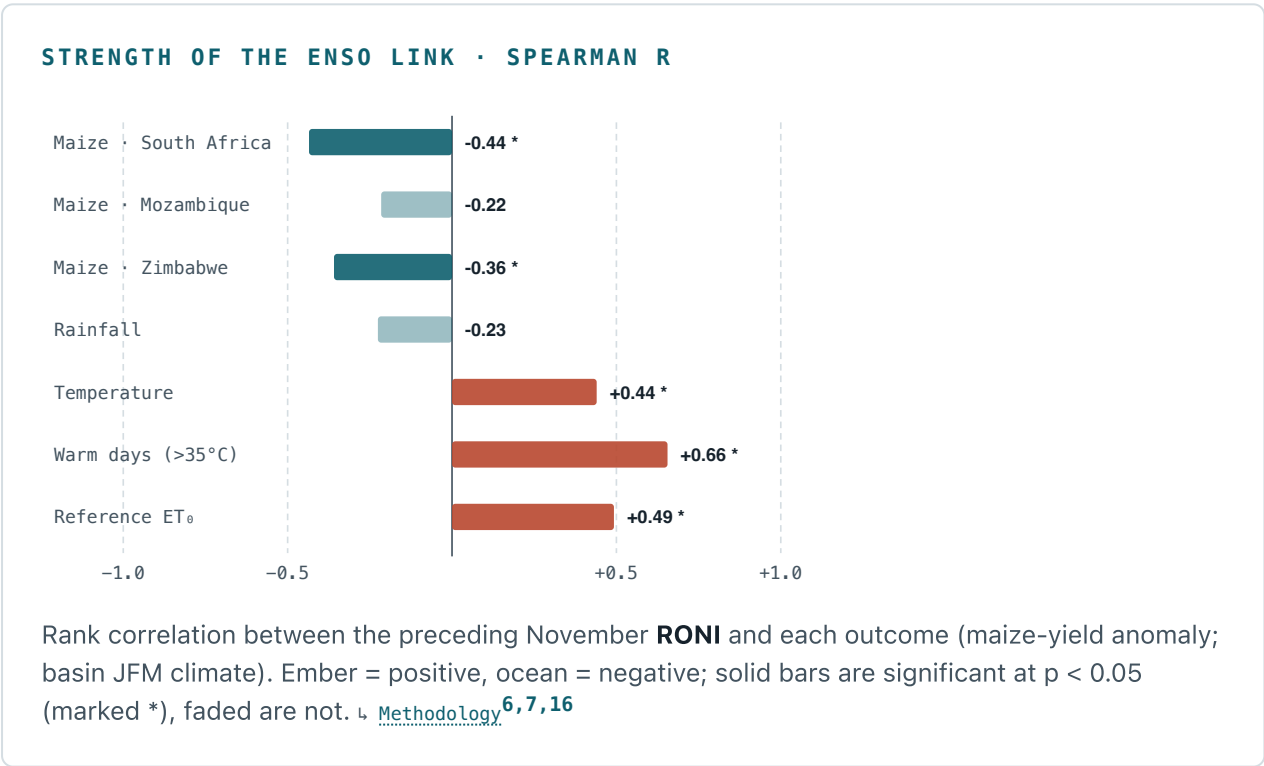


**Figure 5.** Limpopo Basin JFM climate versus the preceding November **RONI**: rainfall, temperature, warm days and reference  $ET_0$ . [Methodology](#)<sup>1,3,16</sup>

|                                                                                       |                                                                                           |
|---------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------|
| <p><b>Rainfall</b></p> <p>Spearman <b>-0.23</b> · p = 0.057 · n=72</p>                | <p><b>Temperature</b></p> <p>Spearman <b>+0.44</b> · p &lt; 0.001 · n=72</p>              |
| <p><b>Warm days (&gt;35°C)</b></p> <p>Spearman <b>+0.66</b> · p &lt; 0.001 · n=44</p> | <p><b>Reference ET<sub>0</sub></b></p> <p>Spearman <b>+0.49</b> · p &lt; 0.001 · n=44</p> |

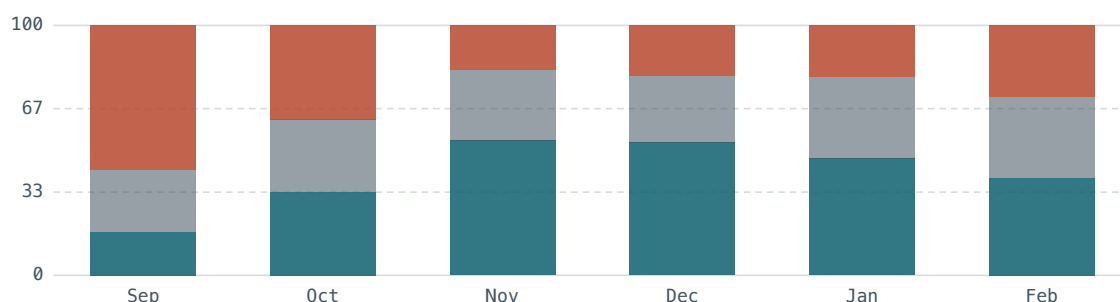


## Where the maize actually grows

Maize-growing cells span about 47% of the basin footprint (2,459,815 ha harvested area, SPAM 2010), concentrated in the South African and Zimbabwean portions of the catchment. Re-aggregating the identical multi-model forecast by maize harvested area, rather than averaging the whole basin uniformly, sharpens the agriculturally relevant signal: it is driest for maize around **Nov** (54% below-normal, -1 pts vs the

basin average); hottest around **Feb** (93% above-normal, +2 pts vs basin). The same skill caveats apply as for the basin forecast.

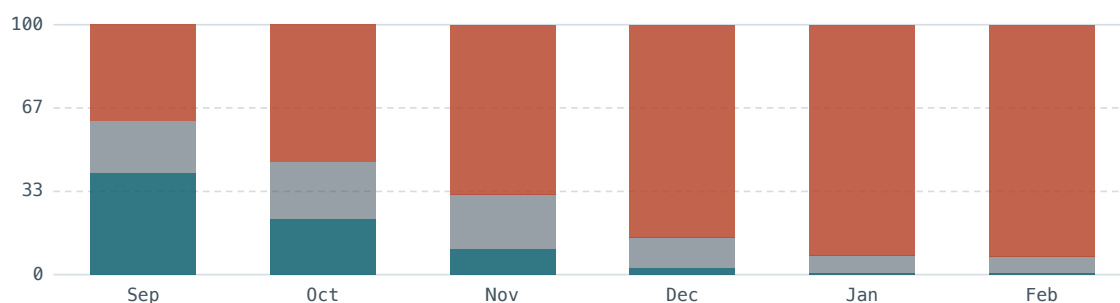
#### MAIZE-AREA RAINFALL TERCILE · BY MONTH



**Weighted to maize-growing area.** Probability of the below / near / above-normal tercile each month (ocean = below, grey = near, ember = above; dashed guides at 33/67% mark equal-odds climatology). Ensemble counted against each model's own 1993-2016 hindcast terciles. **Verified skill** (leave-one-out vs CHIRPS, 24 yr): RPSS +0.08, ROC 0.63 (below) / 0.69 (above).

↳ [Methodology](#) **2,9,10**

#### MAIZE-AREA TEMPERATURE TERCILE · BY MONTH



**Weighted to maize-growing area.** Probability of the below / near / above-normal tercile each month (ocean = below, grey = near, ember = above; dashed guides at 33/67% mark equal-odds climatology). Ensemble counted against each model's own 1993-2016 hindcast terciles. **Verified skill** (leave-one-out vs ERA5, 24 yr): RPSS +0.20, ROC 0.78 (below) / 0.72 (above).

↳ [Methodology](#) **1,2,10**

#### METHODOLOGY

**Forecast anomalies.** Each of the 8 C3S systems is converted to anomalies against its own 1993–2016 hindcast climatology, matched by initialization and lead month, so system-

specific drift and bias cancel before combination; systems are regridded to a common grid and combined with equal weight per model (a run needs  $\geq 6$  systems, targets 8).<sup>1,2</sup>

**Niño 3.4 recalibration (MOS).** The raw multi-model Niño 3.4 is corrected toward observations by ordinary-least-squares,  $\text{observed} \approx \text{intercept} + \text{slope} \times \text{model}$ , fit on Sep–Feb season-mean pairs over 1993–2016 against NOAA ERSSTv6; here slope = 0.74,  $r = 0.97$ . Skill and the 80% interval come from leave-one-out cross-validation (RMSE = 0.26 °C), not the over-dispersed ensemble spread; the pipeline falls back to the raw value if cross-validated  $r < 0.5$ .<sup>4</sup>

**Spatial weighting & historical composites.** Basin means weight each cell by  $\cos(\text{latitude}) \times$  its fraction inside the basin polygon. Historical impact is the January–March composite anomaly over the RONI-defined El Niño years; reference  $ET_0$  follows FAO-56 Penman–Monteith from AgERA5, and a warm day exceeds 35 °C.<sup>3,5,8</sup>

**ENSO index: RONI (dual-index).** ENSO phase, strength and the historical comparison use the **Relative Oceanic Niño Index (RONI)**, NOAA CPC's standard ENSO index since February 2026, and the index on IWMI's ENSO platform ([enso.iwmi.org](https://enso.iwmi.org)). RONI is the 3-month Niño 3.4 SST anomaly minus the 20°S–20°N tropical-mean anomaly (variance-adjusted), removing the background tropical-ocean warming that inflates a raw fixed-base Niño 3.4 index over a multi-decade record. We use CPC's published RONI series. The **raw Niño 3.4 SST anomaly** is retained wherever the physical Pacific temperature is meant, in particular the forecast itself, which C3S issues as a Niño 3.4 anomaly. The forecast is placed on the RONI scale via the observed raw→RONI relationship (linear fit over 2010–2025,  $n = 16$ ,  $r \approx 0.98$ ) and reported as an estimate, because CPC's variance adjustment cannot be reproduced from Niño 3.4 alone. In our own leave-one-out validation RONI predicts basin JFM rainfall, warm-days and reference  $ET_0$  at least as well as raw (temperature a tie), so the composites use it too.<sup>4,16</sup>

**Relationships & classification.** ENSO links use the Spearman rank correlation (OLS lines and forecast bands where shown; significance at  $\alpha = 0.05$ ). Maize-yield anomalies are departures from an 11-year moving normal, pairing the preceding-November RONI with the following harvest. A season is an "El Niño" when its November-centred (OND) RONI  $\geq +0.5$ , NOAA's threshold, used to select analogue seasons and build the impact composites (1950–present, the RONI series span).<sup>6,7,16</sup>

**Probabilistic forecast & verified skill.** Tercile probabilities keep every ensemble member and count it against each model's own 1993–2016 hindcast terciles (equal weight per model). Skill is out-of-sample: leave-one-year-out over the hindcast, scored by the ranked probability skill score (RPSS, vs an equal-odds climatology) and ROC area, verifying temperature against ERA5 and rainfall against CHIRPS gauge data. Probabilities are flagged where cross-validated RPSS falls to climatology ( $\leq 0.02$ ), so a sharp-looking signal is never presented as confident without demonstrated skill.<sup>9</sup>

**Cropland (maize) weighting.** The maize-area outlook re-aggregates the identical multi-model forecast, weighting each cell by SPAM 2010 maize harvested area rather than

averaging the basin uniformly, so the agriculturally relevant signal reflects where maize is actually grown. It carries its own leave-one-out skill on the same weighting.<sup>10</sup>

**Antecedent conditions.** The soil-water state the outlook lands on is summarised by the basin-mean CHIRPS rainfall over the three completed months before issue, expressed as an SPI-3-style index: its empirical percentile in the 1991-2020 distribution of the same three-month window, mapped to a normal quantile (distribution-free, so it is robust to rainfall's skew). Alongside it, root-zone soil moisture (ERA5-Land, 0–100 cm, depth-weighted) is reported as an equivalent SSI-3 on the same percentile scale.<sup>9</sup>

**Water resources (reservoirs).** Basin storage aggregates 231 monitored dams (of which 77 are Tier 1/2 validated or gauged) from the Limpopo Digital Twin's reservoir monitoring: satellite surface area (DE Africa Waterbodies, filled by IWMI's Sentinel-2 series on the same outlines where DE Africa has no observation) converted to volume per dam, satellite altimetry (water level) for four gauged dams, blended with DWS gauge records, every estimate capped at the dam's capacity, and the SWAT Control forecast substituted where a satellite observation is stale (> 30 days). The forward projection uses a fixed rule applied every issue: the median basin storage change over the same calendar dates in past seasons (8 seasons here, range -10.3 to -4.5 points), added to the published figure, to the end of the second full month after the readings. The Digital Twin's SWAT ensemble-median (pc50) projection is recorded in the run data but not printed, and is used only when fewer than five past seasons qualify. The storage panel is a live snapshot dated in the panel, separate from the frozen forecast run.<sup>11</sup>

## DATA SOURCES

# Datasets & provenance

| DATASET                                                 | PROVIDER                                  | VERSION / PERIOD                                                                                                   | ACCESS                    | LICENCE            | ROLE IN BRIEFING                                                                    |
|---------------------------------------------------------|-------------------------------------------|--------------------------------------------------------------------------------------------------------------------|---------------------------|--------------------|-------------------------------------------------------------------------------------|
| C3S seasonal forecast<br>seasonal-monthly-single-levels | Copernicus C3S multi-system · CDS / ECMWF | 8 operational systems (ECMWF SEAS5, UKMO, Météo-France, DWD, CMCC, NCEP, JMA, ECCC); hindcast 1993–2016; leads 0–5 | cds.climate.copernicus.eu | Copernicus licence | <b>Primary forecast: rainfall (mm/mo), 2 m temperature (°C), SST &amp; Niño 3.4</b> |
| ERA5 monthly reanalysis                                 | C3S / ECMWF                               | 1940–present · 0.25°                                                                                               | doi:10.24381/cds.f17050d7 | Copernicus licence | <b>Temperature verification obs for forecast skill (RPSS/ROC)</b>                   |

| DATASET                         | PROVIDER                      | VERSION / PERIOD                                                        | ACCESS                                              | LICENCE            | ROLE IN BRIEFING                                                                                               |
|---------------------------------|-------------------------------|-------------------------------------------------------------------------|-----------------------------------------------------|--------------------|----------------------------------------------------------------------------------------------------------------|
| ERA5-Land monthly reanalysis    | C3S / ECMWF                   | 1950–present · 0.1° · soil layers 1–3 (0–100 cm)                        | doi:10.24381/cds.68d2bb30                           | Copernicus licence | <b>Root-zone soil moisture for the SSI-3 antecedent indicator</b>                                              |
| CHIRPS v2.0 monthly             | UCSB Climate Hazards Center   | 1981–present · 0.05° · Africa                                           | doi:10.15780/G2RP4Q                                 | Public domain      | <b>Gauge-blended rainfall, verification obs for rainfall skill</b>                                             |
| SPAM 2010 v2.0 (maize)          | IFPRI / MapSPAM               | H_MAIZ_A harvested area · ~10 km · 2010                                 | doi:10.7910/DVN/PRFF8V                              | CC0 1.0            | <b>Cropland weighting: aggregate the forecast to maize-growing area</b>                                        |
| AgERA5 agro-met indicators      | C3S / ECMWF                   | v2.0 · 1979–present · 0.1°                                              | doi:10.24381/cds.6c68c9bb                           | Copernicus licence | <b>Daily inputs for warm-days (&gt;35 °C) &amp; FAO-56 ET<sub>0</sub></b>                                      |
| NOAA ERSST v6 (Niño 3.4)        | NOAA NCEI / PSL               | ERSSTv6 · anomaly base 1981–2010                                        | psl.noaa.gov/data/correlation/nina34.anom.data      | U.S. public domain | <b>Observed raw Niño 3.4 (physical SST forecast reference) &amp; MOS calibration target</b>                    |
| NOAA long Niño 3.4 (HadISST)    | NOAA PSL                      | 1870–present · anomaly base 1981–2010                                   | psl.noaa.gov/data/correlation/nina34.long.anom.data | U.S. public domain | <b>Historical Niño 3.4 behind the analogue table and the relationship series (reaches before 1950)</b>         |
| NOAA CPC RONI                   | NOAA CPC                      | 3-mo running · ERSSTv6 · 1991–2020 base · 20°S–20°N removed · from 1950 | cpc.ncep.noaa.gov/data/indices/RONI.ascii.txt       | U.S. public domain | <b>ENSO classification, analogue ranking &amp; impact-composite year selection (standard index since 2026)</b> |
| FAOSTAT crops & livestock (QCL) | FAO                           | Yield (kg/ha), maize · from 1961                                        | fao.org/faostat/#data/QCL                           | CC BY 4.0 IGO      | <b>National maize-yield series (ZAF, MOZ, ZWE)</b>                                                             |
| 20th-Century Crop Statistics    | NASA SEDAC / CIESIN, Columbia | v1 · 1900–2017                                                          | doi:10.7927/tmsp-sg82                               | CC BY 4.0          | <b>Long-record maize cross-reference (provenance only)</b>                                                     |

| DATASET                   | PROVIDER                          | VERSION / PERIOD                                              | ACCESS                | LICENCE             | ROLE IN BRIEFING                                                        |
|---------------------------|-----------------------------------|---------------------------------------------------------------|-----------------------|---------------------|-------------------------------------------------------------------------|
| IWMI reservoir monitoring | Limpopo Digital Twin · eflow_iwmi | 231 dams · satellite area→volume + DWS gauges + SWAT forecast | digitaltwins.iwmi.org | IWMI                | <b>Live basin storage + forward projection (water-resources buffer)</b> |
| Limpopo basin boundary    | HydroSHEDS / HydroBASINS          | boundary v2026-01                                             | hydrosheds.org        | HydroS HEDS licence | <b>Basin mask for cos-lat area weighting</b>                            |

## REFERENCES

1. **Hersbach, H. et al. (2020).** The ERA5 global reanalysis. *Q. J. R. Meteorol. Soc.* 146, 1999–2049. doi:10.1002/qj.3803
2. **Copernicus Climate Change Service (C3S).** Seasonal forecast monthly statistics on single levels. CDS. doi:10.24381/cds.68dd14c3
3. **C3S / ECMWF.** AgERA5: agrometeorological indicators from 1979 to present. CDS. doi:10.24381/cds.6c68c9bb
4. **Huang, B. et al.** NOAA Extended Reconstructed SST, version 6 (ERSSTv6). NOAA NCEI. Niño 3.4 monthly anomaly series (base 1981–2010) via NOAA PSL: [psl.noaa.gov/data/correlation/nina34.anom.data](https://psl.noaa.gov/data/correlation/nina34.anom.data)
5. **Allen, R.G. et al. (1998).** Crop evapotranspiration: FAO-56 Penman–Monteith. FAO Irrigation & Drainage Paper 56.
6. **FAO.** FAOSTAT: Crops and livestock products (QCL). [fao.org/faostat](https://fao.org/faostat)
7. **NASA SEDAC / CIESIN.** Twentieth-Century Crop Statistics 1900–2017. doi:10.7927/tmsp-sg82
8. **Lehner, B. & Grill, G. (2013).** HydroSHEDS / HydroBASINS. *Hydrol. Process.* 27, 2171–2186. doi:10.1002/hyp.9740
9. **Funk, C. et al. (2015).** The climate hazards infrared precipitation with stations (CHIRPS). *Sci. Data* 2, 150066. doi:10.1038/sdata.2015.66
10. **International Food Policy Research Institute (2019).** Global Spatially-Disaggregated Crop Production Statistics (SPAM) 2010 v2.0. Harvard Dataverse. doi:10.7910/DVN/PRFF8V
11. **Limpopo Digital Twin.** Limpopo reservoir storage monitoring: satellite surface-area→volume estimates, DWS gauge records, and SWAT Control volume forecasts (eflow\_iwmi). [digitaltwins.iwmi.org](https://digitaltwins.iwmi.org)
12. **Cullis, J., Munnik, V. & Damons, M. (2025).** Future Water Demand Scenarios Report: Future Water Resources Scenario and Climate Resilient Investment Analysis for the Limpopo River Basin. Limpopo Watercourse Commission (LIMCOM), UNDP-GEF; prepared by Zutari, 18 March 2025.
13. **Cullis, J., Aparicio Medrano, E., Schults, R. & Lutz, A. (2025).** Climate Change Analysis for the Limpopo River Basin. Limpopo Watercourse Commission (LIMCOM), UNDP-GEF; prepared by Zutari, 14 March 2025.

14. **Muñoz-Sabater, J. et al. (2021).** ERA5-Land: a state-of-the-art global reanalysis dataset for land applications. *Earth Syst. Sci. Data* 13, 4349–4383. doi:10.5194/essd-13-4349-2021
15. **Rayner, N.A. et al. (2003).** Global analyses of sea surface temperature, sea ice, and night marine air temperature (HadISST). *J. Geophys. Res.* 108(D14), 4407. doi:10.1029/2002JD002670. Long Niño 3.4 anomaly series (1870–present, base 1981–2010) via NOAA PSL: [psl.noaa.gov/data/correlation/nina34.long.anom.data](https://psl.noaa.gov/data/correlation/nina34.long.anom.data)
16. **L'Heureux, M.L. et al. (2024).** Are we trending toward more El Niño events? / the Relative Oceanic Niño Index (RONI). NOAA CPC adopted RONI as its standard ENSO index in February 2026: [cpc.ncep.noaa.gov/products/analysis\\_monitoring/enso/roni](https://cpc.ncep.noaa.gov/products/analysis_monitoring/enso/roni) (data: [cpc.ncep.noaa.gov/data/indices/RONI.ascii.txt](https://cpc.ncep.noaa.gov/data/indices/RONI.ascii.txt)).

## LIMITATIONS & CAVEATS

- **Forecast amplitude is uncertain.** Coupled models can mis-scale the Niño 3.4 signal; the MOS slope is diagnosed and flagged if it significantly departs from 1. Even recalibrated, amplitude carries real uncertainty: the reported 80% band (leave-one-out) is the honest error, wider than the raw spread.
- **Extrapolation beyond the record.** The calibration is trained on 1993–2016; a forecast outside that observed range is an extrapolation where the linear correction is least trustworthy. This issue is such a case: the raw multi-model forecast (+3.73 °C) lies 1.0 °C beyond the largest hindcast value in the training set (+2.75 °C, 1997), so the calibrated headline relies on the fitted line holding beyond the data.
- **Association is not causation.** ENSO–climate and ENSO–yield links are statistical associations mediated by many non-ENSO factors; composites describe typical patterns, not guaranteed outcomes.
- **Provisional data drift.** Recent ERA5 (ERA5T), ERSST/Niño 3.4, CPC RONI and FAOSTAT values are revised as observations arrive, and the 8 C3S system versions are re-checked ~twice a year as centres upgrade.
- **ENSO is not the only driver.** Limpopo seasonal climate is also shaped by the Indian Ocean Dipole, the subtropical Indian Ocean Dipole, the Southern Annular Mode and local land-surface feedbacks, which may reinforce or oppose the ENSO signal shown here.
- **Absolute vs relative Niño 3.4.** As the tropical oceans warm, a given absolute Niño 3.4 anomaly overstates ENSO's atmospheric influence, which is why NOAA CPC adopted the Relative Oceanic Niño Index (RONI). This briefing classifies the event, ranks analogues and builds composites on RONI, so the event scores lower on that scale than its calibrated Niño 3.4 alone would suggest. The forecast RONI is an estimate placed on the RONI scale through an observed raw→RONI fit (linear fit over 2010–2025,  $n = 16$ ,  $r \approx 0.98$ ) and inherits that window's sensitivity; and the RONI record begins in 1951, so earlier events drop out of the analogue set.

Every figure traces to the frozen, hashed config manifest.

IWMI, CGIAR Digital Transformation Accelerator · [limpopo.digitaltwins.iwmi.org](https://limpopo.digitaltwins.iwmi.org)

Automated Limpopo climate-briefing pipeline · rasters: public S3 COGs · statistics: dt\_enso (RDS).