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ENSO DRIVES CHILD UNDERNUTRITION
IN THE GLOBAL TROPICS*

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Abstract

The El Niño Southern Oscillation (ENSO) is a principal component of global climate variability known to influence a host of social and economic outcomes, but its systematic effects on human health remain poorly understood. We estimate ENSO’s association with child nutrition at global scale by combining variation in ENSO intensity from 1986-2018 with children’s height and weight from 186 surveys conducted in 51 teleconnected countries, containing 48% of the world’s under-5 population. Warmer, drier El Niño conditions predict worse child undernutrition in most of the developing world, but better ones in the small number of areas where precipitation is positively affected by ENSO. This relationship looks similar at both global and regional scale, and has not appreciably weakened over the last four decades. Results imply that the 2015 El Niño pushed over 7 million children into undernutrition, demonstrating the degree to which human well-being remains subject to predictable climatic processes.

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1 Introduction

Climate variability is increasingly recognized as a key determinant of health outcomes (1) and a major concern for global climate policy and international public health (2), with the IPCC warning that anthropogenic climate change will very likely increase the frequency and intensity of extreme events (3, 4). The El Niño Southern Oscillation (ENSO) is a major source of climate variability known to affect key social, economic and health outcomes (5–14), however, the systematic effects that these correlated shifts in the tropical climate have on global health remain understudied. ENSO’s adverse large-scale effects have been documented for hundreds of years (15), yet despite our improved predictive capacity over ENSO, much of humanity is still susceptible to its consequences. Given that probabilistic forecasts of ENSO have skill at predicting conditions months in advance, there is an opportunity to decouple food insecurity and human nutrition from this predictable climate process. However, analyses of ENSO’s impacts on food security have generally focused on a single country or El Niño episode (16) and lack global or regional scope to guide national and international public investments that preempt adverse effects of ENSO.

This paper provides the first estimate of ENSO’s impacts on human nutrition in the global tropics, leveraging over one million geolocated child records spanning four decades and all developing country regions. We estimate the systematic effect of ENSO-driven tropical climate variability by examining the association between annual eastern equatorial Pacific ENSO state and measures of children’s weight from surveys conducted during that year. Children’s anthropometric measures are extremely sensitive to nutritional shocks due to their high caloric needs while growing (17), and provide a summary measure of contemporary household food security (18). Our interest is in estimating the total effect of ENSO variability across all channels of influence – from agricultural productivity to infectious disease to conflict – that might affect human nutrition, and documenting systematic differences in ENSO response within sample.

We capture ENSO variation using the widely-used Niño 3.4 index of equatorial Pacific sea surface temperature (19, 20), which spans 5°N-5°S, 170°W-120°W (Fig. 1A). Children’s weight-for-age z-scores (WAZ) at time of survey (Fig. 1B) are calculated using the NCHS/CDC/WHO International Reference Standard (21) intended to provide a single measure of child nutritional outcomes comparable across ages and sexes. We first identify all countries with local climates teleconnected to ENSO (Fig. 1C) for which Demographic and Health Surveys (DHS) anthropometric data exist. This yields a sample of 1.3 million children ages 0-4 interviewed in 186 household surveys between 1986 and 2018. The sample includes 51 countries containing 38% of the world’s population and 48% of the world’s under-5 population as of 2018. We assign treatment (i.e., the ENSO state when the child was surveyed) annually by tropical year, accounting for the spring barrier delay in ENSO state change (8), by calculating the maximum Niño 3.4 value between May-Dec of
a given year. We assign that to all children interviewed by DHS during that period, as well as all children interviewed during the following year’s Jan-Apr months (i.e., before the following year’s spring barrier).

While a warmer ENSO leads to higher temperature throughout the tropics, shifts in precipitation pattern lead to some areas getting wetter than normal while others get drier. We account for potential differences in the effects of ENSO by allowing for different effects in subnational regions where precipitation is positively correlated to warmer ENSO (Figs. 1D and S1). Since only 6.4% of our sample lives in regions where warmer ENSO leads to clear wet anomalies, we focus our discussion on results for the majority of the sample. In order to remove potential confounders (22, 23), we purge the estimates of average differences across countries and across rural and urban areas within each country using location fixed effects, and we detrend the data annually and remove monthly seasonality by major world regions. The temporal variation in ENSO anomalies – measured as a deviation from long-run average conditions – is used to statistically isolate the association of ENSO state and child malnutrition.

2 Results

We find that warmer, more El Niño-like ENSO conditions increase short-term undernutrition in children across the tropics, with the opposite occurring in places where precipitation tends to increase during El Niño. Even in the absence of controls, the empirical distribution of detrended WAZ is significantly and substantially different ($p < 0.001$) between El Niño and La Niña years (Fig. 2A). After detrending the data and controlling for location-specific unobservable confounders and mother characteristics (Table 1), a 1°C increase in the ENSO index is associated with $0.03\sigma$ ($p = 0.02$) average decrease in WAZ. We allow the relationship between ENSO and WAZ to vary flexibly (Fig. 2B) and find that the negative association remains across the distribution of ENSO values. The result is substantively similar across a broad range of model specifications (Table S2), and across other outcomes reflecting recent nutrition, including weight-for-height and body mass index ($-0.04\sigma/°C$ and $p<0.01$ for both measures). Height-for-age or stunting do not decrease with warmer ENSO conditions, consistent with height being slower to respond to health shocks than weight (24). Using WHO z-score classification thresholds, warmer ENSO increases the prevalence of undernourishment (below -2σ in weight for age) significantly by 0.6 percentage points per 1°C ($p < 0.05$). We find that the risk of wasting (below -2σ in weight for height) is positive but not significant ($0.3pp/°C$, $p = 0.21$), consistent with higher noise in height measurements, especially for very sick children (25). ENSO conditions do not have a contemporaneous effect on stunting (below -2σ in height for age). All of these patterns are reversed in the minority of places in our sample (6.4%) where warmer ENSO is correlated to wet anomalies. The heterogeneity in results across regions of wet and dry anomalies point towards the importance
Figure 1: A) NINO3.4 time-series. El Niño or La Niña highlighted in red or blue, respectively. El Niño and La Niña states defined as when the maximum of a three month rolling mean of monthly values was greater than 0.5°C (Niño-like) or less than -0.5°C (Niña-like) compared to a 1981-2010 reference climatology following NOAA CPC guidelines. B) Weight-for-Age z-score distribution over time from all Demographic and Health Survey (DHS) data in teleconnected countries. Box represents interquartile range. Country composition within each year is different, as a rotating sample of countries is surveyed in each year under the DHS programme. C) Pixel-level monthly correlation of surface temperature (1980-2010) and two-month lag of NINO3.4 Sea Surface Temperature (SST), showing teleconnections. Values represent number of months in a year significantly associated with ENSO at the 10% level. D) Pixel-level monthly correlation of precipitation (1980-2010) and two-month lag NINO3.4 SST. Colors indicate the direction of the precipitation effects, highlighting Eastern Africa, the only major region in the DHS sample where precipitation is positively correlated with NINO3.4.
Table 1: Anthropometric effects of ENSO

|                  | (1) Weight for age | (2) Weight for height | (3) Body mass index | (4) Height for age | (5) Pr(WHO standard): undernourished | (6) Pr(WHO standard): wasted | (7) Pr(WHO standard): stunted |
|------------------|--------------------|-----------------------|---------------------|-------------------|---------------------------------------|----------------------------|------------------------------|
| Max NINO3.4      |                    |                       |                     |                   |                                       |                            |                              |
| std. error       | (0.0105)           | (0.0130)              | (0.0132)            | (0.00955)         |                                       |                            |                              |
| p-value          | 0.0234             | 0.00654               | 0.00674             | 0.706             |                                       |                            |                              |
| 95% CI (lower)   | (-0.0466)          | (-0.0641)             | (-0.0649)           | (-0.0158)         |                                       |                            |                              |
| 95% CI (upper)   | -0.00363           | -0.0113               | -0.0113             | 0.0231            |                                       |                            |                              |
| p(\text{precip, NINO}) > 0 |                     |                       |                     |                   |                                       |                            |                              |
| std. error       | (0.0222)           | (0.0301)              | (0.0330)            | (0.0304)          |                                       |                            |                              |
| Mean of dep. var.| -0.931             | -0.228                | -0.0895             | -1.311            |                                       | 0.204                      | 0.100                        | 0.343                        |
| Observations     | 1,254,176          | 1,205,335             | 1,206,659           | 1,218,846         |                                       | 1,254,176                  | 1,205,335                    | 1,218,846                    |
| R-squared        | 0.129              | 0.093                 | 0.081               | 0.069             |                                       | 0.087                      | 0.040                        | 0.074                        |

Notes: Different anthropometric effects of ENSO are concentrated on short run measures (1-3) weight-for-age, weight-for-height, and body mass index z-scores, which all measure shorter-run effects of scarce nutrition, show evidence of contemporaneous ENSO effects measured in °C, while (4) height-for-age, a slower-varying measure, shows only weak evidence in the minority (~6%) of the sample where NINO3.4 is positively correlated to precipitation. Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific mother’s age at child’s birth, total years of mother’s education, and rural vs. urban indicator; and UNICEF world region-specific linear trends in survey year and fixed effects for month of interview. Standard errors are two-way clustered at the level of tropical year and subnational administrative unit, and observations are reweighted using DHS sample weights and country size weights in order for estimates to be representative for an average country. (5-7) WHO threshold outcomes show ENSO increases the likelihood of being undernourished (below -2σ in weight for age), but shows a weaker, statistically insignificant effect on wasting (below -2σ in weight for height) and no relationship with stunting (below -2σ in height for age). Asterisks indicate statistical significance at the 1% (***) and 5% (**) levels.

of agriculture in mediating the ENSO-nutrition link, though others (e.g., conflict) cannot be ruled out.

The several degree variation in ENSO cycle implies that it is a meaningful source of variation in population nutrition in the tropics. According to these estimates, the 2.25°C increase in the Niño 3.4 index during the 2015 El Niño event, one of the largest on record, likely caused average WAZ in the representative child of our sample countries to decrease by 0.1σ. The human scale of this impact is large given that the under-5 population in our sample countries was 311 million in 2015. To give context to the size of these effects, we look at the scale of public health interventions needed to offset an event of similar magnitude to the 2015 El Niño, using published effect sizes of nutritional interventions (26). Fig. 3 shows that around 134 million children would have to receive either multiple micronutrient supplementation (CI 75-193 million), or 72 million (CI 33-105 million) would have to receive provision of complementary foods, or 72 million (CI 26-118) would have to receive nutrition education. The effect of the 2015 El Niño is also equivalent to the WAZ reduction from moving 46 million children from urban to rural areas, based on our model results. The 2015 El Niño increased risk of being below the WHO threshold for undernourished by 2.3 percentage points, i.e., an increase of nearly a tenth of the current population rate of 24%. This corresponds to an additional 7.1 million children being driven into undernourished status.

Our main result is consistent across alternative specifications, observation weighting, and ENSO variable
Figure 2: A) Distribution of Weight-for-Age z-scores (WAZ) during years classified as El Niño (red) and La Niña (blue) according to NOAA definition using NINO3.4 SSTs, with means of each distribution shown. B) Epanechnikov kernel-weighted local polynomial estimate (bandwidth 0.7) of association of WAZ with ENSO for areas where more than 50% of the land area of a country has precipitation correlated with ENSO for more than three months in the year negatively (green) and positively (orange). Histograms represent number of observations in each precipitation correlation subsample. C) Effect of ENSO on WAZ for each decade and UNICEF world region in the sample, excluding locations with positive precipitation teleconnections. Dots signify point estimates, bars signify 95% confidence intervals, and grey shaded region and dashed line show main effect from Table 1.
definitions (Tables S1-S3). Positive deviations from the ENSO index mean state decrease z-scores, and negative deviations of the ENSO index mean (La Niña events) reduce undernutrition compared to baseline state (Table S3). For the purposes of population-wide attribution statistics, we also calculate the average effect of warmer ENSO in the average country, without separating the sample by whether warm ENSO leads to dry or wet anomalies (Table S4). The average effect across the sample suggests that warmer ENSO leads to a $0.04\sigma/\circ C$ reduction in weight-for-age ($p = 0.02$), and a 1 percentage point increase in prevalence of undernourishment ($p < 0.01$). We also test the use of alternative detrending of the data with decade fixed effects (Table S5). The lagged effects of ENSO (Table S6) indicates no persistent effect of ENSO on child nutrition, except in the subsample with positively correlated rainfall. Finally, we show that timing of DHS survey does not vary as a result of ENSO state (Figure S2 and Table S10) and that results hold under a placebo randomization test (Figure S3).

![Figure 3: Interventions Required to Offset 2015 El Niño. Millions of children who must be targeted with specific interventions in order to reverse the effects on malnourishment caused by the 2015 El Niño. Effect sizes calculated using treatment effects in Bhutta et al. (2013).](image)

3 Discussion

The negative relationship between child nutrition and warm ENSO state does not appear to vary appreciably across space and time, with the effects for major world regions and different decades in the sample being statistically indistinguishable from our main effect (Fig. 2C). That there has been little progress in attenuating the food security effects of ENSO despite increasing incomes and trade connectivity implies that the limits to adaptation may be strict, at least over the income range of countries in the sample. The international community has set the target of eliminating all forms of malnutrition worldwide by 2030 as part of the Sustainable Development Goals (SDG) agenda, and is making efforts to establish metrics, monitor, and implement policies to achieve this goal (27). Developing countries deemed to be making insufficient progress
are being pressured to do more (28). During 2015-2018, 34% of the children in our sample countries were undernourished, implying that in order to meet the hunger SDG the percentage of undernourished children would have to decrease by 2.6 percentage points per year. Our estimates suggest that ENSO conditions similar to the 2015 El Niño would eliminate one year of progress towards that goal. Indeed, the 2015 El Niño likely played a major role in worsening famine conditions, and these results support a view of ENSO driving episodic famine in the tropics where yields are low during El Niño years even as global average yields increase due to gains in the extra-tropics. Governments and agencies engaged in multi-year humanitarian planning and budgetary frameworks could incorporate ENSO forecasts to anticipate fluctuations in availability of local vs. global resource streams needed to ensure progress in fighting malnutrition. Despite scientific progress characterizing ENSO and documenting its various channels of influence on society, much remains to be done to decouple nutrition outcomes in developing countries from this predictable interannual phenomenon.

4 Data and Methods

4.1 Data

ENSO Time Series Data capturing original monthly values of the NINO 3.4 index are from the NOAA Center for Weather and Climate Prediction website (29). We assemble our treatment variable by taking the maximum monthly anomaly value of the index during the May-Dec period of a given calendar year, assigning it to all children interviewed during that tropical year (May-April). We note that alternative constructions of ENSO3.4 state perform similarly (see Table S3).

DHS Children’s Anthropometric Data are from all DHS surveys containing children’s anthropometric data (N=186, 51 countries, 1986-2018). We standardize DHS administrative region names, aggregating to supersets if any regions changed borders or split during our sample period. We calculate each child’s anthropometrics using his/her height and weight following the NCHS/CDC/WHO International Reference Standard (21) intended to provide a single measure of child nutritional outcomes comparable across ages and genders.

4.2 Methods

Time series data on El Niño are from the NOAA Climate Prediction Center’s monthly time series. We designate a country as teleconnected if its temperature is closely coupled to ENSO9, defined as having at least 50% of the population living in locations where local temperature as reported in the UDEL global gridded temperature dataset (30) at month \( t \) is significantly correlated with the second month lag \((t-2)\) of
the ENSO state (NINO3.4 SST index) for at least three months of the year. We designate teleconnection at country level since price effects from ENSO in one subnational region would affect all parts of the country through domestic markets. Our treatment variable of interest is the maximum value of the NINO3.4 index between May and December in a given year. We also record the correlation between ENSO temperatures and precipitation at pixel-level within teleconnected countries, in order to differentiate between places where warmer ENSO leads to dry or wet precipitation anomalies. Our estimates separately identify effects in DHS clusters located in first-level administrative units (e.g., state/province) where more than 50% of land area has three months or more per year with a statistically significant positive correlation between precipitation and the second monthly lag of NINO3.4 (8).

Microdata on children’s health are from the Demographic and Health Surveys (DHS). We identify all standard DHS surveys from teleconnected countries for which children’s anthropometric data are available, generating a sample of 1,253,176 child-level observations in 186 surveys from 51 countries between 1986 and 2018. We calculated children’s anthropometrics according to the WHO Anthro Child Growth Standard1.

We estimate the effect of ENSO on anthropometric measure \( Y_{ict} \) for child \( i \) living in country \( c \) in year \( t \) (Table 1) using an equation of the form

\[
Y_{ict} = \alpha + \beta_n NINO_t + \beta_p [NINO_t \times I(Positive(precip))] + \gamma X_{ic} + f(t_{(globalregion)}) + FE_{cr} + \varepsilon_{ict}
\]

for NINO3.4 anomalies defined as above for the tropical year \( t \) in which the anthropometrics for child \( i \) were measured, as well as country-specific controls for whether the household is urban or rural \((FE_{c\times rural})\), the mother’s education in years, and the mother’s age at time of child birth. \( f(t) \) captures detrending and seasonality adjustments to the data for each of five major UNICEF world regions using both linear year trends and month of survey fixed effects. We normalize the data by country using fixed effects FEcr separately identified for rural and urban location within each country. This research design corresponds to looking at average differences in child outcomes within the same country, separately for rural and urban areas, under different global ENSO states. This allows for identification of ENSO’s effect under minimal assumptions of potential confounding (23, 31). Standard errors are two-way clustered at the level of interview year \((N = 33)\) in order to correct for a common global ENSO shock, as well as at the level of subnational first administrative unit \((N=532)\) in order to adjust for serial correlation in anthropometric indicators over time and space.

Most specifications identify \( \beta \), the effect of ENSO, separately for children living in teleconnected areas where El Niño conditions tend to produce wet anomalies \((\beta_p)\) and those with neutral or dry anomalies \((\beta_n)\).

1Available at: http://www.who.int/childgrowth/software/en/
Depending on the specification, the regression weights observations either to produce an estimate of $\beta$ that represents the effect of ENSO on the average country in our sample (that is, using the DHS sampling weights for observations, normalized such that all observations across all surveys sum to unity for each country), or an estimate of $\beta$ that represents the effects on the average child in the countries of our sample (combining normalized DHS sampling weights with population weights for each country). In either case, weights adjust for the fact that countries had different numbers of DHS surveys with different sample sizes over the time period.

For Fig. 2B, we utilize the Frisch-Waugh-Lovell theorem and first residualize our outcome, WAZ, and our independent variable, NINO3.4 SST. That is, we run the following regressions separately for locations with negative / neutral precipitation correlation and positive precipitation correlation, weighted as in equation 1:

$$Y_{ict} = \alpha + \gamma X_{ic} + f(t(global\text{region})) + FE_{cr} + \varepsilon_{ict}$$  \hspace{1cm} (2)

$$NINO_t = \alpha + \gamma X_{ic} + f(t(global\text{region})) + FE_{cr} + \varepsilon_{ict}$$  \hspace{1cm} (3)

We plot the relationship between these residuals using an Epanechnikov kernel-weighted local polynomial regression with a bandwidth of 0.7 in the residualized x-variable.
References

[1] T. A. Carleton and S. M. Hsiang, “Social and economic impacts of climate,” *Science*, vol. 353, no. 6304, 2016.

[2] N. Watts, W. N. Adger, P. Agnolucci, J. Blackstock, P. Byass, W. Cai, S. Chaytor, T. Colbourn, M. Collins, A. Cooper, *et al.*, “Health and climate change: policy responses to protect public health,” *The Lancet*, vol. 386, no. 10006, pp. 1861–1914, 2015.

[3] Y. Pan, L. Li, X. Jiang, G. Li, W. Zhang, X. Wang, and A. P. Ingersoll, “Earth’s changing global atmospheric energy cycle in response to climate change,” *Nature communications*, vol. 8, no. 1, pp. 1–8, 2017.

[4] M. E. Mann, S. Rahmstorf, K. Kornhuber, B. A. Steinman, S. K. Miller, and D. Coumou, “Influence of anthropogenic climate change on planetary wave resonance and extreme weather events,” *Scientific Reports*, vol. 7, p. 45242, 2017.

[5] R. S. Kovats, M. J. Bouma, S. Hajat, E. Worrall, and A. Haines, “El niño and health,” *The Lancet*, vol. 362, no. 9394, pp. 1481–1489, 2003.

[6] T. Iizumi, J.-J. Luo, A. J. Challinor, G. Sakurai, M. Yokozawa, H. Sakuma, M. E. Brown, and T. Yamagata, “Impacts of el niño southern oscillation on the global yields of major crops,” *Nature communications*, vol. 5, no. 1, pp. 1–7, 2014.

[7] S. M. Hsiang and K. C. Meng, “Tropical economics,” *American Economic Review*, vol. 105, no. 5, pp. 257–61, 2015.

[8] S. M. Hsiang, K. C. Meng, and M. A. Cane, “Civil conflicts are associated with the global climate,” *Nature*, vol. 476, no. 7361, pp. 438–441, 2011.

[9] M. C. Thomson, S. J. Mason, T. Phindela, and S. J. Connor, “Use of rainfall and sea surface temperature monitoring for malaria early warning in botswana,” *The American journal of tropical medicine and hygiene*, vol. 73, no. 1, pp. 214–221, 2005.

[10] W. H. Organization *et al.*, “El nino and health,” tech. rep., WHO/SDE/99.4. World Health Organization, Geneva, Switzerland, 1999.

[11] B. Cazelles, M. Chavez, A. J. McMichael, and S. Hales, “Nonstationary influence of el niño on the synchronous dengue epidemics in thailand,” *PLoS Med*, vol. 2, no. 4, p. e106, 2005.
[12] M. Pascual, X. Rodó, S. P. Ellner, R. Colwell, and M. J. Bouma, “Cholera dynamics and el niño-southern oscillation,” *Science*, vol. 289, no. 5485, pp. 1766–1769, 2000.

[13] A. Bennett, L. D. Epstein, R. H. Gilman, V. Cama, C. Bern, L. Cabrera, A. G. Lescano, J. Patz, C. Carcamo, C. R. Sterling, *et al.*, “Effects of the 1997–1998 el niño episode on community rates of diarrhea,” *American journal of public health*, vol. 102, no. 7, pp. e63–e69, 2012.

[14] C. Rosenzweig and D. Hillel, *Climate variability and the global harvest: Impacts of El Niño and other oscillations on agro-ecosystems*. Oxford University Press, 2008.

[15] M. Davis, *Late Victorian holocausts: El Niño famines and the making of the third world*. Verso Books, 2002.

[16] H. E. Danysh, R. H. Gilman, J. C. Wells, W. K. Pan, B. Zaitchik, G. González, M. Alvarez, and W. Checkley, “El niño adversely affected childhood stature and lean mass in northern peru,” *Climate Change Responses*, vol. 1, no. 1, p. 7, 2014.

[17] M. B. Prieto and J. L.-H. Cid, “Malnutrition in the critically ill child: the importance of enteral nutrition,” *International journal of environmental research and public health*, vol. 8, no. 11, pp. 4353–4366, 2011.

[18] H. De Haen, S. Klasen, and M. Qaim, “What do we really know? metrics for food insecurity and undernutrition,” *Food Policy*, vol. 36, no. 6, pp. 760–769, 2011.

[19] C. F. Ropelewski and M. S. Halpert, “Global and regional scale precipitation patterns associated with the el niño/southern oscillation,” *Monthly weather review*, vol. 115, no. 8, pp. 1606–1626, 1987.

[20] E. S. Sarachik and M. A. Cane, *The El Nino-southern oscillation phenomenon*. Cambridge University Press, 2010.

[21] S. O. Rutstein and G. Rojas, “Guide to dhs statistics,” *Calverton, MD: ORC Macro*, vol. 38, 2006.

[22] P. W. Holland, “Statistics and causal inference,” *Journal of the American statistical Association*, vol. 81, no. 396, pp. 945–960, 1986.

[23] S. Hsiang, “Climate econometrics,” *Annual Review of Resource Economics*, vol. 8, pp. 43–75, 2016.

[24] R. E. Baker and J. K. Anttila-Hughes, “Characterizing the contribution of high temperatures to child undernourishment in sub-saharan africa,” *Scientific Reports*, vol. 10, pp. 2045–2322, 2020.
[25] W. H. Organization et al., *Physical status: The use of and interpretation of anthropometry*, Report of a WHO Expert Committee. World Health Organization, 1995.

[26] Z. A. Bhatta, J. K. Das, A. Rizvi, M. F. Gaffey, N. Walker, S. Horton, P. Webb, A. Larrey, R. E. Black, T. L. N. I. R. Group, et al., “Evidence-based interventions for improvement of maternal and child nutrition: what can be done and at what cost?,” *The lancet*, vol. 382, no. 9890, pp. 452–477, 2013.

[27] S.-G. H. L. T. F. on Global Food and Nutrition, “Compendium - final report,” tech. rep., 2015.

[28] S. Boseley, “World bank to name and shame countries that fail to prevent stunting in children,” *The Guardian*, Sep 2016.

[29] . N. Oceanic and A. Administration, “Equatorial pacific sea surface temperatures,” 2020. Retrieved in February 2020 from https://www.ncdc.noaa.gov/teleconnections/enso/indicators/sst/.

[30] K. Matsuura and C. J. Willmott, “Terrestrial air temperature: 1900–2014 gridded monthly time series,” Available at climate.geog.udel.edu/~climate/html_pages/Global2014/README.GlobalTsT2014.html. Accessed December 14, 2016., 2015.

[31] M. Dell, B. F. Jones, and B. A. Olken, “What do we learn from the weather? the new climate-economy literature,” *Journal of Economic Literature*, vol. 52, no. 3, pp. 740–98, 2014.

[32] A. C. Cameron, J. B. Gelbach, and D. L. Miller, “Robust inference with multiway clustering,” *Journal of Business & Economic Statistics*, 2012.

[33] S. M. Hsiang and A. S. Jina, “The causal effect of environmental catastrophe on long-run economic growth: Evidence from 6,700 cyclones,” tech. rep., National Bureau of Economic Research, 2014.
Supplementary Information

Robustness of empirical results

The negative association between the ENSO index and undernutrition remains robust to a variety of different model specifications controlling for a variety of different plausible observable and unobservable factors. Table S1 shows the build-up of our basic model for weight-for-age and undernourishment to illustrate this point. In Panel A (1), the negative association between higher NINO3.4 temperature and weight for age is apparent (though not statistically significant), with the opposite being true in places where precipitation is positively correlated with NINO3.4. Model (2) flexibly detrends the data by (tropical) year of interview, and normalizes by interview month and country using fixed effects to provide a plausibly causal estimate that is not confounded by trends, seasonality and country of survey. The association between NINO3.4 and weight-for-age is statistically significant at 95% confidence levels, with opposite signs in areas that have a positive correlation between precipitation and NINO3.4 and those that do not. Note that the coefficient of -0.026 for places without positive correlation (93.6% of observations) is statistically consistent for all subsequent specifications. Model (3) normalizes data by rural/urban location, and adds child-level controls, and results in a decrease in the coefficient for positive precipitation correlation locations but no change for other locations, consistent with anthropometric measures being standardized and comparable across age and sex of child. Model (4) flexibly detrends the data separately by UNICEF region and adds country-specific rural/urban fixed effects, resulting in no statistical change in the coefficients while increasing significance levels to 1% confidence. Model (5) adds country-specific interview month fixed effects to remove seasonality separately by country. This stricter specification makes estimates noisier, but they are not statistically different from those in (4). Model (6) controls for mother and child characteristics separately by country, resulting in no significant change in results. Finally, model (7) replaces the country fixed effects with fixed effects in first level administrative unit, thus comparing children living in the same state/province interviewed during different ENSO states. This stricter specification also does not lead to changes in results. Panel B performs all the same specifications using the binary outcome of undernourishment (below -2σ in weight for age). The pattern across specifications is similar: effects are consistent in direction and magnitude across all models, with statistical significance emerging after the data are detrended in model (2).

Table S2 presents models that vary observation weights to inform interpretation. Models (1)-(4) show results on weight for age, while (5)-(8) show results on undernourished (below -2σ in weight for age). Models (1) and (5) use weights as in main results in Table 1 in order produce estimates interpreted as ENSO’s effect on a child in the average country. These weights use the DHS sampling weights, adjust for survey size...
differences across countries, and then adjust for different numbers of DHS surveys in different countries:

$$\omega_{\text{avg\_country}} = \left(\frac{\text{DHSweight}_{isc}}{\text{survey\_size}_{sc}}\right) \left(\frac{1}{\text{totalsurveys}_c}\right)$$  (4)

Models (2) and (6) weight observations such that results are interpreted as the effect on the average child in the sample countries. The weights are the same as above, but now weight across countries by country population:

$$\omega_{\text{avg\_child}} = \left(\frac{\text{DHSweight}_{isc}}{\text{survey\_size}_{sc}}\right) \left(\frac{\text{population}_c}{\text{totalsurveys}_c}\right)$$  (5)

Results with these weights suggest larger effects of ENSO, although estimates are less precisely identified in the case of weight for age (2). Given that India represents 23% of the data and is by far the country with largest population, models (3) and (7) use average child weights but exclude India and find that results on the average child are larger than in (1) and (5) but not statistically different. In order to gauge whether the results might be driven by observation weights, models (4) and (8) use no weights and find results very similar to the main model. We maintain that weights are appropriate for the main specification given the stratified nature of DHS sampling and the fact that countries have different numbers of DHS surveys.

Table S3 columns (1)-(5) show alternative definitions of the ENSO variable for models on weight for age, while columns (6)-(10) are on undernourished (below -2σ in weight for age). While our main model uses the maximum monthly value of the May-Dec anomaly, models (1) and (6) use the maximum monthly value observed over the full (May-April) tropical year. Models (2) and (7) use the maximum over the May-Dec tropical year; models (3) and (8) use the mean over the tropical year; and models (4) and (9) use the maximum of a three month rolling mean of monthly values observed during the full tropical year. Columns (5) and (10) use indicator variables for El Niño-like and La Niña-like states designating all years where the maximum of a three month rolling mean of monthly values was greater than 0.5°C (Niño-like) or less than -0.5°C (Niña-like) from its 1981-2010 climatology. We note that in every case the association between decreased child weight for age and increased ENSO values remains, with some variation. The binary indicator for El Niño-like events in (5) and (10) is not statistically significant, while La Niña-like events exhibit statistically significant effects on increasing weight for age and reducing undernutrition, with opposite effects in places where precipitation correlation with NINO3.4 is positive.

Table S4 does not distinguish effects by the precipitation correlation to NINO3.4 to produce an average treatment effect of warmer ENSO across all children. The average effect is consistent with the effect size in Table 1 on children outside areas where precipitation is positively correlated to NINO3.4. The average effect is that warmer ENSO leads to a 0.04σ/°C reduction in weight-for-age (p = 0.02), and a 1 percentage point
increase in prevalence of undernourishment ($p < 0.01$).

Table S5 implements an alternative detrending of the data using decade fixed effects and shows that coefficients are not statistically different from Table 1. Table S6 explores the lagged effects of ENSO by adding a one-year lag to the specification. There is only evidence of persistent effects of warmer ENSO on child nutrition in the subsample with positively correlated rainfall.

Tables S7-S8 test whether results are robust to alternative definitions of teleconnection. Figure S1 shows the global map of ENSO correlations to precipitation and temperature used for teleconnection assignment. Table S7 extends the main sample to include countries that are teleconnected with NINO3.4 in terms of precipitation but not temperature. Specifically, we added countries that are not already in the main sample, have DHS surveys and have at least 30% of their land area showing correlation between precipitation and NINO3.4. These countries are Kyrgyz Republic, Azerbaijan, Armenia, Turkey, Pakistan, Kazakhstan, and Egypt. No coefficient is statistically different from its analogue in Table 1.

Table S8 restricts the sample to include only those countries which have both a significant teleconnection with ENSO via temperatures and precipitation. This leads to a strictly smaller subsample of countries than the main tables in Table 1. The sample size drops to approximately 250,000, a significant change compared to approximately 1.25 million for the main sample, and 1.35 million for the extended sample in Table S7. We note that there is a priori ambiguity on whether the effects of ENSO in this smaller sample would be larger or smaller. On the one hand, the subsample represented by this table are those with presumably stronger (or at least more noticeable) climate variability induced by ENSO. This could imply that these countries are better adapted, and hence might display smaller effects of ENSO on outcomes. On the other hand, a number of other results would imply that, as a set of lower income countries, their ability to adapt to this climate variability may be limited. Therefore, by restricting to countries with stronger ENSO effects, we might expect that the effects would be stronger. The results in the table are supportive of the second hypothesis, i.e., worsening effects, but we they are nonetheless not statistically different from the results in Table 1.

Figure S2 and Tables S10-S11 explore whether the ENSO state might affect the timing of DHS surveys within the year, and therefore spuriously lead to changes in child anthropometrics due to seasonality. Figure S2 plots sample sizes by month and ENSO state with 95% CIs to show variation in these patterns across DHS surveys. There is no statistically different monthly pattern across ENSO states. Table S10 adds country-specific monthly fixed effects to ensure that only children interviewed in the same country during the same month of the year are being compared across ENSO states in their anthropometrics. Table S11 regresses the DHS month of interview on the ENSO state (including all covariates, detrending and fixed effects in the main regression) and shows that the two are not associated. These results suggest that the effects of ENSO
state on child anthropometrics are not the result of correlated interview timing changes.

Table S12 employs a variety of standard error clustering in order to adjust for a covariate shock (all observations experience the same ENSO treatment variable per year) as well as spatial and serial correlation in child anthropometric estimates. Inference remains consistent whether standard errors are not clustered (1); clustered at UNICEF region (2), country (3) or admin1/state (4) to adjust for arbitrary serial and spatial autocorrelation at these geographic units. Inference is also consistent under two-way clustering at UNICEF region and decade (5), country and year (6), or admin1 and year (7, the main specification). Note that (7) is designed to address possible spatial and temporal autocorrelation through use of two-way clustering of standard errors (32) at the levels of interview year and first subnational administrative subunit (e.g., state or province, at which level the DHS is representative). This approach is conservative, and controls for arbitrary autocorrelation within both the level of treatment (i.e. tropical year) across space as well as within the DHS sample frame across multiple surveys at different times.

Finally, Figure S3 shows that a randomization inference test rejects the possibility that the structure of the data is spuriously resulting in the estimated effects on child anthropometrics (33). The procedure randomly permutes yearly NINO3.4 values across years, and estimates the main specification on child weight for age (as in Table 1 column 1, excluding the observations with positive precipitation correlation to NINO3.4):

$$Y_{ict} = \alpha + \beta_{n}NINO_{t} + \gamma X_{i} + f(t_{globalregion}) + FE_{(c \times rural)} + \varepsilon_{ict}$$

The figure plots the distribution of $\beta_{n}$ estimated from the 2,000 random permutations of NINO3.4. This, in effect, creates 2,000 placebo datasets where every child surveyed in tropical year $T$, i.e., between May of calendar year $T$ and April of calendar year $T+1$, is assigned a random NINO3.4 anomaly value from the time series of NINO3.4 without replacement. The distribution of estimates from running our main specification on these 2,000 datasets is the blue shaded region. It is centered at 0, providing evidence that this research design is not biased by, for example, temporal autocorrelation. Further, the coefficient we estimate using the actual NINO3.4 variation (-0.025) is substantially different from zero ($p = 0.08$). This Fisher randomization inference test illustrates that the residual annual variation in NINO3.4 and the child anthropometric data is meaningful compared to arbitrary degrees of freedom at the annual level.
Figure S1: Global Map of ENSO Precipitation and Temperature Correlations. Upper Panel: teleconnection areas based on precipitation correlations. Teleconnections are defined as pixels where the local precipitation, as measured by UDEL gridded precipitation, show 3 or more statistically significant months of correlation with the second month lag of NINO3.4 SSTs. There is substantial heterogeneity in how precipitation is affected by ENSO, with areas of both positive and negative correlation. Lower Panel: teleconnection areas based on temperature correlations, defined as in the upper panel but using monthly temperatures from the UDEL climate dataset. This is the sample selection criterion used in the paper, and the direction of precipitation correlations informs the heterogeneity analysis.
Figure S2: Sample sizes show no statistically different monthly pattern in DHS interviews across ENSO states. Graph plots the result of calculating the sample percentage of each DHS survey separately by month and ENSO state. Bar heights and error bars indicate mean and 95% confidence interval across DHS surveys.
Figure S3: Randomization inference test indicates association of ENSO state and nutrition unlikely due to chance. The figure plots the distribution of coefficients $\beta_n$ from the following regression matching the estimation in column 1 of Table 1 after excluding locations with positive precipitation correlation: $Y_{ict} = \alpha + \beta_n NINO_t + \gamma X_i + f(t_{globalregion}) + FE_{(extrural)} + \varepsilon_{ict}$. $Y$ is child weight for age. Estimates of $\beta_n$ are produced after values of NINO3.4 are reshuffled across tropical years. The process is repeated with 2,000 random permutations of NINO3.4. The randomized permutation exercise rejects the possibility that the estimated $\beta_n$ of -0.025 (shown by the vertical line) is a spurious result ($p = 0.08$). Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother’s age at child’s birth and total years of mother’s education; country-specific fixed effects for rural vs. urban; and UNICEF world region-specific linear trends in survey year as well as fixed effects for month of interview. Observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country.
Table S1: Results under various fixed effect specifications

|                | (1)        | (2)        | (3)        | (4)        | (5)        | (6)        | (7)        |
|----------------|------------|------------|------------|------------|------------|------------|------------|
| **Panel A: Weight for Age** |            |            |            |            |            |            |            |
| Max NINO3.4   | -0.00625   | -0.0260**  | -0.0294**  | -0.0302*** | -0.0181*   | -0.0284*** | -0.0276*** |
| std. error    | (0.0357)   | (0.0126)   | (0.0116)   | (0.0104)   | (0.00931)  | (0.00984)  | (0.00939)  |
| p-value       | 0.862      | 0.0476     | 0.0162     | 0.00637    | 0.0605     | 0.0694     | 0.0600     |
| 95% CI (lower)| -0.079     | -0.0516    | -0.0529    | -0.0513    | -0.0371    | -0.0484    | -0.0468    |
| 95% CI (upper)|            |            |            |            |            |            |            |
| ρ(precip, NINO)>0 | 0.0569    | 0.184**    | 0.0652**   | 0.0683***  | 0.0592**   | 0.0718***  | 0.107**    |
| std. error    | (0.175)    | (0.0741)   | (0.0260)   | (0.0229)   | (0.0258)   | (0.0223)   | (0.0408)   |
| p-value       | 0.747      | 0.0184     | 0.0176     | 0.00747    | 0.0285     | 0.00298    | 0.0130     |
| 95% CI (lower)| -0.299     | 0.0331     | 0.0122     | 0.0196     | 0.00665    | 0.0263     | 0.0242     |
| 95% CI (upper)|            |            |            |            |            |            |            |
| Mean of dep. var. | -0.941   | -0.941     | -0.931     | -0.931     | -0.931     | -0.931     | -0.931     |
| R-squared     | 0.000      | 0.099      | 0.125      | 0.127      | 0.132      | 0.130      | 0.139      |

|                |            |            |            |            |            |            |            |
| **Panel B: Undernourished (low weight for age)** |            |            |            |            |            |            |            |
| Max NINO3.4   | 0.00310    | 0.00537    | 0.00604*   | 0.00714**  | 0.00409*   | 0.00646**  | 0.00571**  |
| std. error    | (0.00913)  | (0.00340)  | (0.00301)  | (0.00263)  | (0.00226)  | (0.00239)  | (0.00240)  |
| p-value       | 0.736      | 0.124      | 0.0536     | 0.0107     | 0.0796     | 0.0110     | 0.0233     |
| 95% CI (lower)| -0.0155    | -0.00156   | -0.000101  | 0.00178    | -0.00511   | 0.00158    | 0.00827    |
| 95% CI (upper)|            |            |            |            |            |            |            |
| ρ(precip, NINO)>0 | -0.0267   | -0.0539**  | -0.0188*** | -0.0187*** | -0.0178*** | -0.0191*** | -0.0278**  |
| std. error    | (0.0408)   | (0.0215)   | (0.00637)  | (0.00532)  | (0.00468)  | (0.00502)  | (0.0110)   |
| p-value       | 0.518      | 0.0173     | 0.00592    | 0.00136    | 0.00597    | 0.00623    | 0.0169     |
| 95% CI (lower)| -0.11      | -0.0976    | -0.0318    | -0.0295    | -0.0274    | -0.0293    | -0.0503    |
| 95% CI (upper)|            |            |            |            |            |            |            |
| Mean of dep. var. | 0.206      | 0.206      | 0.204      | 0.204      | 0.204      | 0.204      | 0.204      |
| R-squared     | 0.000      | 0.069      | 0.083      | 0.085      | 0.089      | 0.087      | 0.094      |

|                |            |            |            |            |            |            |            |
| **Observations** | 1,268,295  | 1,268,295  | 1,253,176  | 1,253,176  | 1,253,173  | 1,253,176  | 1,253,176  |
| Country FE     | yes        | yes        | yes        | yes        | yes        | yes        | yes        |
| Year trend     | yes        | yes        | × region   | × region   | × region   | × region   | × region   |
| Interview month FE | yes     | yes        | × country  | × country  | × country  | × country  | × country  |
| Rural FE       | yes        | yes        | × country  | × country  | × country  | × country  | × country  |
| Child & Mother controls | yes     | yes        | × country  | × country  | × country  | × country  | × country  |
| Admin1 FE      | yes        | yes        | × country  | × country  | × country  | × country  | × country  |

Notes: The top panel examines weight for age z-scores, while the bottom panel examines a binary variable for whether the child is undernourished by WHO standards (below -2σ in weight for age). Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions, and observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country. Asterisks indicate statistical significance at the 1% (***) 5% (**) and 10% (*) levels.
Table S2: Results under various observation weighting options

| Weight for age | Probability of meeting WHO standard for undernourished |
|----------------|--------------------------------------------------------|
| Max NINO3.4    |                                                        |
| std. error:    | (0.0105) (0.0194) (0.0253) (0.00985) (0.00264) (0.00370) (0.00321) (0.00229) |
| p-value:       | 0.0234 0.0383 0.0875 0.0255 0.0329 0.00608 0.0633 0.0322 |
| 95% CI (lower):| (-0.0466) (-0.0815) (-0.0961) (-0.0431) (0.000510) (0.00333) (-0.000362) (0.000464) |
| 95% CI (upper):| -0.00363 -0.00242 0.00693 -0.00301 0.0113 0.0184 0.0127 0.00978 |
| ρ(precip, NINO) > 0 |                                                |
| std. error:    | (0.0222) (0.0418) (0.0338) (0.00793) (0.00489) (0.0126) (0.00293) (0.00287) |

Mean of dep. var. | -0.991 | -1.425 | -1.019 | -1.078 | 0.204 | 0.343 | 0.242 | 0.238 |
Observations      | 1,253,176 | 1,253,176 | 960,857 | 1,253,233 | 1,253,176 | 1,253,176 | 960,857 | 1,253,233 |
R-squared         | 0.129 | 0.179 | 0.159 | 0.162 | 0.087 | 0.118 | 0.107 | 0.111 |
Weights           | Avg Ctry | Avg Child | Avg Child | None | Avg Ctry | Avg Child | Avg Child | None |
Sample            | All | All | Exclude India | All | All | All | Exclude India | All |

Notes: 1-4 examine weight for age z-scores, while 5-8 examine a binary variable for whether the child is undernourished by WHO standards (below -2σ in weight for age). Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother’s age at child's birth and total years of mother’s education; country-specific fixed effects for rural vs. urban; and UNICEF world region-specific linear trends in survey year as well as fixed effects for month of interview. Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions. 1 and 5 use weights to represent the effect on an average country in the sample; 2 and 6 weigh observations to represent the average child in the sample; 3 and 7 use the same weights but exclude India given its dominance in the sample; 4 and 8 use no weights. Asterisks indicate statistical significance at the 1% (***) , 5% (**) and 10% (*) levels.
Table S3: Results under various definitions of ENSO

| NINO3.4 variable | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|
|                  | May-Apr Max NINO3.4 | May-Dec Max NINO3.4 | May-Apr Mean of 3mo Rolling NINO3.4 | May-Apr Max NINO3.4 | May-Dec Mean NINO3.4 | May-Apr Max NINO3.4 | May-Dec Max NINO3.4 | Mean NINO3.4 | El Niño / La Niña binary |
| Weight for age   | Probability of meeting WHO standard for undernourishment |
|                  | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) |
|                  | -0.0301** | -0.0306** | -0.0215** | -0.0322** | 0.00569 | 0.00651 | 0.00459* | 0.00595 |
| std. error       | (0.0141) | (0.0145) | (0.0103) | (0.0152) | 0.0406 | 0.0420 | 0.0417 | 0.0413 |
| p-value          | 0.0406 | 0.0420 | 0.0453 | 0.0417 | 0.0060 | 0.0060 | 0.0060 | 0.0060 |
| 95% CI (lower)   | -0.0588 | -0.0601 | -0.0425 | -0.0631 | -0.00273 | -0.00206 | -0.000865 | -0.00309 |
| 95% CI (upper)   | 0.0141 | 0.0151 | 0.0101 | 0.0150 | 0.0141 | 0.0151 | 0.0101 | 0.0150 |
| \(\rho(\text{precip, NINO}) > 0\) | 0.00443 | 0.00446 | 0.00463 | 0.00444 | 0.00884 | 0.00510 | 0.00485 | 0.00485 |
| std. error       | (0.0146) | (0.0146) | (0.0153) | (0.0146) | 0.0211 | 0.0211 | 0.0211 | 0.0211 |
| p-value          | 0.0406 | 0.0420 | 0.0453 | 0.0417 | 0.0060 | 0.0060 | 0.0060 | 0.0060 |
| 95% CI (lower)   | -0.0588 | -0.0601 | -0.0425 | -0.0631 | -0.00273 | -0.00206 | -0.000865 | -0.00309 |
| 95% CI (upper)   | 0.0141 | 0.0151 | 0.0101 | 0.0150 | 0.0141 | 0.0151 | 0.0101 | 0.0150 |
| El Niño State    | 0.116*** | -0.0256*** | 0.0161 | -0.0175* | 0.0616 | -0.0175* | 0.0616 | -0.0175* |
| std. error       | (0.0342) | (0.0342) | 0.0440 | (0.0440) | 0.0415 | 0.0415 | 0.0415 | 0.0415 |
| p-value          | 0.00183 | 0.00183 | 0.0171 | 0.0171 | 0.0060 | 0.0060 | 0.0060 | 0.0060 |
| 95% CI (lower)   | -0.0281 | -0.0281 | -0.0281 | -0.0281 | -0.0281 | -0.0281 | -0.0281 | -0.0281 |
| 95% CI (upper)   | 0.151 | 0.151 | 0.151 | 0.151 | 0.0060 | 0.0060 | 0.0060 | 0.0060 |
| La Niña State    | 0.0354 | 0.0354 | 0.0354 | 0.0354 | 0.00884 | 0.00510 | 0.00485 | 0.00485 |
| std. error       | (0.0342) | (0.0342) | 0.0440 | (0.0440) | 0.0415 | 0.0415 | 0.0415 | 0.0415 |
| p-value          | 0.00183 | 0.00183 | 0.0171 | 0.0171 | 0.0060 | 0.0060 | 0.0060 | 0.0060 |
| 95% CI (lower)   | -0.0281 | -0.0281 | -0.0281 | -0.0281 | -0.0281 | -0.0281 | -0.0281 | -0.0281 |
| 95% CI (upper)   | 0.151 | 0.151 | 0.151 | 0.151 | 0.0060 | 0.0060 | 0.0060 | 0.0060 |
| Mean of dep. var. | -0.893 | -0.893 | -0.893 | -0.893 | -0.893 | -0.893 | -0.893 | -0.893 |
| Observations     | 1,253,176 | 1,253,176 | 1,253,176 | 1,253,176 | 1,253,176 | 1,253,176 | 1,253,176 | 1,253,176 |
| R-squared        | 0.129 | 0.129 | 0.129 | 0.129 | 0.129 | 0.129 | 0.129 | 0.129 |

Notes: 1-5 examine weight for age z-scores, while 6-10 examine a binary variable for whether the child is undernourished by WHO standards (below -2σ in weight for age). (1) and (6) use the maximum monthly value observed over the full (May-April) tropical year; (2) and (7) use the maximum over the May-Dec tropical year; models (3) and (8) use the mean over the tropical year; and models (4) and (9) use the maximum of a three month rolling mean of monthly values observed during the full tropical year. (5) and (10) use indicator variables for El Niño-like and La Niña-like states designating all years where the maximum of a three month rolling mean of monthly values was greater than 0.5°C (Niño-like) or less than -0.5°C (Niña-like) from its reference climatology following NOAA CPC guidelines. Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother’s age at child’s birth and total years of mother’s education; country-specific fixed effects for rural vs. urban; and UNICEF world region-specific linear trends in survey year as well as fixed effects for month of interview. Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions, and observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country. Asterisks indicate statistical significance at the 1% (***) , 5% (**) and 10% (*) levels.
### Table S4: Results as an average treatment effect

|                | (1)           | (2)           | (3)           | (4)           | (5)           |
|----------------|---------------|---------------|---------------|---------------|---------------|
|                | Weight Pr(WHO standard) for age | Weight Pr(WHO standard) for height | Body mass Pr(WHO standard) index | undernourished | wasted |
| Max NINO3.4    | -0.0405*      | -0.0357***    | -0.0327**     | 0.0101**      | 0.00312**      |
| std. error:    | (0.0217)      | (0.0170)      | (0.0142)      | (0.00422)     | (0.00141)      |
| p-value:       | 0.0710        | 0.0436        | 0.0277        | 0.0225        | 0.0336        |
| 95% CI (lower) | (-0.0847)     | (-0.0704)     | (-0.0615)     | (0.00152)     | (0.000257)     |
| 95% CI (upper) | 0.00307       | -0.00108      | -0.00383      | 0.0187        | 0.00598        |
| Mean of dep. var. | -1.422      | -0.664        | -0.501        | 0.342         | 0.168         |
| Observations   | 1,274,773     | 1,226,664     | 1,228,010     | 1,274,773     | 1,226,664     |
| R-squared      | 0.179         | 0.130         | 0.107         | 0.118         | 0.052         |

Notes: Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother’s age at child’s birth and total years of mother’s education; country-specific fixed effects for rural vs. urban; and UNICEF world region-specific linear trends in survey year as well as fixed effects for month of interview. Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions, and observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average child in the sample countries. Asterisks indicate statistical significance at the 1% (***) 5% (**) and 10% (*) levels.

### Table S5: Results using decade fixed effects

|                | (1)           | (2)           | (3)           | (4)           | (5)           |
|----------------|---------------|---------------|---------------|---------------|---------------|
|                | Weight Pr(WHO standard) for age | Weight Pr(WHO standard) for height | Body mass Pr(WHO standard) index | undernourished | wasted |
| Max NINO3.4    | -0.0217**     | -0.0370***    | -0.0373***    | 0.00501*      | 0.00201       |
| std. error:    | (0.0122)      | (0.0122)      | (0.0117)      | (0.00288)     | (0.00182)     |
| p-value:       | 0.0835        | 0.00466       | 0.00311       | 0.0918        | 0.278         |
| 95% CI (lower) | (-0.0465)     | (-0.0617)     | (-0.0610)     | (-0.000801)   | (-0.00170)    |
| 95% CI (upper) | 0.00305       | -0.0122       | -0.0135       | 0.0109        | 0.00573       |
| ρ(precip, NINO) > 0 | 0.0681*** | 0.0464       | 0.0349       | -0.0180***    | -0.00562      |
| std. error:    | (0.0232)      | (0.0324)      | (0.0354)      | (0.00508)     | (0.00419)     |
| Mean of dep. var. | -0.931      | -0.228        | -0.0895       | 0.204         | 0.100         |
| Observations   | 1,253,176     | 1,205,335     | 1,206,659     | 1,253,176     | 1,205,335     |
| R-squared      | 0.129         | 0.093         | 0.081         | 0.087         | 0.040         |

Notes: Different anthropometric effects of ENSO are concentrated on short run measures (1-3) weight for age, weight for height, and body mass index z-scores, which all measure shorter-run effects of scarce nutrition, show evidence of contemporaneous ENSO effects measured in °C. Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother’s age at child’s birth and total years of mother’s education; country-specific fixed effects for rural vs. urban; fixed effects for month of interview, and fixed effects for decade of survey year. Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions, and observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country. (4-5) WHO threshold outcomes show ENSO increases the likelihood of being undernourished (below -2σ in weight for age) or wasted (below -2σ in weight for height). Asterisks indicate statistical significance at the 1% (***) 5% (**) and 10% (*) levels.
Table S6: Results as a distributed lag model

|                        | (1) Weight for age | (2) Weight for height | (3) Body mass index | (4) Pr(WHO standard): undernourished | (5) wasted |
|------------------------|--------------------|-----------------------|---------------------|--------------------------------------|-----------|
| Max NINO3.4            |                    |                       |                     |                                      |           |
| Weight                 | -0.0257**          | -0.0374***            | -0.0378***          | 0.00597***                           | 0.00325   |
| std. error             | (0.0105)           | (0.0128)              | (0.0131)            | (0.00268)                            | (0.00252) |
| p-value                | 0.0197             | 0.00641               | 0.00691             | 0.0339                               | 0.207     |
| 95% CI (lower)         | (-0.0471)          | (-0.0635)             | (-0.0644)           | (0.000514)                           | (-0.00189) |
| 95% CI (upper)         | -0.00439           | -0.0113               | -0.0111             | 0.0114                               | 0.00389   |
| ρ(precip, NINO) > 0    | 0.0691***          | 0.0419                | 0.0303              | -0.0185***                           | -0.00654  |
| std. error             | (0.0135)           | (0.0292)              | (0.0333)            | (0.00211)                            | (0.00532) |
| First lag of Max NINO3.4|                    |                       |                     |                                      |           |
| Weight                 | -0.0101            | 0.00332               | 0.00391             | 0.00151                              | 0.00103   |
| std. error             | (0.0104)           | (0.0140)              | (0.0150)            | (0.00209)                            | (0.00236) |
| p-value                | 0.335              | 0.814                 | 0.796               | 0.476                                | 0.667     |
| 95% CI (lower)         | (-0.0312)          | (-0.0252)             | (-0.0267)           | (-0.00276)                           | (-0.00379) |
| 95% CI (upper)         | 0.0110             | 0.0319                | 0.0345              | 0.00577                              | 0.00584   |
| ρ(precip, NINO) > 0    | 0.0809***          | 0.0960***             | 0.0893**            | -0.0168**                            | -0.0107   |
| std. error             | (0.0292)           | (0.0324)              | (0.0327)            | (0.00730)                            | (0.00660) |

Mean of dep. var.      | -0.931             | -0.228                | -0.0895             | 0.204                                | 0.100     |
Observations           | 1,253,176          | 1,205,335             | 1,206,659           | 1,253,176                            | 1,205,335 |
R-squared              | 0.129              | 0.093                 | 0.081               | 0.087                                | 0.040     |

Notes: Different anthropometric effects of ENSO are concentrated on short-run measures (1-3) weight for age, weight for height, and body mass index z-scores, which all measure shorter-run effects of scarce nutrition, show evidence of contemporaneous ENSO effects measured in °C. Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother’s age at child’s birth and total years of mother’s education; country-specific fixed effects for rural vs. urban; and UNICEF world region-specific linear trends in survey year as well as fixed effects for month of interview. Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions, and observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country. (4-5) WHO threshold outcomes show ENSO increases the likelihood of being undernourished (below -2σ in weight for age), but shows a statistically insignificant effect on wasting (below ‘2σ in weight for height). Asterisks indicate statistical significance at the 1% (***) , 5% (** ) and 10% (*) levels.
Table S7: Results with precipitation teleconnected countries added

|                | (1) Weight for age | (2) Weight for height | (3) Body mass index | (4) Pr(WHO standard): |
|----------------|------------------|----------------------|---------------------|-----------------------|
| Max NINO3.4    | -0.0212**        | -0.0364***           | -0.0369***          | 0.00537**             |
|                | (0.00997)        | (0.0119)             | (0.0121)            | (0.00248)             |
|                | 0.0412           | 0.00447              | 0.00468             | 0.0375                |
| p-value        | (-0.0415)        | (-0.0607)            | (-0.0616)           | (0.000332)            |
| 95% CI (lower) | -0.000990        | -0.0122              | -0.0122             | 0.0104                |
| 95% CI (upper) |                  |                      |                     | 0.00799               |
| \(\rho(\text{precip, NINO}) > 0\) | 0.0916*** | 0.0808*** | 0.0646**           | -0.0148***            |
|                | (0.0210)         | (0.0252)             | (0.0245)            | (0.00217)             |
| Mean of dep. var. | -0.882          | -0.185               | -0.0503             | 0.196                 |
| Observations   | 1,356,895        | 1,305,087            | 1,306,592           | 1,356,895             |
| R-squared      | 0.146            | 0.101                | 0.086               | 0.094                 |

Notes: effects on (1-3) weight for age, weight for height, and body mass index z-scores, which all measure shorter-run effects of scarce nutrition, show evidence of contemporaneous ENSO effects measured in °C. Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother’s age at child’s birth and total years of mother’s education; country-specific fixed effects for rural vs. urban; and UNICEF world region-specific linear trends in survey year as well as fixed effects for month of interview. Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions, and observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country. (4-5) WHO threshold outcomes show ENSO increases the likelihood of being undernourished (below -2σ in weight for age) and wasted (below -2σ in weight for height). Asterisks indicate statistical significance at the 1% (***) , 5% (**) and 10% (*) levels.

Table S8: Results including only locations teleconnected through both precipitation and temperature

|                | (1) Weight for age | (2) Weight for height | (3) Body mass index | (4) Pr(WHO standard): |
|----------------|------------------|----------------------|---------------------|-----------------------|
| Max NINO3.4    | -0.0321*         | -0.0456**            | -0.0501**           | 0.00780               |
|                | (0.0159)         | (0.0202)             | (0.0197)            | (0.00523)             |
| p-value        | 0.0530           | 0.0317               | 0.0167              | 0.147                 |
| 95% CI (lower) | (-0.0647)        | (-0.0870)            | (-0.0904)           | (-0.00291)            |
| 95% CI (upper) | 0.000449         | -0.00429             | -0.00973            | 0.0185                |
| \(\rho(\text{precip, NINO}) > 0\) | 0.0679** | 0.0701** | 0.0672**           | -0.0290***            |
|                | (0.0247)         | (0.0295)             | (0.0325)            | (0.00419)             |
| Mean of dep. var. | -0.835          | -0.163               | -0.0352             | 0.185                 |
| Observations   | 247,154          | 238,174              | 238,456             | 247,154               |
| R-squared      | 0.152            | 0.110                | 0.090               | 0.103                 |

Notes: effects on (1-3) weight for age, weight for height, and body mass index z-scores, which all measure shorter-run effects of scarce nutrition, show evidence of contemporaneous ENSO effects measured in °C. Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother’s age at child’s birth and total years of mother’s education; country-specific fixed effects for rural vs. urban; and UNICEF world region-specific linear trends in survey year as well as fixed effects for month of interview. Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions, and observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country. (4-5) WHO threshold outcomes show ENSO increases the likelihood of being undernourished (below -2σ in weight for age) and wasted (below -2σ in weight for height). Asterisks indicate statistical significance at the 1% (***) , 5% (**) and 10% (*) levels.
Table S9: Countries and surveys in sample.

| Country                                | Survey Years                                      |
|----------------------------------------|--------------------------------------------------|
| East Asia & Pacific                    |                                                  |
| Cambodia                               | 2000, 2005, 2010, 2014, 2009                      |
| Timor Leste                            |                                                  |
| Latin America & Caribbean              |                                                  |
| Bolivia                                | 1989, 1994, 1998, 2003, 2008                      |
| Brazil                                 | 1986, 1996                                        |
| Colombia                               | 1986, 1995, 2000, 2005, 2010                      |
| Dominican Republic                     | 1986, 1991, 1996, 2002, 2007, 2013, 2014          |
| Guatemala                              | 1987, 1995                                        |
| Haiti                                  | 1995, 2000, 2006, 2017                            |
| Honduras                               | 2006, 2012                                        |
| Nicaragua                              | 1998, 2001                                        |
| Peru                                   | 1992, 1996, 2000                                  |
| Middle East & North Africa             |                                                  |
| Morocco                                | 1987, 1992, 2003                                  |
| Yemen                                  | 1992                                             |
| Sub-Saharan Africa                     |                                                  |
| Angola                                 | 2016                                             |
| Benin                                  | 1996, 2001, 2006, 2012, 2018                      |
| Burkina Faso                           | 1993, 1999, 2003, 2010                            |
| Burundi                                | 2010                                             |
| Cameroon                               | 1991, 1998, 2004, 2011                            |
| Central African Republic               | 1994                                             |
| Chad                                   | 1997, 2004                                        |
| Comoros                                | 1996, 2012                                        |
| Congo, Rep.                            | 2005, 2012                                        |
| Congo, Dem. Rep.                       | 2007, 2014                                        |
| Cote d’Ivoire                          | 1994, 1998, 2012                                  |
| Ethiopia                               | 2000, 2005, 2010, 2016                            |
| Gabon                                  | 2000, 2012                                        |
| Ghana                                  | 1988, 1993, 1998, 2003, 2008, 2014                |
| Guinea                                 | 1999, 2005, 2012                                  |
| Kenya                                  | 1993, 1998, 2003, 2008, 2014                      |
| Lesotho                                | 2004, 2009, 2014                                  |
| Liberia                                | 2007, 2013                                        |
| Madagascar                             | 1992, 1997, 2004                                  |
| Malawi                                 | 1992, 2000, 2004, 2010, 2016                      |
| Mali                                   | 1987, 1996, 2001, 2006, 2013                      |
| Mozambique                             | 1997, 2003, 2011                                  |
| Namibia                                | 1992, 2000, 2006, 2013                            |
| Niger                                  | 1992, 1998, 2006, 2012                            |
| Nigeria                                | 1990, 1999, 2003, 2008, 2013                      |
| Rwanda                                 | 1992, 2000, 2005, 2010, 2015                      |
| São Tomé e Principe                    | 2009                                             |
| Senegal                                | 1986, 1993, 2005, 2010, 2014, 2015, 2016, 2017    |
| Sierra Leone                           | 2008, 2013                                        |
| Swaziland                              | 2006                                             |
| Tanzania                               | 1992, 1996, 1999, 2005, 2010                      |
| Togo                                   | 1988, 1998, 2014                                  |
| Uganda                                 | 1989, 1995, 2000, 2006, 2011                      |
| Zambia                                 | 1992, 1996, 2002, 2007, 2014                      |
| Zimbabwe                               | 1988, 1994, 1999, 2005, 2010, 2015                |
| South Asia                             |                                                  |
| Bangladesh                             | 1997, 2000, 2004, 2007, 2011, 2014                |
| India                                  | 1993, 1999, 2006, 2016                            |
| Maldives                               | 2017                                             |
**Table S10:** Results adding country-month fixed effects

|                | (1)      | (2)      | (3)      | (4)      | (5)      |
|----------------|----------|----------|----------|----------|----------|
|                | Weight   | Weight   | Body mass| Pr(WHO standard): |
| Max NINO3.4    |          |          |          | undernourished | wasted  |
| std. error:    | (0.00943)| (0.00986)| (0.00982)| 0.00328   | 0.00139  |
| p-value:       | 0.0975   | 0.02118  | 0.00106  | 0.132     | 0.505    |
| 95% CI (lower):| (-0.0353)| (-0.0529)| (-0.0554)| (-0.00104)| (-0.00281) |
| 95% CI (upper):| 0.00311  | -0.0128  | -0.0154  | 0.00759   | 0.00559  |
| ρ(precip, NINO) > 0 | 0.0617**| 0.0243   | 0.0152   | -0.0178***| -0.00417 |
| std. error:    | (0.0234) | (0.0330) | (0.0372) | (0.00421) | (0.00483) |

Mean of dep. var. | -1.078 | -0.371 | -0.228 | 0.238 | 0.122 |
Observations      | 1,253,173 | 1,205,332 | 1,206,655 | 1,253,173 | 1,205,332 |
R-squared         | 0.133 | 0.099 | 0.087 | 0.099 | 0.043 |

Notes: Different anthropometric effects of ENSO are concentrated on short run measures (1-3) weight for age, weight for height, and body mass index z-scores, which all measure shorter-run effects of scarce nutrition, show evidence of contemporaneous ENSO effects measured in °C. Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother’s age at child’s birth and total years of mother’s education; country-specific fixed effects for rural vs. urban; country-specific fixed effects for month of interview, and linear and quadratic trends in survey year. Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions, and observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country. Asterisks indicate statistical significance at the 1% (***) ,5% (**) and 10% (*) levels.

**Table S11:** Month of interview not associated to NINO3.4 Anomaly

|                | (1) |               |
|----------------|-----|---------------|
| VARIABLES      |     | Month of interview |
| Max NINO3.4    | -0.309 |               |
| std. error:    | (0.442) |               |
| p-value:       | 0.373 |               |
| 95% CI (lower):| (-1.007) |               |
| 95% CI (upper): | 0.388 |               |
| Observations   | 1,445,660 |       |
| R-squared      | 0.283 |               |
| Sample         | All  |               |

Notes: Estimate is from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother’s age at child’s birth and total years of mother’s education; country-specific fixed effects for rural vs. urban; and UNICEF world region-specific linear trends in survey year as well as fixed effects for month of interview. Standard errors are two-way clustered at the level of tropical year and admin1 (province) regions, and observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country. Asterisks indicate statistical significance at the 1% (***) ,5% (**) and 10% (*) levels.
Table S12: Alternative standard error clustering strategies

| Weight for age | (1) | (2) | (3) | (4) | (5) | (6) | (7) |
|----------------|-----|-----|-----|-----|-----|-----|-----|
| Max NINO3.4    | -0.0251*** | -0.0251** | -0.0251** | -0.0251*** | -0.0251* | -0.0251** | -0.0251** |
| std. error:    | (0.00182) | (0.00666) | (0.0116) | (0.00767) | (0.00792) | (0.0119) | (0.0105) |
| p-value:       | 0   | 0.0196 | 0.0359 | 0.00113 | 0.0504 | 0.0435 | 0.0234 |
| 95% CI (lower):| (-0.0287) | (-0.0436) | (-0.0485) | (-0.0402) | (-0.0503) | (-0.0495) | (-0.0466) |
| 95% CI (upper):| -0.0215 | -0.00662 | -0.00172 | -0.0100 | 8.90e-05 | -0.000780 | -0.00363 |
| \( \rho(\text{precip, NINO}) > 0 \) | 0.0733*** | 0.0733*** | 0.0733*** | 0.0733*** | 0.0733** | 0.0733** | 0.0733*** |
| std. error:    | (0.00765) | (0.00900) | (0.0246) | (0.0204) | (0.0223) | (0.0285) | (0.0222) |

Notes: Anthropometric effects of ENSO on weight for age show evidence of contemporaneous ENSO effects measured in °C. Estimates are from OLS regressions with controls consisting of: fixed effects (indicators) for each country; country-specific controls for mother’s age at child’s birth and total years of mother’s education; country-specific fixed effects for rural vs. urban; fixed effects for month of interview; and UNICEF world region-specific linear trends in survey year. Inference remains consistent whether standard errors are not clustered (1); clustered at UNICEF region (2), country (3) or admin1/state (4) to adjust for arbitrarily serial and spatial autocorrelation at these geographic units, or two-way clustered at UNICEF region & decade (5), country & year (6), or admin1 & year (7, the main specification). Observations are reweighted using DHS sample weights and country size weights in order for estimates to represent an effect on the average country. Asterisks indicate statistical significance at the 1% (***), 5% (**), and 10% (*) levels.