The Exogenous Effects of Climate Indices on Human Development: An Econometric Analysis

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Abstract:

This paper attempts to outline the relationship between annual measures of human development and key climate indicators from 1990 to 2018, in order to better understand the impact that climate has had on human development throughout this period and to possibly predict future outcomes. Development indicators were chosen along the lines of those used in the Human Development Index, namely life expectancy at birth and the education index. Several primary indicators of climate were utilized with representative indices, namely those drivers of ocean dynamics, temperature effects, and atmospheric pressure and precipitation: the North Atlantic Oscillation (NAO) Index, the El Nino Southern Oscillation (ENSO 3.4) Index, the Pacific-North American Oscillation (PNA) Index, and the two measures of the Madden Julian Oscillation (MJO RMM1 and RMM2). A portion of the time-invariant effects of each country's development on climate is represented by the total annual atmospheric concentrations of Carbon Dioxide emissions by each country and territory, and the effects of nutrition and crop yields on education and health outcomes controlled by the food production index and crop production index.

1. Introduction

The relationship between economic development and environmental change has become a prominent concern in the fields of economics with the rising awareness of climate and its impacts beyond the sphere of the environment. Existing economic research on development and the environment has focused primarily on attempting to understand the impacts that the former has on the later. The emphasis has been on utilizing GDP as a primary measurement of development against environmental factors and performing a cost/benefit analysis for the purpose of policy-making and developing measures of adaptation and mitigation. Rarely however, is the Human Development Index (HDI) or its indicators utilized as a measure of development to analyze the impacts that it has on environmental change, and vice versa. The Human Development Index indicators are far more useful in a dynamic analysis of human development outcomes than simply using income as a proxy, as they are more robust in outlining the health and education effects that are significant towards development. Furthermore, there has been a lack of significant attention given to the reverse causality effects that climate has on development, which are fixed effects as defined by these climate measures. Little research has been done in analyzing dynamic climate patterns, with much of the literature focusing on simple environmental factors. This has been done at the micro-level, studying regional or country effects of changes in climate indicators and their impacts on development variables such as mortality rates or school attendance, however what is not often considered is how climate can differ regionally even within countries. Through a generalized approach, this problem becomes less of an issue with the use of global climate indices that better explain patterns of oceanic and atmospheric pressure, temperature, and precipitation. This paper seeks to chart the path forward in correcting these oversights by analyzing the relationship between annual measures of human development in comparison to key climate indicators at a broader global scale by country. Climate indicators should be used in lieu of the environmental factors within the existing research out of a need for a more robust analysis of global patterns over static measurements and observations. Environmental factors are only significantly useful at the micro level, where they are defined in specific spatial regions and are not suited towards an analysis of synoptic climate patterns. The analysis of climate's impact on human development is not possible at the macro-scale utilizing these measures as one region's environmental factors do not necessarily impact those of another. Thus, developing a general understanding of how human development is impacted by the environment through an analysis of climate patterns at a broader global level is necessary.

The outline of the paper is as follows: Section 2 explores the existing literature, the trends that researchers have followed, and the gaps within the research. Section 3 outlines the study area, the data used, and its sources. Section 4 describes the model utilized in regressing the data. Section 5 provides a brief explanation of each climate variable. Section 6 discusses regression results and problems encountered. Finally, section 7 highlights the implications of the results and the paths for future research.

2. Literature Review

The majority of historical economic research on the environment has focused on explaining trends of greenhouse gas emissions (mainly that of CO2) as derived from economic activity, treating the environment as endogenous of development, and later performing cost benefit analysis of mitigation and adaptation measures.[1] Given this perspective, it is understandable that there has been little focus on climate patterns which are more exogenous in nature and are not necessarily driven by anthropogenic causes. The econometric analysis done by Nemat Shafik is a perfect example of this type of research. The key takeaway from this paper is that amongst his determinants of environmental quality, he allowed for fixed effects analysis of each countries' endowment of climate and geography, similar to our research, and then performs a macro-level econometric analysis that broadly analyzes 149 countries[2]. The problem again is that the focus is on environmental factors such as deforestation and levels of fecal coliform in rivers which are treated as endogenous, highlighting the gap in neglecting to study the effects of climate on economic activity, a gap that has only had its surface scratched by scant few economists and the curiosity of some climatologists.

Some economists have pushed towards filling this gap, such as the research of Rodriguez-Oreggia et. al. which attempts to outline the relationship between climate disasters and HDI on the municipal level in Mexico.[3] The model that has been utilized in this field of developmental research considers the exogeneity of climate as represented by natural disasters. This is a refreshing step away from the broad assumption of endogeneity that has dominated economic research that has continued to either conflate climate and environment, or only consider the latter. However, the problem remains the same in that climate is measured statically in isolation, rather than as a part of a broader pattern. They are able to make the case that the occurrence of a natural disaster in the period 2000-2005 reduced the HDI by the equivalent of losing on average 2 years of human development gains over the same period, but this conclusion is applied to singular events rather than patterns.

Where the impacts of climate patterns on development are significantly researched is not in the field of economics, but rather in the field of climatology, where climatologists rely on their

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[1] Dobes, Leo, et. al., "The Economics of Global Climate Change: A Historical Literature Review." *Jahrbuch Für Wirtschaftswissenschaften / Review of Economics* 65, no. 3 (2014): 281-320

[2] Shafik, Nemat. "Economic Development and Environmental Quality: An Econometric Analysis." *Oxford Economic Papers*, New Series, 46 (1994): 757-73

[3] Oreggia, Eduardo, et. al., "Natural Disasters, Human Development and Poverty at the Municipal Level in Mexico." *The Journal of Development Studies*, 49, no.3 (2013): 442-455

own models of analysis with only slight application of economic analysis. Papers such as that written by Cherry et.al., which study energy markets, are a good example where the main crossover between the fields takes place. Through a simplistic case study, the authors were able to outline the relationship between the NAO index and spot prices of energy in Norway's (formerly) hydroelectric based grid.[4] This exemplifies how, even within climatology, the relationship between climate and economic activity between has been generally studied in the literature; one specific climate pattern, one industry, one country. While this ultimately works towards reducing excess noise, it can also have the effect of overlooking or understating the interactions between the many climate indices that drive global climate patterns.

Where the divergence between the fields becomes starker is in the many spatial modeling surveys that analyze dynamic climate effects on key development indicators. Emphasis is on geographic information system (GIS) spatial modeling rather than any econometric model. From the many climatological case studies, we can find the studied regional and country specific effects of climate indices on development indicators. From the study of Almendra et.al. there is no statistically significant effect in admissions of circulatory diseases in Lisbon hospitals despite there being a significant association between NAO and air pollutions tracts that would increase the likelihood of hospitalizations.[5] This can partially be explained by anthropogenic contributions to emissions of pollutants that are irrespective of long-scale NAO patterns. This issue can become much less of an observed problem if the focus of research is observed at the global-scale, with each countries' emissions accounted for and the remainder primarily being the exogenous patterns of climate that contribute to movements of pollutants across countries. A similar paper by Pausata et.al. explains how the impacts of climate patterns can vary regionally. For example, during a positive NAO phase, countries in southern Europe and the Mediterranean may be negatively impacted in terms of the concentrations of particulate matter, whereas northern Europe may benefit.[6] It is for this reason that stepping back to a larger scale may make more apparent which regions necessarily have to begin development adaptation measures as a consequence of exogenous, climate driven impacts on health outcomes.

The crossover between health and education outcomes becomes apparent in certain key geographical surveys, such as the one by Jankowska et.al. Their study of Mali explored the intersection between the local 'velocity' of climate change, population distributions, climate sensitivity, and livelihoods; primarily studying geographical variables, along with crop yields and malnutrition. Their findings that crop yield changes may drop significantly, along with forage yields and livestock weight, by 2050 potentially exposes a large portion of the country's population at risk of hunger and malnutrition.[7] In the context of Heather Randal's work on educational attainment in Ethiopia, it becomes clear what potential impacts of changes in climate variability can have on health and education. They found that milder temperatures during all seasons and greater rainfall during the summer agricultural season are associated with an increased likelihood of a child having completed any education. In addition, greater summer

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[4] Cherry, Jessie, et al., "Impacts of the North Atlantic Oscillation on Scandinavian Hydropower Production and Energy Markets." *Water Resources Management* 19, no.6 (2005): 673

[5] Almendra, Ricardo, et al., "The Influence of the Winter North Atlantic Oscillation Index on Hospital Admissions through Diseases of the Circulatory System in Lisbon, Portugal." *International Journal of Biometeorology*, 61 (2017): 61

[6] Pausata, Francesco, et. al., "Impacts of Changes in North Atlantic Atmospheric Circulation on Particulate Matter and Human Health in Europe." *Geophysical Research Letters*, 40, (2013): 4074-4080

[7] Jankowska, Marta, et. al., "Climate Change and Human Health: Spatial Modeling of Water Availability, Malnutrition, and Livelihoods in Mali, Africa." *Applied Geography*, 33 (2012): 4-15

rainfall during both early life and school ages is associated with having completed any schooling as well as with attending school at the time of the survey.[8] This is due to the association of these patterns with relatively high crop yield and higher levels of nutrition within the population. Investment in education has been emphasized heavily within the field of development economics as a way of stimulating a country's economy and improving development outcomes. However, it is difficult to net the benefits of said investment if children are malnourished and sent to working in the fields to make up for lost crop yield, resulting in lower attendance rates and lower levels of literacy. While these surveys are specific to countries or regions and not macro-studies, we can still extrapolate the general regional effects of climate indices on development and further understand the necessary variables for input, such as crop yield and type.

Another key trend in this area of economic research is the scarcity in using measures of human development other than GDP in analysis of climate and environment, especially amongst those pursuing policy recommendations. Jeroen et.al. prominently showcases the necessity for framing the impacts of climate in terms of HDI as well as GDP, to better explain the effects of international policy changes on global development. They do this by using the framework of the +2^0C temperature cap of the Paris Climate Agreement to introduce the idea of maximizing HDI rather than GDP in determining emissions pathways.[9] Utilizing GDP alone has resulted in the perspective of a cost-benefit analysis in terms of country output and income that has made it easy to frame the climate debate around the cost of mitigation, whereas a focus on human development indicators may clearly spell out the negative health and education outcomes of climate variability and the positive outcomes in mitigation.

3. Study Area and Data Sources

The research of this paper is targeted towards the period 1990-2018, for the simple reason that it studies human development indicators and the start date of the human development reports is 1990. The study area of this paper began with the 195 UN recognized countries and quickly expanded to 228 sovereign states and dependent territories after consideration of the availability of data. Theses 228 states and territories were organized into several groups by region and sub-region (as specified by the United Nations Statistical Commission), and by income (2018 World Bank Classification). The regional groups were as follows:

Table 1.

Asia	**Africa**	**Europe**	**Latin America & The Caribbean**	**Oceania**	**Northern America**
Western	Western	Western	South America	Australia & New Zealand	
Eastern	Eastern	Northern	Central America	Polynesia	
South-Eastern	Northern	Southern	Caribbean	Micronesia	
Southern	Southern				
Central	Middle				

The income groups were as follows:

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[8] Randell, Heather, Gray, Clark, "Climate Variability and Educational Attainment: Evidence from Rural Ethiopia." *Global Environmental Change*, 41 (2016): 111-123

[9] Van den Bergh, Jeroen, Botzen, W.J., "Global Impact of a Climate Treaty If the Human Development Index Replaces GDP as a Welfare Proxy" *Climate Policy*, 18, no.1 (2018): 76-85

Table 2.

Low	Lower-Middle	Upper-Middle	High
($995 or less)	($996 to $3,895)	($3,896 to $12,055)	(12,056 or more)

Data on GNI/Capita[10], life expectancy[11], crop production index[12], and food production index[13] were retrieved from the World Bank. Data regarding CO2 emissions[14] was retrieved from the Emissions Database for Global Atmospheric Research (EDGAR). Data regarding HDI and its education index[15] component were retrieved from the Human Development Reports. The climate indices used measure variations in their corresponding climate patterns on the daily level, giving us a sense of the general monthly, seasonal, and annual behavior of these patterns. For the purposes of this paper however, annual values were necessary to regress on annually measured economic variables. The climate explorer research tool of the Royal Netherlands Meteorological Institute (KNMI) is a web application developed specifically for the purpose of statistical analysis of climate data.[16] The mean of all index values (centered on Jan-December) was retrieved from this research tool.

4. Statistical Model

A one-way within fixed effects model was utilized in analyzing the data, in order to isolate the time-invariant effects that each country/territory has on the human development indicator in question (life expectancy and the education index). This controls for geography (diseases, access to water, etc.), diet, regionally based genetics, etc. The model is as follows:

$$y = (a + u_i) + b_i X'_{it} + v_{it}$$[17]

Where *i* is equal to the country group and *t* is equal to the time period in question (1990-2018). While not every group passed the Hausmann test, enough did that it was clear that this model was ideal over the random effects or pooled effects models.

While all of these climate variables work alongside each other as a part of a global dynamic system, most interaction terms included in attempting to reflect this relationship produced excess noise in the results due to the nature of narrowing down daily values into a

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[10] The World Bank. *GNI per capita, PPP (current international $)*. (Washington, D.C.: The World Bank, 2017). https://data.worldbank.org/indicator/NY.GNP.PCAP.PP.CD

[11] The World Bank. *Life expectancy at birth, total (years)*. (Washington, D.C.: The World Bank, 2017). https://data.worldbank.org/indicator/SP.DYN.LE00.IN

[12] The World Bank. *Crop production index (2004-2006 = 100)*. (Washington, D.C.: The World Bank, 2016). https://data.worldbank.org/indicator/AG.PRD.CROP.XD

[13] The World Bank. *Food production index (2004-2006 = 100)*. (Washington, D.C.: The World Bank, 2016). https://data.worldbank.org/indicator/AG.PRD.FOOD.XD

[14] Muntean, M., et. al., “Fossil CO2 Emissions of all World Countries – 2018 Report.” *Publications Office of the European Union* (2018)

[15] Human Development Reports. *Education Index*. (United Nations Development Programme, 2017). http://hdr.undp.org/en/data

[16] Oldenborgh, G.J, et. al., “Western Europe is warming much faster than expected” *Climate of the Past*, 5, 1 (2009): 1-12

[17] Park, Hun Myoung. “Practical Guides To Panel Data Modeling: A Step-by-step Analysis Using Stata.” *Graduate School of International Relations, International University of Japan*, (2011): 8

single mean value and the varying time scales of these variables. As a result, only interactions between the Arctic Oscillation and the North Atlantic Oscillation, and between the El Nino Southern Oscillation and Pacific North American Teleconnection Pattern were utilized. These interactions being well documented as significantly correlated also contributed to the decision to use them.

5. Empirical Specification of Model Variables

Table 3.

Variable	Description
NAO Index (North Atlantic Oscillation)	Mean of annual NAO Index values, centered on yearly midpoints
ENSO Index (El Nino Southern Oscillation)	Mean of annual ENSO 3.4 Index values, centered on yearly midpoints
AO (Arctic Oscillation)	Mean of annual AO Index values, centered on yearly midpoints
PNA (Pacific-North American Teleconnection Pattern)	Mean of annual PNA Index values, centered on yearly midpoints
MJO (Madden Julian Oscillation) Real-time Multivariate 1 (RMM1)	Mean of annual MJO RMM1 Index values, centered on yearly midpoints
MJO (Madden Julian Oscillation) Real-time Multivariate 2 (RMM2)	Mean of annual MJO RMM2 Index values, centered on yearly midpoints
Carbon Dioxide Emissions	Metric tons of CO2 emissions per year from fossil fuel use, industrial processes, and product use
GNI/Capita	In 2011 US$ PPP
Crop Yield Index	Weighted average of all crop production relative to the base period 2004-2006, minus fodder crops
Food Production Index	Weighted average of production of all food crops considered edible and containing nutrients relative to the base period 2004-2006, minus coffee and tea
Education Index	((Mean years of schooling / 15) + (Expected years of schooling /18)) / 2
Life Expectancy	Total life expectancy at birth in years

5.1 North Atlantic Oscillation (NAO)

The NAO is driven by an atmospheric pressure gradient between the Azores subtropical high-pressure region over the central North Atlantic, and the Icelandic subpolar low-pressure region over Greenland and Iceland. The oscillation of higher than normal pressure in the former and lower than normal pressure in the latter of these two regions is what defines the phases of the NAO. A negative phase of the NAO occurs when the subpolar low and subtropical high experience weaker than average pressure, causing the Atlantic jet stream and storm tracks to orient more directly from east to west. This results in greater than average precipitation over the regions of southern Europe and northern Africa and lower than average precipitation in northern Europe and eastern United States. A positive phase of the NAO experiences the opposite pattern of precipitation as the subpolar low and subtropical high experience greater than average pressure, causing the Atlantic jet stream and storm tracks to orient itself more northwards.[18]

5.2 El Nino Southern Oscillation (ENSO)

ENSO is driven primarily by changes in the relative levels of oceanic temperatures of the Pacific. ENSO can be considered a “balancing act” between the western and eastern regions of the pacific depending on where temperatures are relatively warmer. During an El Nino phase of the oscillation, oceanic temperatures are relatively warmer in the eastern pacific, resulting in trade winds that are weakened and may even reverse. This allows warmer than average water to traverse towards the central and eastern Pacific, causing increased precipitation over the parts of the region of Oceania and southeastern Asia. During a La Nina phase of the oscillation, oceanic temperatures are relatively warmer in the western pacific, resulting in trade winds that are stronger. This allows the warmer than average water to move into the western Pacific, causing increased precipitation in the region of southern North America and western South America. When no particularly significant gradients occur in the region, ENSO is said to be in its neutral phase. ENSO events are associated with characteristics that can last several seasons.[19]

5.3 Arctic Oscillation (AO)

The AO is driven by changes in the strength of the polar low-pressure system (the polar vortex). The AO is in a negative phase when the polar vortex is weaker, which weakens the Atlantic jet stream and causes weaker upper level winds. This allows cooler arctic winds to push further south in the United States and Northern Europe, along with keeping the trade winds and storm track farther south. When the AO is in a positive phase the polar vortex is stronger, which contains cooler arctic winds and storms of the arctic region. This allows for stronger jet streams, trade winds, and allows the North Atlantic Current to traverse more northwards. The AO often shares phases with the NAO and is strongly correlated with the phases of the NAO that impact weather across the United States.[20]

5.4 Pacific North American Teleconnection Pattern

The PNA is driven by the relative temperature and strength of pressure in the regions surrounding Hawaii and western North America, and in the regions surrounding Alaska and over southeastern United States. In a positive phase PNA, there is higher than average pressure over Hawaii and western North America and lower than average pressure over Alaska and the

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[18] NOAA, "North Atlantic Oscillation (NAO)." *National Climatic Data Center*.
[19] US Department of Commerce, and NOAA, "What Is ENSO?" *National Weather Service* (2016)
[20] NOAA, "Arctic Oscillation (AO)." *National Climatic Data Center*

southeastern United States, which results in a stronger East Asian jet stream that forces cold air residing in Canada to head southeastward. This causes below normal temperatures over the southeastern United States and above normal temperatures over the western United States and Canada. The negative phase of the PNA is characterized by the reverse pattern of pressure strength, which causes below normal temperatures over western United States and Canada and above normal temperatures in southeastern United States. The PNA can also share phases with ENSO patterns, with the positive phase of PNA being correlated with El Nino and the negative phase of the PNA with La Nina.[21]

5.5 Madden Julian Oscillation

The Madden Julian Oscillation is a pressure system that has similar characteristics to ENSO, but rather than remaining stationary it quickly moves eastward along the tropics, traversing the planet and returning to its initial starting point in 30-60 days on average. The two phases of the MJO are driven by the patterns of rainfall in the tropics, with strong MJO activity dividing the planet into halves that each experience a phase of the oscillation. During the enhanced rainfall/convective phase of the MJO, winds converge at the surface, pushing air up throughout the atmosphere where they diverge. This pattern results in increased precipitation. The suppressed rainfall/convective phase of the MJO is when winds converge at the top of the atmosphere and force air to sink to the surface where it diverges. This pattern results in reduced precipitation. There can be several MJO events within a single season as it makes its way around the tropics.[22] Wheeler and Hendon’s measurements for the behavior of MJO were utilized in this paper. They assert that:

> Much of the signal of the MJO can be isolated in minimally filtered (high-pass only) daily data simply by projection of that data onto spatial patterns characteristic of the MJO. Through this spatial projection, a large portion of the variability on other time and space scales is removed can be reflected in the spatially projected measures.[23]

For this reason, both of the time-series RMM1 and RMM2 were utilized, which “combine cloud amount and winds at upper and lower levels of the atmosphere to provide a measure of the strength and location of the MJO.”[24] The two time series measure the MJO as it changes phase space throughout its cycle:

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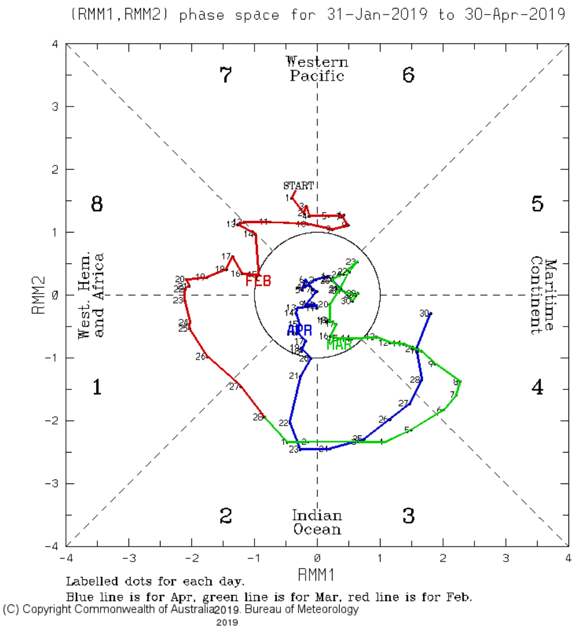
[21] Dahlman, LuAnn, "Climate Variability: Pacific - North American Teleconnection Pattern." *Climate.gov* (2009)

[22] Gottschalck, Jon, "What Is the MJO, and Why Do We Care?" *Climate.gov* (2014)

[23] Wheeler, Matthew C., Harry H. Hendon. "An All-Season Real-Time Multivariate MJO Index: Development of an Index for Monitoring and Prediction." *Monthly Weather Review*, 132, no. 8 (2004): 1918

[24] Bureau of Meteorology, "Madden-Julian Oscillation (MJO)," Commonwealth of Australia – Bureau of Meteorology



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6. Model Results

6.1 Regression Analysis

The following sections discuss the results of the regression analysis starting with major regions and the sub region's within and ending with income groups. Graphs reflect the coefficients for index values that are positive, for phases when the index values are negative simply flip the graphs. The first bar of every graph represents the total impact on the region as a whole, while each subsequent bar reflects the various sub-regional impacts.

6.11 Life Expectancy

Asia

The results indicate that across the region of Asia as a whole, assuming immediate impacts of climate index variability on life expectancy, that an annual running mean of climate index behavior (in the phases where index values are positive) has a highly significant impact across all indices, barring ENSO.

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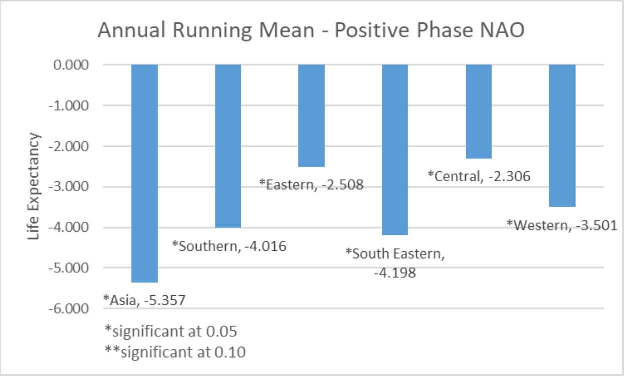
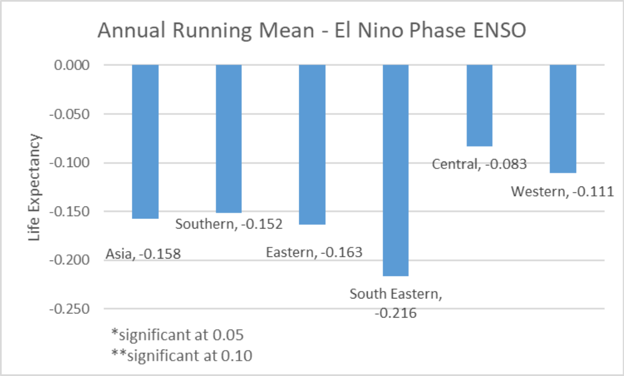
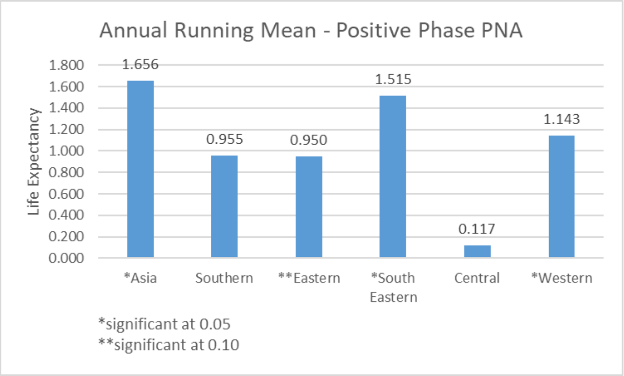
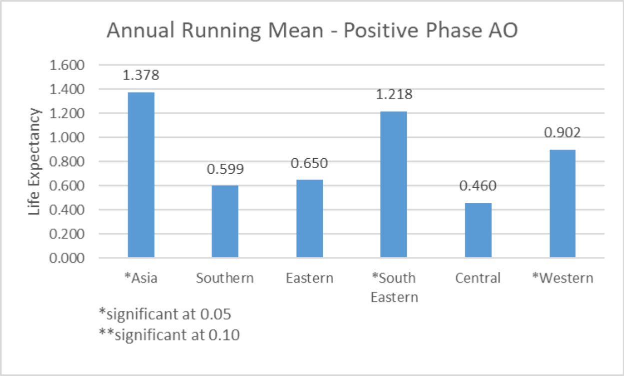
[25] Australian Bureau of Meteorology, *MJO Phase Diagram*, http://www.bom.gov.au/climate/mjo/





An annual average of positive phase NAO has a -5.36 year impact on life expectancy at birth. This relationship between the NAO and Asia as a region, while seeming somewhat strange considering the NAO's regional positioning being centered over the Atlantic, is nonetheless in line with climate research in which "it is shown that the NAO generates a significant climate response over East Asia during both the dry and wet seasons, whose spatial pattern is highly dependent on the phase of the NAO's life cycle."[26] Positive phase NAO has been shown to be correlated with increased precipitation in a number of regions across Eastern Asia which can be somewhat explanatory for the significance of the results across Asia as a greater region. Conversely however, results for the ENSO index were insignificant and showed a much more negligible impact on life expectancy.





Results for AO and PNA, while significant, were much more muted than those of NAO. An annual average of positive phase PNA has a 1.66 year increase in life expectancy at birth. Results were significant across most sub-regions of Asia, barring Southern and Central Asia, but were generally in the realm of about a year increase of life expectancy for an annual average positive phase of PNA. The AO had similar results to those of the PNA, resulting in 1.38 year increase in life expectancy at birth for Asia as a greater region. That there is an impact can be somewhat explained by the role of the East Asian jet stream in PNA activity, whilst its magnitude is likely due to the regional centralization of the PNA over the United States and Canada, and the AO being more impactful on regions with more countries in the arctic.

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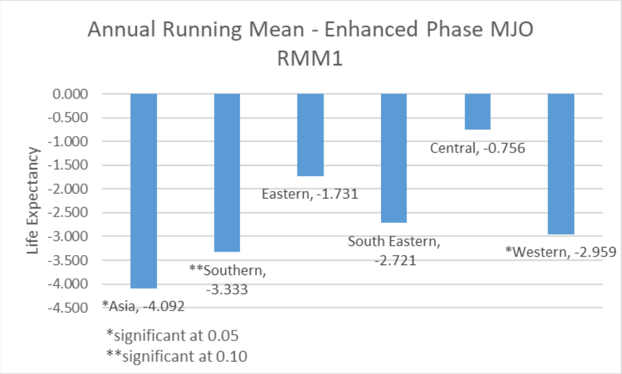
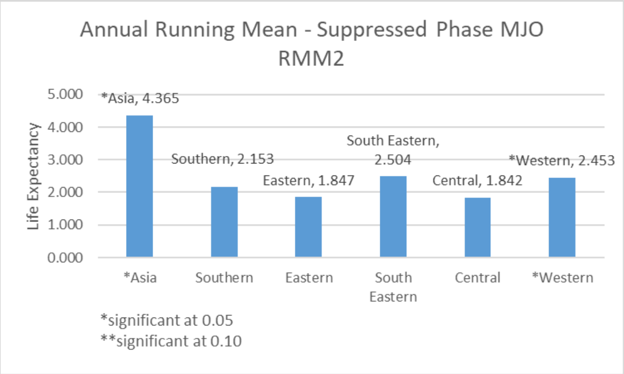
[26] Bollasina, Massimo A., and Gabriele Messori. "On the Link between the Subseasonal Evolution of the North Atlantic Oscillation and East Asian Climate." *Climate Dynamics*, 51, no. 9-10 (2018): 3537

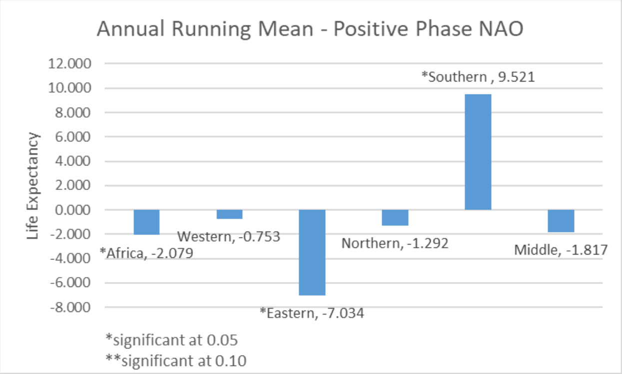


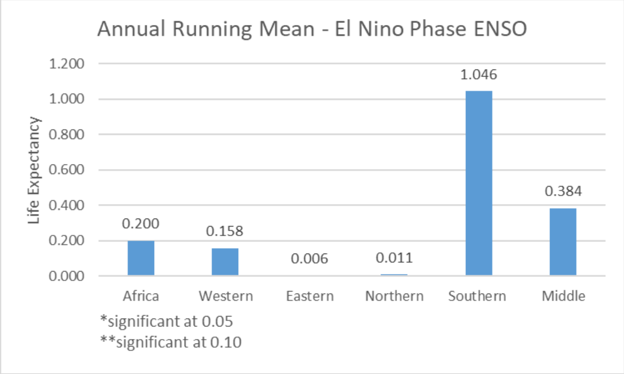


MJO impacts are a bit more difficult to interpret at the annual scale, given that there can be multiple events within a single season. That being said, on average when the MJO is in its enhanced phase, its impact on life expectancy in Asia from the average annual measured variability of its presence in the Indian Ocean results in a -4.09 year drop in life expectancy at birth, whereas the suppressed phase measured in its presence in the Western Hemisphere produces a 4.37 year increase in life expectancy. Considering the fact that MJO occurs several times throughout the year and cuts the world into two parts, each experiences the opposite phase, the impact on life expectancy seems to be balanced out. It results in an almost equal rise and fall in life expectancy from the RMM1 and RMM2 spatial regions during its enhanced convective phase and the inverse in its suppressed convective phase.

Africa

Results in Africa were more varied that those of Asia but were still generally significant across the region as a whole.





The results for NAO variability were mixed and somewhat contradictory. Research indicates that:

> Regression analysis shows that the NAO index is significantly related to the precipitable water content over portions of southeastern Africa in a manner suggesting that heavier, convective, rainfall occurs during the negative NAO phase, when the North Atlantic westerlies are unusually weak[27]

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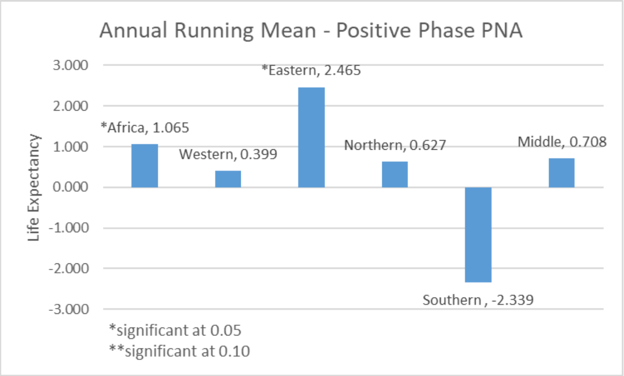
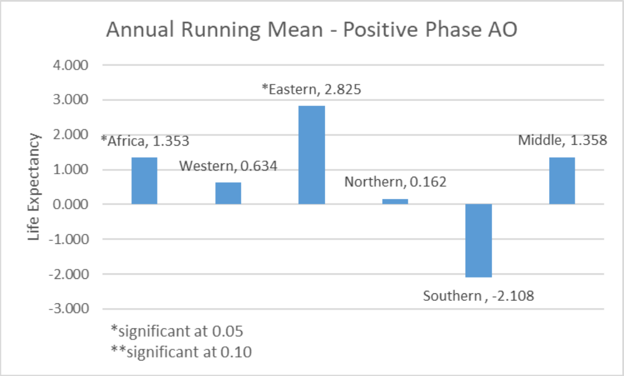
[27] Mchugh, Maurice J., and Jeffrey C. Rogers. "North Atlantic Oscillation Influence on Precipitation Variability around the Southeast African Convergence Zone." *Journal of Climate*, 14, no. 17 (2001): 3641

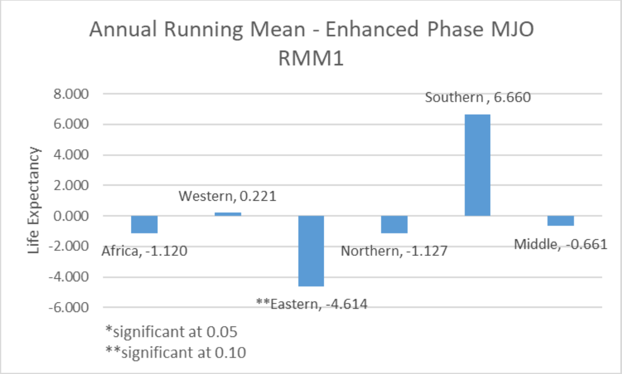
This suggests that positive phase NAO should impact both Eastern and Southern Africa in generally the same ways, creating drier conditions and resulting in decreased life expectancy. However, the results show opposing effects in the two sub-regions, with average annual NAO having a -7.03 year impact on Eastern Africa and 9.5 year impact on Southern Africa. This outcome is difficult to rectify, though the missing data points present in almost all regressions performed may provide some explanation.

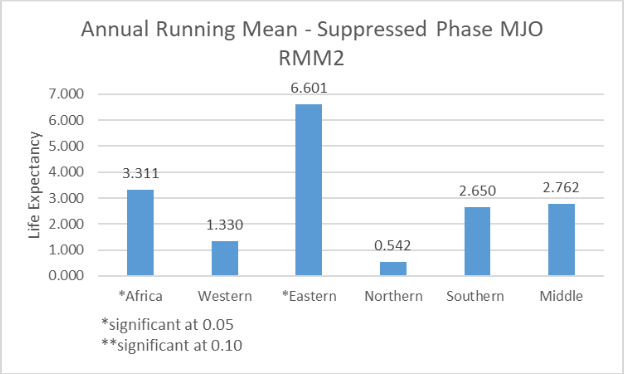
The lack of any significant impact from ENSO on life expectancy was somewhat surprising at first, considering the correlation that has been documented between ENSO and precipitation in Africa. However, some research has indicated that "climate change over Africa is likely not predominantly a result of variations in the El Niño–Southern Oscillation (a teleconnection that has been previously shown to affect climate in some parts of Africa)"[28], which may explain the lack of significance.





Average annual positive phase PNA having a significantly positive effect on African life expectancy (1.07 years) can be explained by the cooler temperature anomalies that are pushed eastward during this phase of the oscillation by the patterns occurring over the eastern United States. That the AO also had a significant effect (1.35 years is also likely due to the increased strength of the North Atlantic Current during a positive phase AO cycle.





It was expected that the RMM indices would have greater significance on Africa and its sub-regions, considering MJO's travel path. During the enhanced phase of the MJO, there is a

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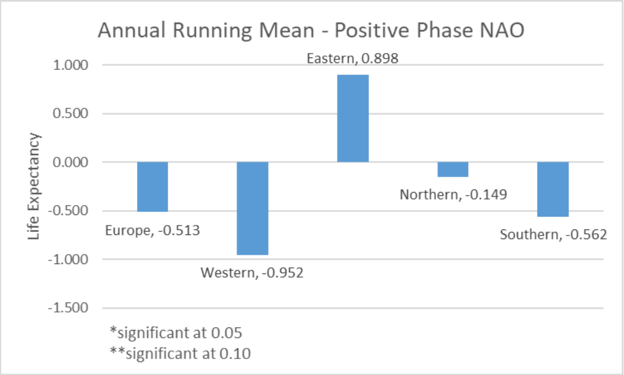
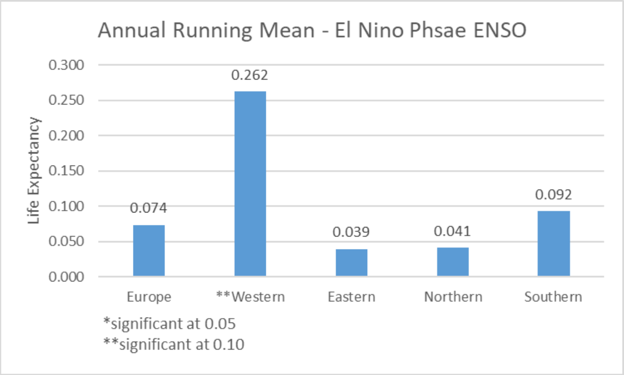
[28] Collins, Jennifer M. "Temperature Variability over Africa." *Journal of Climate*, 24, no. 14 (2011): 3649

significant impact on life expectancy in the east African sub-region (-4.6 years). Likewise, during the suppressed phase of the MJO Eastern Africa, and Africa as a whole, experience significant upticks in life expectancy of 6.6 years sub-regionally and 3.3 years regionally. The impact on Eastern Africa is in line with what was expected, given MJO’s travel path through eastern Africa towards the western hemisphere.

<u>Europe</u>

The European sub-regional relationship with some these indices is well documented, which made it easier to interpret results. However, there was a surprising lack of significance across most indices used in the analysis, likely due to gaps in data and low counts of observations.





The results for the NAO index were not particularly surprising in their lack of significance, as research has already shown the difficulty in proving a direct correlation between health outcomes and the NAO in Europe. Theoretically speaking, positive phase NAO should result in negative health outcomes in the northeast and positive (less negative) health outcomes in southern Europe, and vice versa during negative phase NAO. This is not necessarily the pattern reflected in the regression results. While western Europe faces a much greater negative impact (-0.95 years) in life expectancy than southern Europe (-0.56 years), it appears as though northern Europe is experiencing a much smaller drop in life expectancy (-0.15 years) than southern Europe. The basic relationship should indicate northern and western Europe doing worse than southern Europe in this regard during a positive NAO phase, however given the lack of significance there are likely other factors at play here.

There should have been more than a slight significant effect of ENSO on Western Europe of a 0.26 year increase in life expectancy, given the documented effect of ENSO on European precipitation, “significant ENSO-associated changes in precipitation are evident during the boreal spring and fall seasons, marginal during boreal summer, and absent during boreal winter.”[29] This however can be explained by the missing data points in world bank data producing insignificant results.

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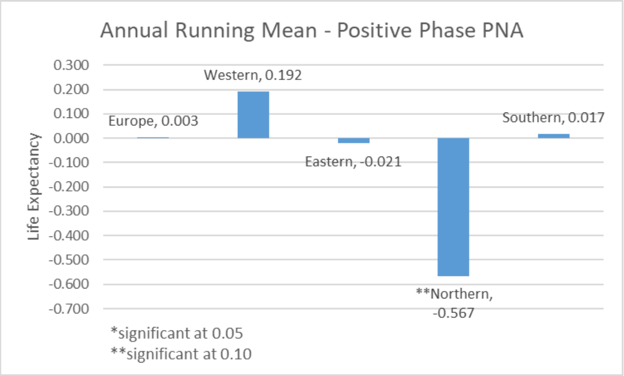
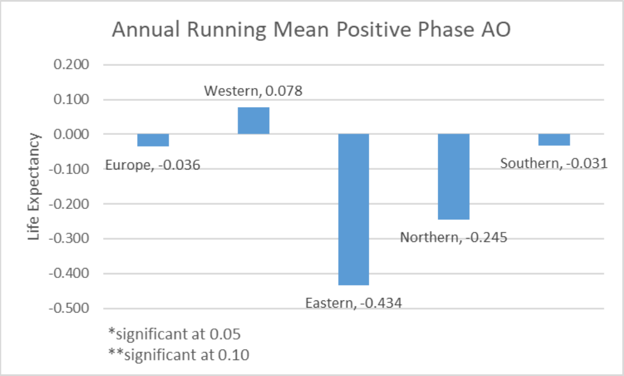
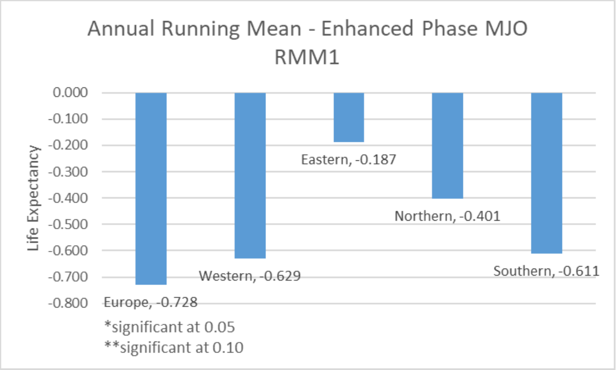
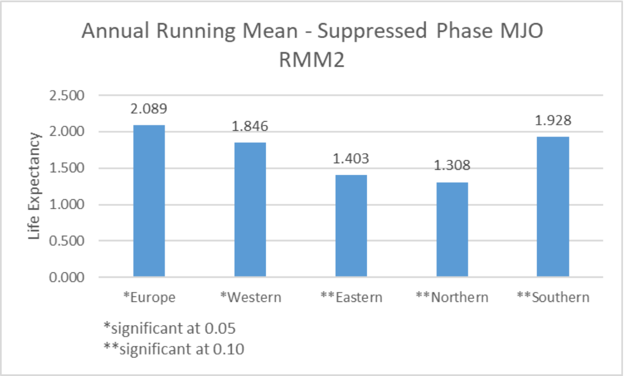
[29] Shaman, Jeffrey, "The Seasonal Effects of ENSO on European Precipitation: Observational Analysis," *Journal of Climate,* 27, no. 17 (2014): 6423





The results for the PNA and AO also suffered from the problem of significance. PNA had little significant impact over Europe, considering its centralization over Canada and the United States. The slight significance in Northern Europe may be explained by the interaction of the PNA with the Arctic region, however this brings up another problem. The AO variability had no significant impact on Europe, not even on Northern Europe where some significant impact was expected. Regardless of its phase, AO should result in cooler temperatures and precipitation in Northern Europe due to its proximity to the arctic, but again the missing data points have produced unreliable results, making it difficult to observe the actual impact.

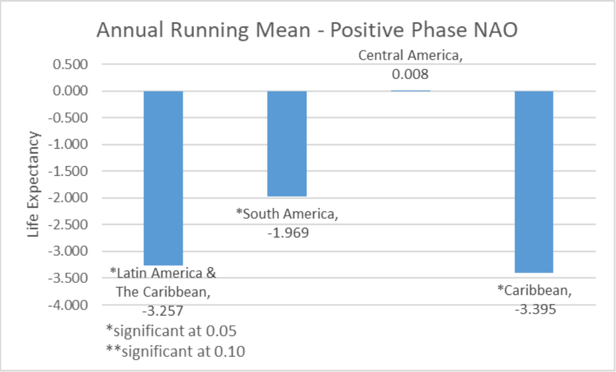


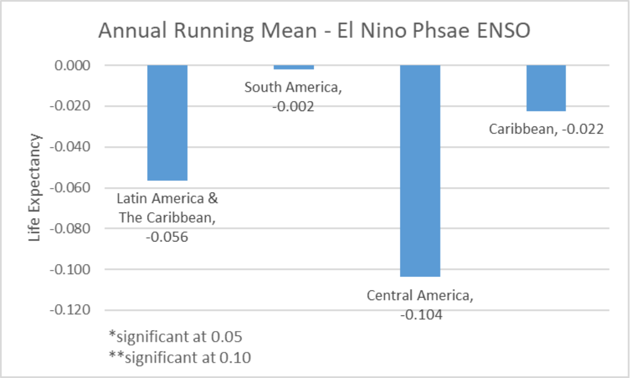


It is unsurprising that RMM2, which reflects the behavior of MJO in the western hemisphere, had a significant impact on parts of Europe. What is surprising however, is the degree to which it significantly impacted all of Europe, considering its regional impact being centralized in the tropics. Still, the results indicate that average annual suppressed phase MJO variability as measured by RMM2 has the effect of increasing life expectancy by 2.09 years across the board in Europe.

Latin America & The Caribbean

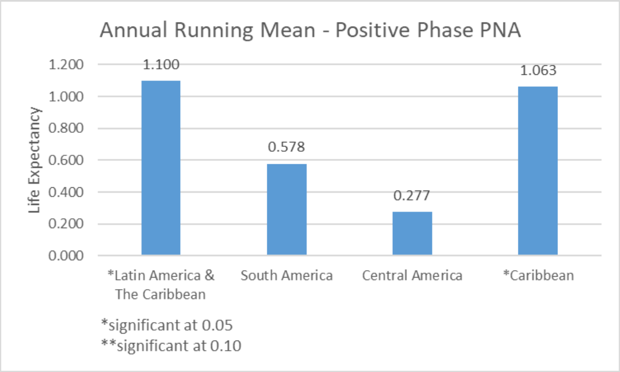
Latin America and the Caribbean generally produced highly significant results for all index measurments, baring annual average el nino phase ENSO.

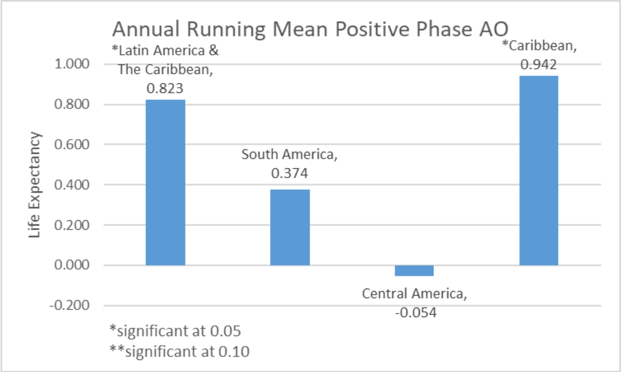




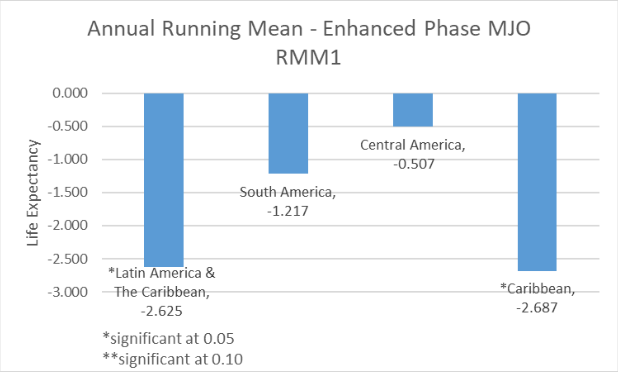
Average annual positive phase NAO index resulted in an expected decreased life expectancy in Latin America and the Caribbean as a greater region (-3.26) and in the sub-regions of South America (-1.97) and the Caribbean (-3.4). It is unsurprising that most of this decreased life expectancy was led by drops in the Caribbean especially, given NAO's direct path through the southeastern United States. Somewhat surprising was the lack of any significant impact on Central America, though given NAO's westward tilt this makes sense.

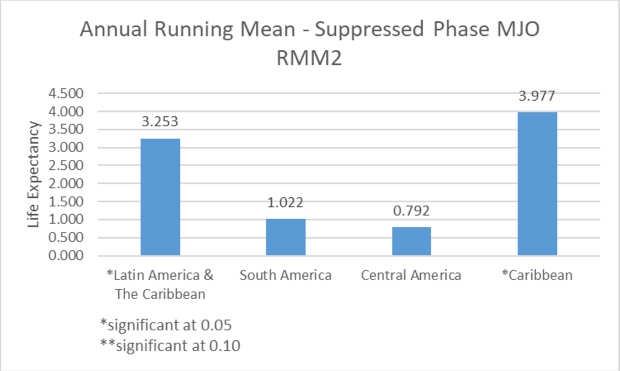
The lack of any significant results from ENSO is somewhat baffling, given ENSO's direct relationship with South America and the name 'El Nino' having been given to it by the South American fishermen who noted this pattern. We likely suspect some lack of complete data or an error in the regression model.





The positive phase of the PNA, in which there are below average temperatures pushed through the southeastern United States, resulted in a significantly increased life expectancy for Latin America and the Caribbean (1.1 years), likely due to reduced temperatures in the tropical regions. The AO produced similar results for likely the same reasons, a significant increase of 0.82 years in the region.

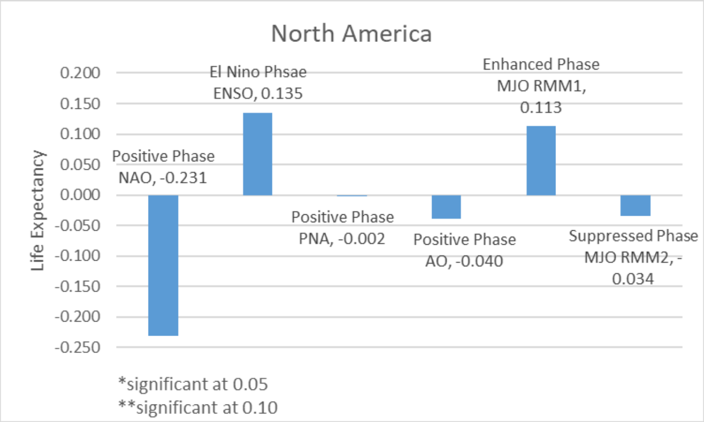




Enhanced phase MJO produced the expected significant drop in life expectancy in Latin America and the Caribbean at -2.63 years and the expected significant increase in life expectancy at 3.25 years. This is unsurprising given MJO's natural path and the logical result of increase precipitation and weather variability along the coasts of Latin America and the Caribbean isles.

North America

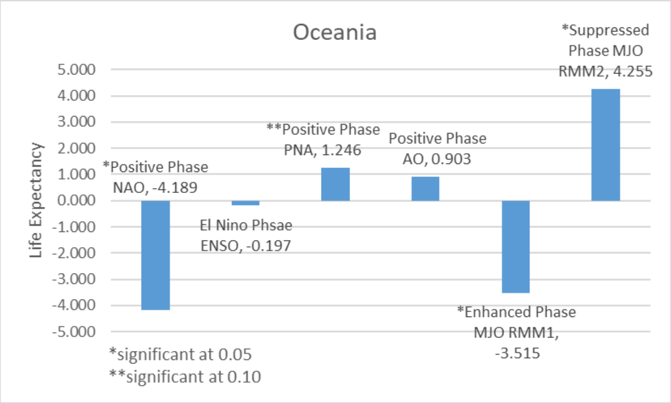
Northern America was unique amongst the UN statistically designated regions in that it contains no sub-regions, as such the results for each of the indices were combined into a single graph.



Results in North America were insignificant and unreliable, especially in the context of a time-lagged variable like life-expectancy. The region designated by the UN statistical commission contains 5 countries, 3 of which were dropped in regression analysis leaving only the United States and Canada. Studying these countries in isolation or as a group together would likely have produced significant results, however they were difficult to analyze in the context of the greater region.

Oceania

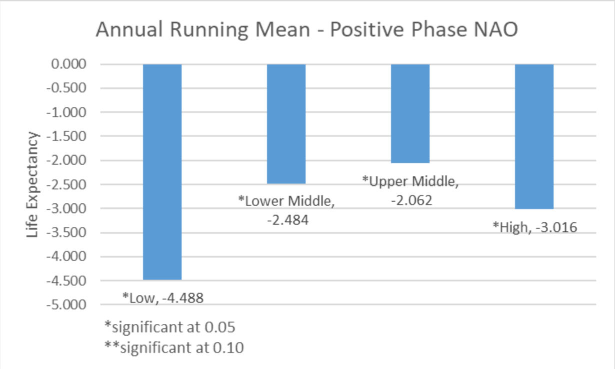
Oceania as a region suffers from a severe lack of data (something we will address later) which resulted in most of the sub-regions having unreliable results. As such, only Oceania as a greater region will be addressed.

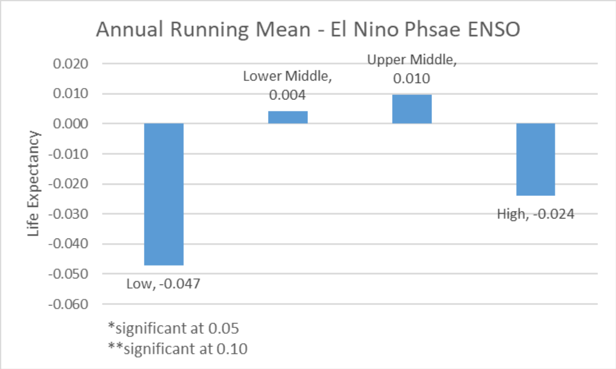


Annual average suppressed phase MJO produced significant results in both RMM1 and RMM2 towards education index values, with approximately inverse results (-3.52 and 4.255 years respectively), depending on the spatial trend of MJO variability. NAO also produced significant results, with annual average positive phase resulting in -0.05 drop in education index values. Again, while seemingly strange, the effect of NAO on Oceania can be somewhat analogous to its impact on Eastern Asia, with a greater observed time-lag. Surprisingly, PNA produced significant results (1.25 year increase) while ENSO did not, however this is likely due to the severe lack of data in this region producing highly unreliable results

Income

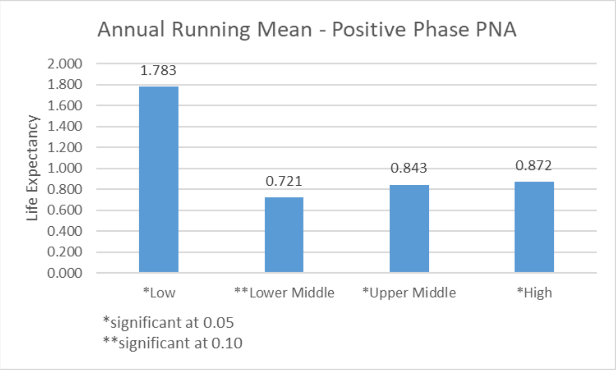
Annual average climate index variability produced highly significant results across all levels of income. This was true for every measure covered in the regression analysis save for ENSO. Results under this category are highly generalized as income groups do not necessary correlate with geographical location. Given that the same phase of a climate measure can impact two different regions in two different ways, analysis on the basis of income was conducted to gain a better understanding of how levels of income can mitigate the exogenous effects of climate.

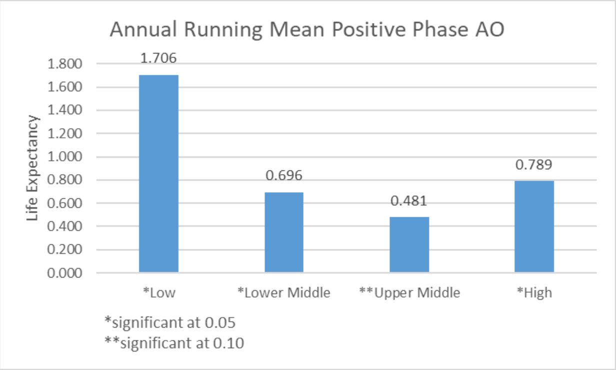




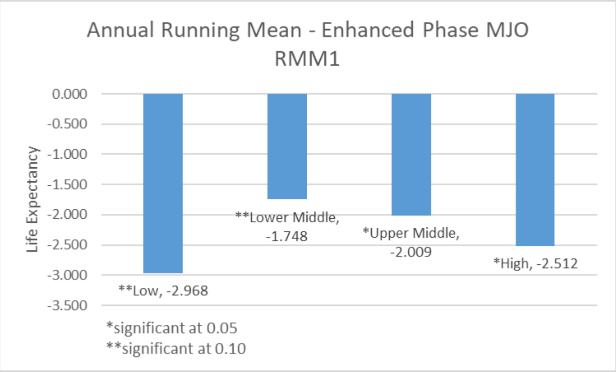
Impacts of positive phase NAO were significant at the highest level in all income groups. The overwhelming result was a negative effect of average annual positive phase NAO on life expectancy, with the low-income group facing the largest drop at -4.49 years. What was surprising was that high-income countries experience a higher drop (-3.02 years) than those of lower-middle and upper-middle countries, even though one would expect them to experience less severe results due to their endowment. This however is likely a result of the country makeup of these groupings. For example, the upper-middle income group contains a number of countries from southeast Asia and Oceania, two areas which had a high degree of missing data.

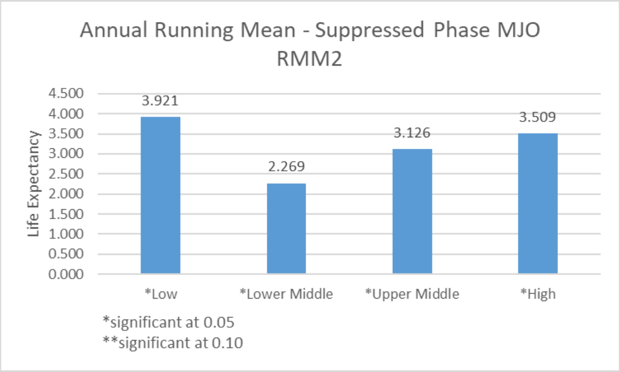
ENSO had no significant impact on any of the income groups, which could be attributed to a byproduct of the varied geographical location of the countries included in these groups, along with the already mentioned missing data, that makes any result unlikely to carry any significance.





Both PNA and AO had highly significant results at all levels of income, resulting in increased life expectancy across the board with an annual average positive phase. Low income countries, which are predominately from the middle Africa sub-region saw a highly significant increase in life expectancy (1.78 years) due to positive phase PNA activity, whereas other income groups saw significant, but modest, increases in life expectancy. The increases in life expectancy during positive phase AO were unsurprising, given that the polar vortex traps cold front movements from the arctic and allows the North Atlantic current at trade winds to increase in strength and push eastward. Low income countries again saw a highly significant increase in life expectancy of around 1.7 years.



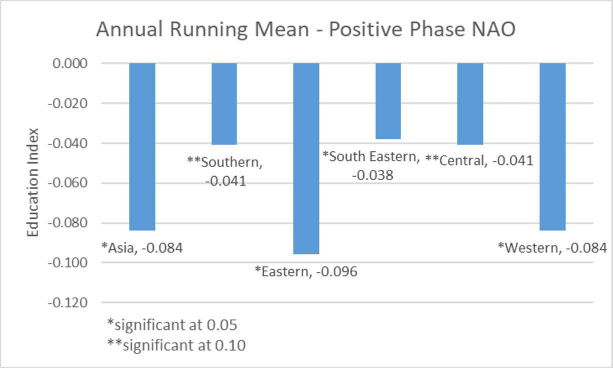


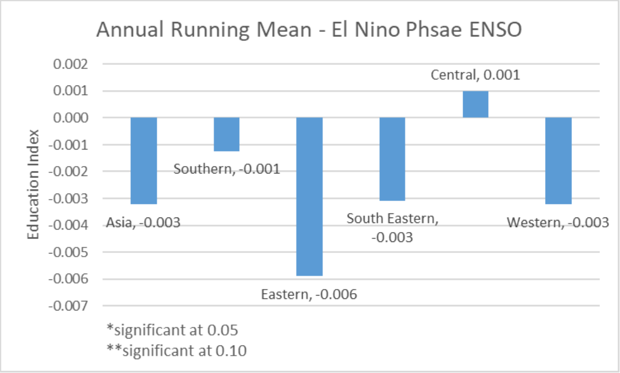
The impact of the MJO variability was expected to be of greater magnitude in the low income and lower-middle income groups as a result of their geographical concentration around the tropics where the MJO cycles through. This was reflected in the significant impact on the Low income group of about -2.97 years (RMM1) to +3.9 years (RMM2), but somehow the impact was felt greater in the upper-middle and high income groups relative to the lower-middle group. This was somewhat surprising as, though the upper-middle income group consists of many Latin American countries that are especially vulnerable to MJO variability, it was expected that noise from countries like Russia and Kazakhstan, that are also included in this group, would obfuscate the results. As for why the lower-income group was impacted relatively less, it is likely due to the fact that there were significant gaps in data in the Lower-middle income group, which consists of many countries from Oceania.

6.12 Education Index

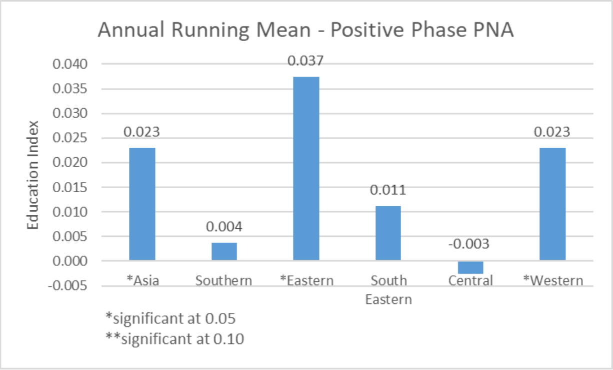
Asia

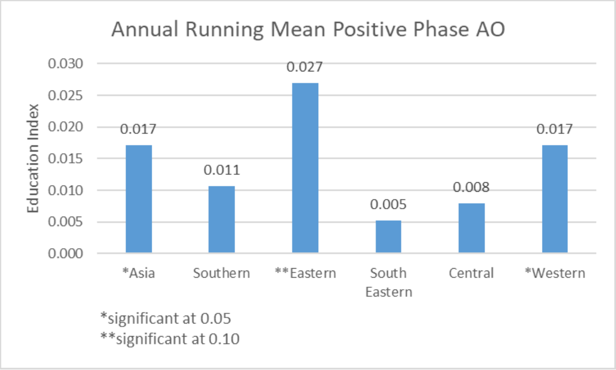
Similarly to those of life expectancy, the results for immediate impacts on the education index again indicate that across the region of Asia as a whole, positive climate index values have a highly significant impact across all indices, excluding ENSO.



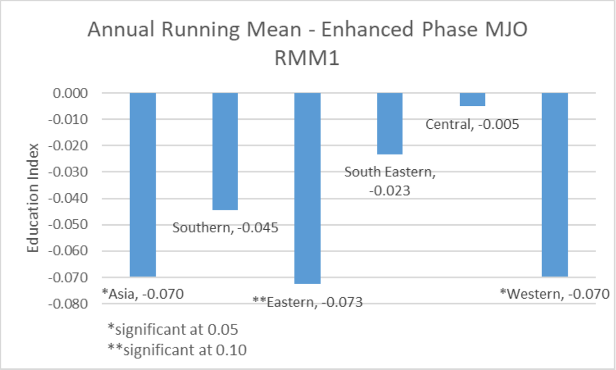


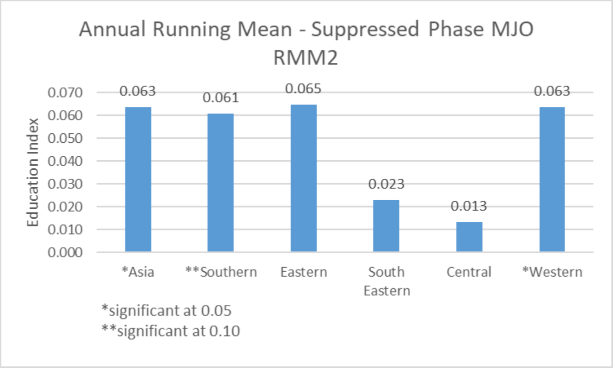
Again, the results for annual average of positive phase NAO were highly significant across all sub-regions of Asia, with an overall -0.084 impact on the education index. An annual average positive phase NAO was particularly impactful in the western most and eastern most regions of Asia on educational outcomes, with a -0.096 effect in Eastern Asia and a -0.084 effect in Western Asia. This is in line with research that emphasizes NAO's significant effect in Eastern Asia but is somewhat strange with regards to the well documented pattern of positive phase NAO directing precipitation more towards the northeast, with negative phase NAO pushing more towards the sub-region of Western Asia. Again, results for the ENSO index were insignificant and showed a much more negligible impact on life expectancy, which is understandable given its regional pattern most affecting the western United States and Oceania.





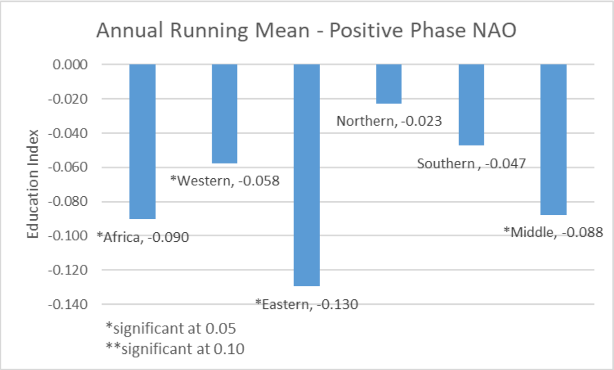
Results for AO and PNA were more muted than those of NAO, though not insignificant and not to be overlooked. An annual average of positive phase PNA has a 0.023 increase in education index values, with Eastern Asia particularly reaping the benefits of this climate pattern at a 0.037 increase. Similarly, with the AO, a less impactful 0.017 increase in education index values can be observed.

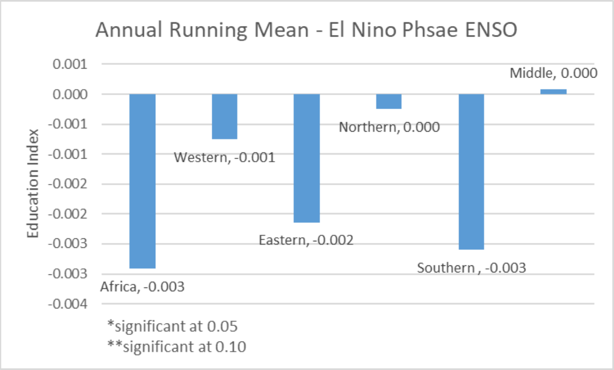




MJO variability is a bit more important to consider with regards to educational outcomes, as the varied precipitation patterns produced by MJO events can have an immediate effect on classroom attendance and crop production. Again however, it is a bit more difficult to interpret at the annual scale. Regardless, on average when the MJO is in its enhanced phase, its impact in Asia from the average annual measured variability of its presence in the Indian Ocean, results in a -0.07 drop in education index values, whereas the variability of is presence in the Western Hemisphere under the suppressed phase produces a 0.063 increase in the education index. For the same reasons listed under life expectancy, it is difficult to extract the overall impact on the macro-scale given the almost equal observed inverse effect of RMM1 and RMM2 measurements on this development indicator. The average annual patterns indicate that their impacts may counteract each other, however this is dependent on what parts of the [school] year the events take place.

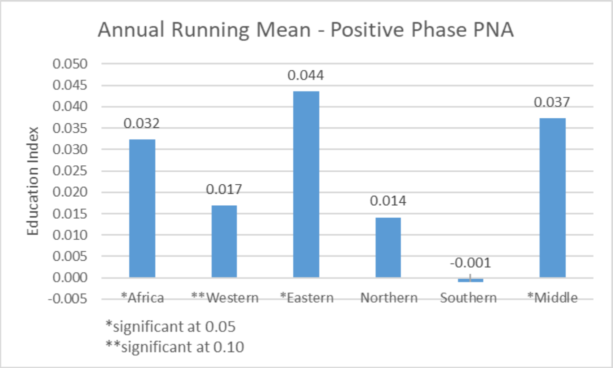
Africa

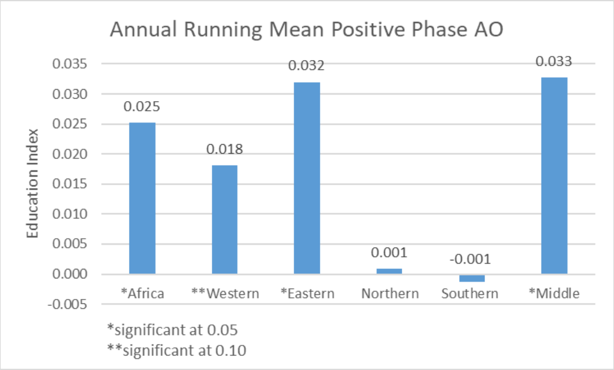




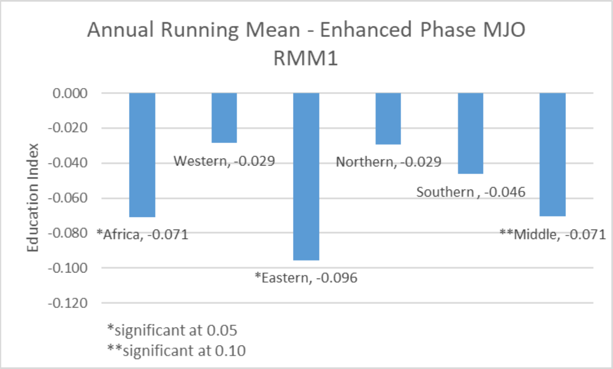
With regards to education index outcomes, NAO impacts were more in line with observed patterns. The drier conditions resulting from annual average positive phase NAO in Africa and its sub-regions have the effect of significantly decreasing education index values across Africa, with eastern Africa facing a particularly sharp decrease of -0.13. Other regions also faced sever drops with middle Africa falling -0.088 and western Africa falling -0.058 in education index values.

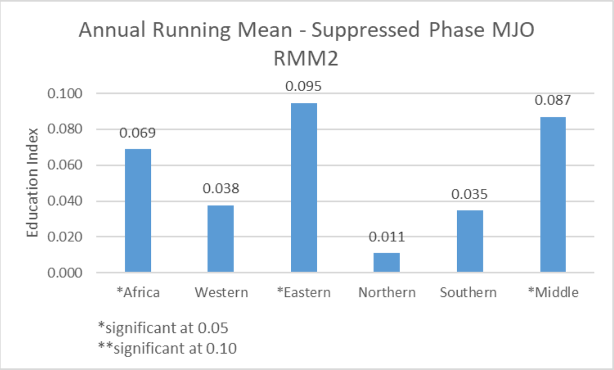
Again, the lack of any significant impact from ENSO on educational impact was somewhat surprising at first, but research that indicates a downplayed relationship between ENSO and African climate can somewhat explain the results.





Again, average annual positive phase PNA having a significantly positive effect on African education index values (0.032) can be explained by the cooler temperature anomalies that are pushed eastward during this phase of the oscillation by the patterns occurring over the eastern United States. The AO's significant effect of 0.025 can again be explained by the increased strength of the North Atlantic Current during a positive phase AO cycle.

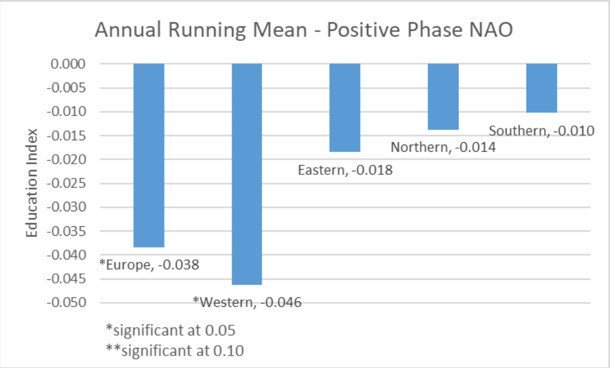


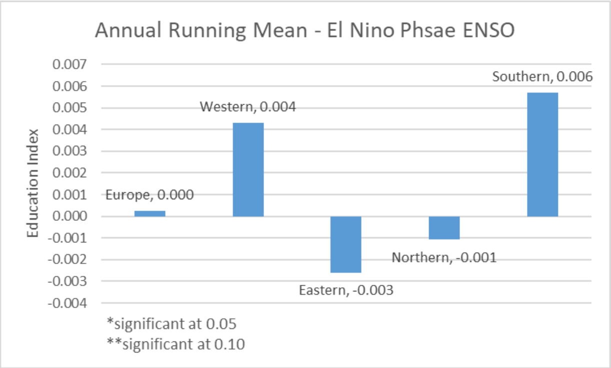


As expected, annual average suppressed phase RMM1 and RMM2 MJO both produced significant impacts in Africa and its sub-regions. The enhanced phase MJO RMM1 measurements resulting in an overall -0.07 drop for Africa as a whole and a -0.096 drop for eastern Africa. Education index values saw an increase as a result of suppressed phase RMM2 measured MJO, with approximately inverse results from RMM1.

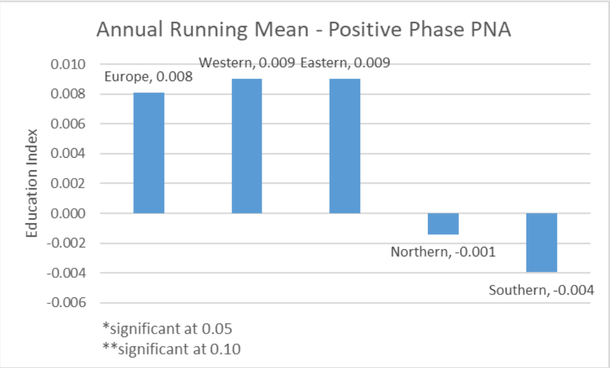
Europe

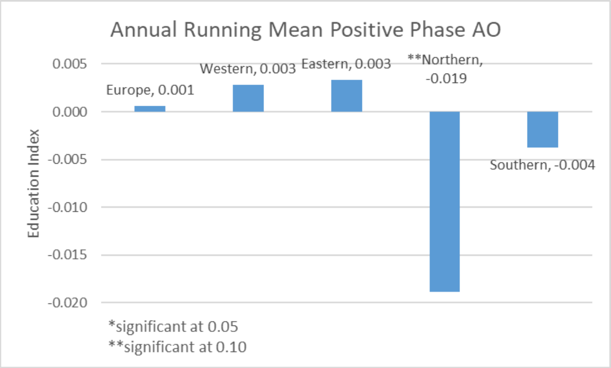
Significance was somewhat less of an issue when regression on the Education Index, considering some of the immediate impacts that can occur on educational outcomes from climate patterns when compared to health outcomes that can sometimes lag.



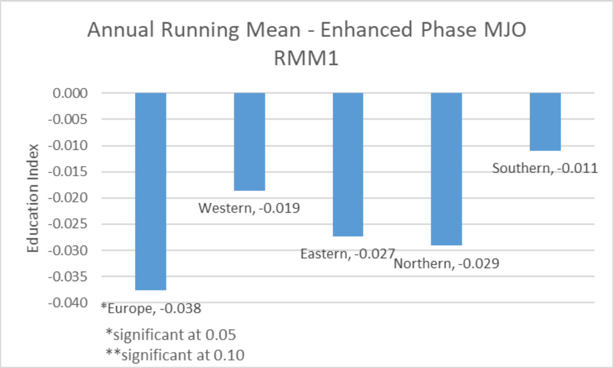


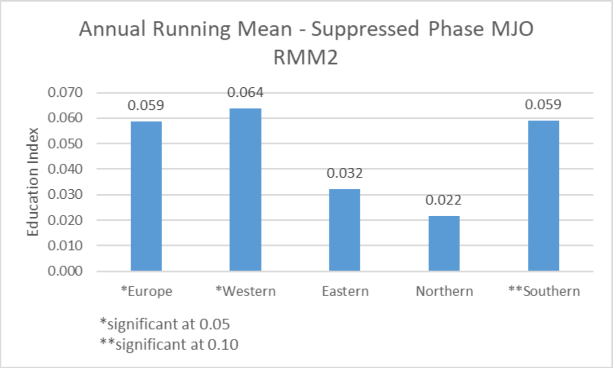
This regression set produced significant results with regards to the NAO. Europe as a whole and particularly western Europe, face an unsurprising -0.038 and -0.046 drop in education index values respectively. This again can be attributed to positive phase NAO patterns being more targeted towards western Europe. While the other sub-regions were not significant, their values reflect the basic relationship expected of positive phase NAO. There is again a strange lack of significance in the results for ENSO, especially given it reflects El Nino phase, but the missing data points continue to produce somewhat unreliable results.





The insignificant results from PNA index variability is unsurprising for the reasons listed prior, however interestingly enough there is a slight significance in Northern Europe due to AO variability. There is a -0.019 drop in education index values as a results of annual average positive phase AO. The significance here versus the lack thereof under life expectancy regression can be attributed to the immediate effect seen in educational outcomes (i.e. classroom attendance) versus the more time-lagged health outcomes.

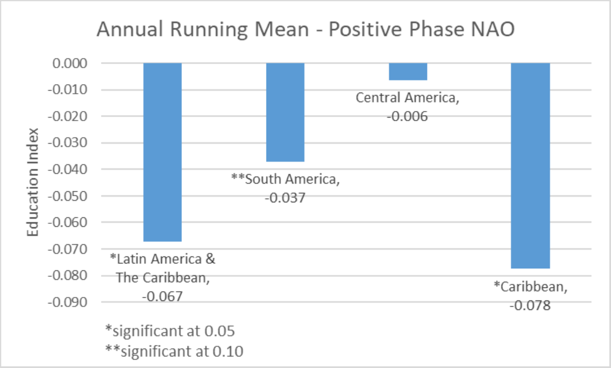


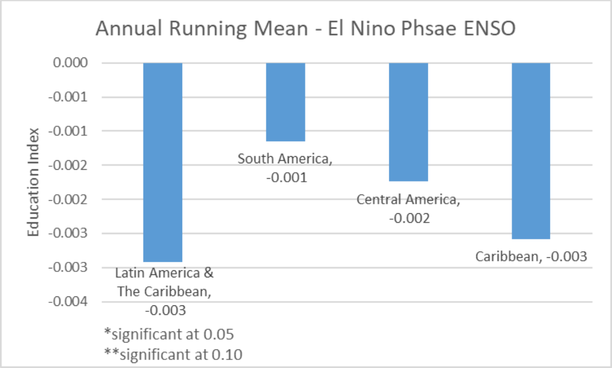


Education index regressions produce another set of significant results due to RMM2 across Europe, but with significance in Europe as a greater region due to RMM1 as well. Suppressed phase RMM2 results in significant increases in education index values, around 0.05 across Europe, likely due to the decreased precipitation and weather variability during this phase. Enhanced phase RMM1, wherein increased precipitation and weather variability takes place, impacts Europe as a whole by -0.038.

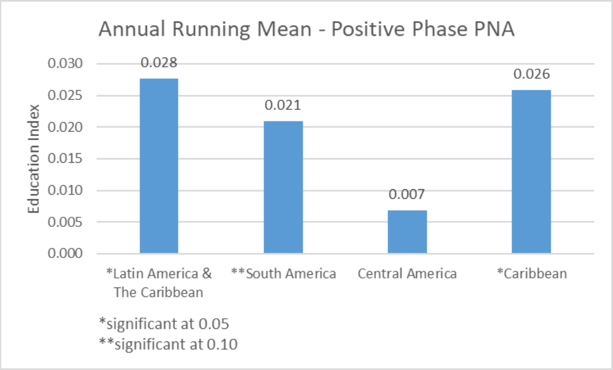
Latin America & The Caribbean

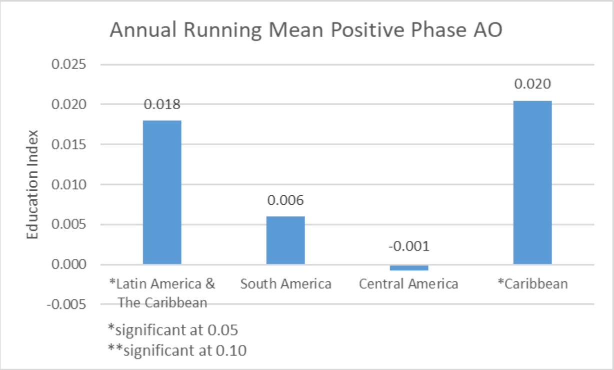
Latin America and the Caribbean again produced highly significant results for all index measurments, with the same confusing lack of significance from ENSO.



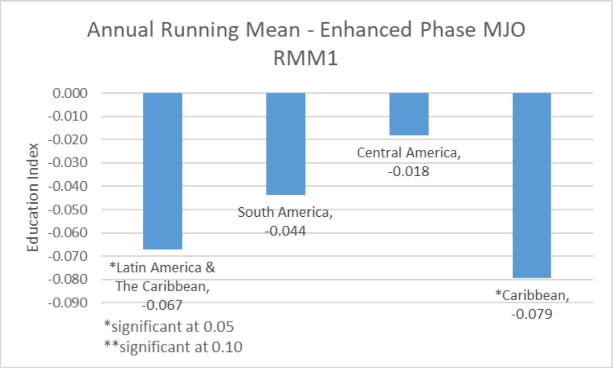


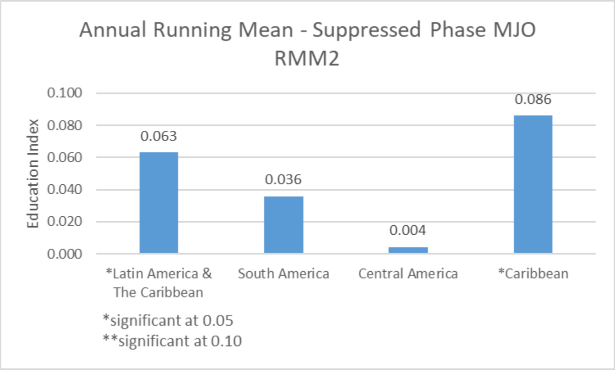
A significant decrease in education index values across Latin America and the Caribbean (-0.067) was the result of average annual positive phase NAO index. Most of the drop in educational outcomes was led by the Caribbean, wherein the weather variability of the NAO can be more strongly felt amongst the island nations in direct path of its pattern. Again, there was still a lack of significance from ENSO, making it highly possible that there was a problem with the data gaps or model with regards to regression analysis of this index.





A significant increase in education index values for Latin America and the Caribbean (0.028 for PNA, 0.018 for AO), was again likely due to reduced temperatures in the tropical regions due to these climate index patterns.

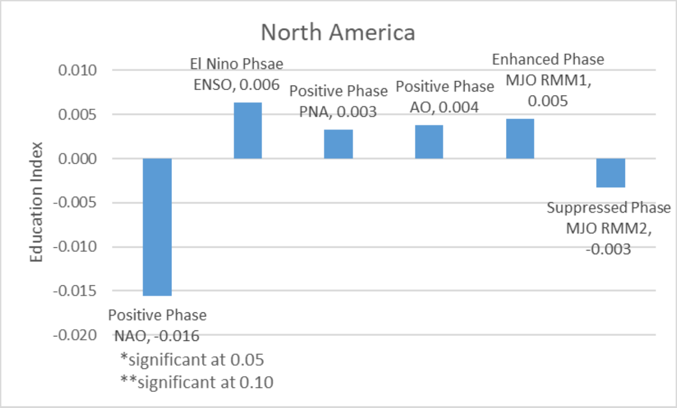




MJO behaved as expected, producing a significant drop in education index values for the entire region during the enhanced rainfall phase (-0.067) and significant increase in education index values during the suppressed rainfall phase (0.063).

<u>North America</u>

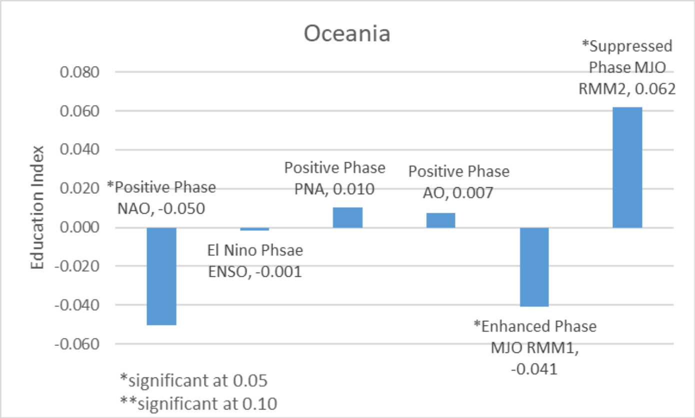
As mentioned above, North America's results were combined into a single graph due to the lack of designated sub-regions.



Again, the same problems encountered under life expectancy regressions for North America were encountered in the education index regressions.

Oceania

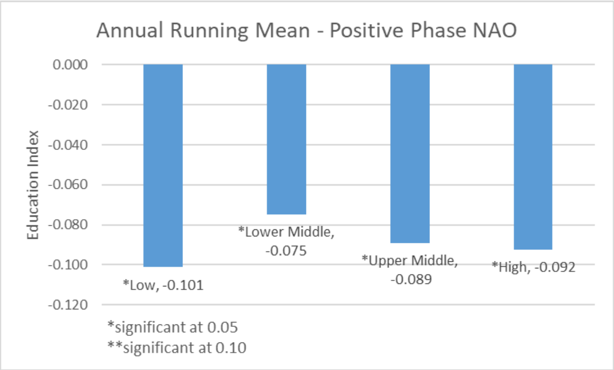
As mentioned above, Oceania's sub-regions were dropped in favor of analyzing the region as a whole due to the lack of data points, as such the results were combined into a single graph.

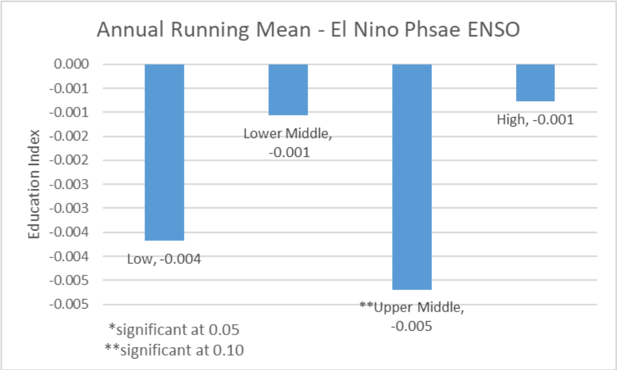


As expected, MJO produced significant results in both RMM1 and RMM2 towards education index values, with approximately inverse results (-0.04 and 0.06 respectively), depending on the spatial trend of MJO variability. NAO also produced significant results, with annual average positive phase resulting in -0.05 drop in education index values. There was again a surprising lack of significant results for ENSO, but the lack of data has produced unreliable results for the region.

Income

Annual average climate index variability again produced highly significant results across all levels of income, this time with ENSO included at the upper-middle level of income.

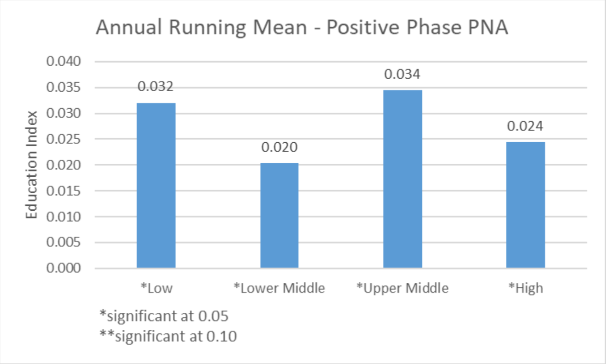


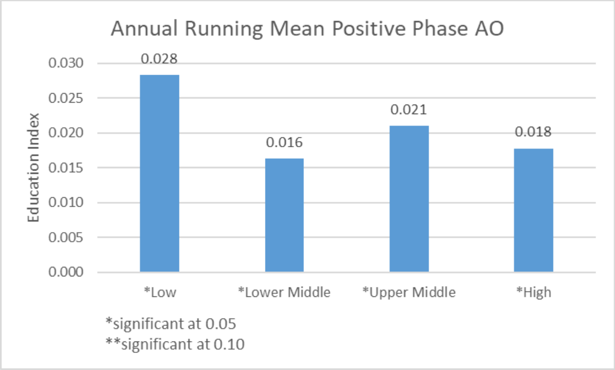


Impacts of positive phase NAO were again significant at the highest level in all income group. The effect of average annual positive phase NAO on continues to be negative, with a more even distribution of shocks across education index levels. Surprisingly, both Low income and high income country groups face nearly the same level of decrease in education index values (around

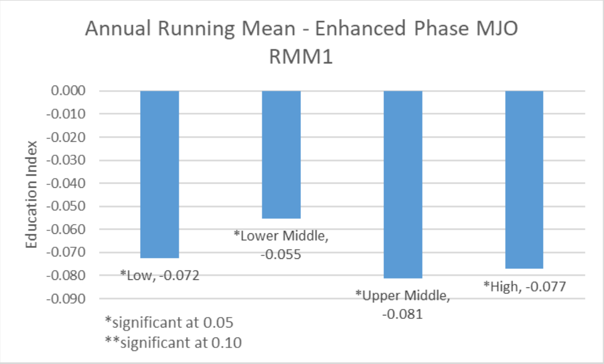
-0.095), indicating that perhaps positive phase NAO is impacting education index values of these two groups in the same ways regardless of income. This is interesting considering the relative geographic location of these groupings, with the high-income group being more spread across the map and the low-income group being more centralized. There is no doubt more at play here, but on the surface, it appears that there is significant correlation between the NAO and education index values at around the same level across the board.

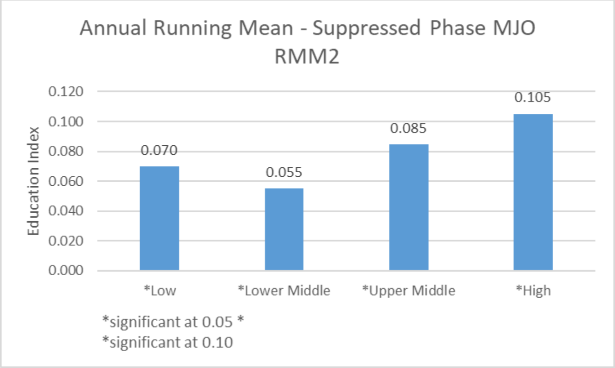
With regards to the ENSO index, there was a slight significant effect on the upper-middle income group of -0.005, however this group being composed of countries ranging from tundra to tropical geographical climates may have produced unreliable results.





Again, both PNA and AO had highly significant results at all levels of income, resulting in increased education index values across all income groups. What was surprising here was that the magnitude of average annual positive phase PNA was somewhat greater than that of AO, which was somewhat unexpected considering the larger coverage area of the AO relative to the PNA. Low income and upper-middle income groups were those most heavily impacted at around -0.03 from the PNA and -0.02 from the AO.





The same expected results were produced in the education index regressions, with significant impacts on low, lower-middle, and upper-middle income groups. However, the same problem of magnitude with the lower-middle income group from the life expectancy regressions carried through to the education index results, again likely due to data gaps. Surprisingly, education index values faced a particularly significant drop (-0.078) during enhanced phase MJO and highly significant increase (0.105) during suppressed phase MJO for high income countries that was of greater magnitude than low and lower-middle income countries. Evidently, baring all other factors, income alone is not a sufficient barrier to the impacts of precipitation and weather variability on educational outcomes in country groups.

6.2 Problems

The biggest problem encountered in performing this research was the abysmal lack of data in some instances. Data sets from the World Bank were riddled with holes across a whole swathe of countries and territories, including data on those countries designated as upper-middle and high income. The initial decision to only utilize UN recognized countries in the regression model fell by the wayside as it became apparent that data was collected in a seemingly random pattern across differing countries and territories, necessitating the expansion of the data set to include dependent territories as well. This however created an additional problem of missing data from the Human Development Reports as well, which carry data from very few, if any, territories. Although the problem was still present in data on Africa, Europe, and Asia, there were enough data points present to present a clear picture. When it came to North America however, the missing data resulted in the region being reduced to just the United States and Canada. A similar problem occurred in Oceania, to the point where it became necessary to drop the sub-regions and simply regress the area as a whole. This is due to the missing data on the smaller territories and countries, particularly island nations. This creates a bias in of itself in the data, as those islands are generally more vulnerable to variations in climate patterns than countries and territories that are more inland.

A problem mentioned above was the difficulty in relating the interaction between the various climate patterns within the regression analysis, however the interactions that are most significant, namely AO*NAO and ENSO*PNA, were able to be utilized.

One of the most significant problems encountered was in interpretation of the results, simply as product of the nature of the research. In order to relate world bank, UN, and Human Development Report data, which is generally only recorded annually, to climate data, which is collected daily and seasonally, it became necessary to derive an annual mean of the climate data. This resulted in greatly simplified climate variables, which are in constant fluctuation, to single values that are not necessarily representative of the pattern, but rather average out the generally behavior of the pattern throughout a given year. As such the regression results do not relate economic variables to climate index values, but rather to the running average of those index values. Furthermore, the way this analysis was conducted produced in the results an assumption that positive and negative values of these indices are simple inverses of each other, which is not really the case and again, greatly simplifies the behavior of climate patterns. This problem could have been avoided, or at least lessened, if there was an availability of monthly or even seasonally recorded HDI and World Bank data, which would have allowed for a better representation of index values in the analysis. However, considering the gaps in data sets as it is, it is difficult to lay expectations on either of these organizations to collect data on this scale.

7. Conclusions and Implications

The biggest assumption generally made in economic research into the environment is the idea of immediate impact, with no real time lag accounted for. This is an issue that has been considered and is still being considered across climatological research, with the question not simply remaining at ‘what are the effects that the environment or climate has on developmental factors and vice versa' but also stepping back and considering 'what is the time lag for the impacts of these factors.' Coondoo and Soumyananda said it best in their discussion of the use of the Environmental Kuznets Curve in economic research into the environment:

> The above discussion, however, is inadequate on at least two counts. First, it takes a partial view of the effect of emission/environment either from the point of view of consumption or from the point of view of production/income generation. Such a partial view is over-simplistic because, as is well recognized, a priori emission or environment may affect both consumers' welfare (as a non-excludable public good) and income generation (by virtue of being a virtual input to the income generation process). More importantly, it presumes immediacy in the causal relationship (i.e. as if a change in one of the variables would instantaneously cause the other to change), and hence does not clearly bring out the dynamic process of changes that is so crucial in the EKC relationship.[30]

The difficulty in answering this question is evident, with the variability across timescales, indices, regions, countries, and even within countries making it extremely difficult to narrow down a time-lag effect that accurately describes global impacts. Introducing any time-lag on the macro-scale has inherent bias as impacts can be observed in one region well before they are observed in another, leaving any estimation of the time-effects prone to error. For this reason, this study made a similar assumption as others, proceeding with regression analysis under the impression of zero time-lag. As such, the results of this research are not necessarily accurately describing the impacts of climate variability on human development factors. This became clear during the regression analysis, as climate indices and agricultural indices returned results that were either insignificant, slight in their impacts, or generally difficult to explain. This paper sought to take a step towards describing development indicators in terms of climate variability over static measurements of environmental factors, in order to introduce the very real difference in environment and climate that economic research has generally overlooked. The research however needs to step back from estimating impacts and move towards determining regional, sub-regional, and country specific time-lags before any impacts can accurately be determined. Introduction of a running mean of index values moving on specified lag periods would provide more accurate results in estimating climatological or even environmental impacts. Utilizing a band of a specific time frame of developmental data, picking a point from which to begin analysis of climatological effects, and then slowly increasing the time-scale within which the impacts of climate index values on that band of developmental data are analyzed would begin to reveal a picture of what the time-lag is that one can expect. This is where future research needs to be targeted. With the effects of climate change worsening and beginning to directly affect human development in a number of countries, it is now more important than ever to determine what the time lag of these effects are in order to develop adaptation plans that consider accurate timelines of impacts.

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[30] Coondoo, Dipankor, and Soumyananda Dinda, "Causality between Income and Emission: A Country Group-specific Econometric Analysis." *Ecological Economics,* 40, no. 3 (2002): 354

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