

# Opportunities for Climate Change Water Stress in Egypt's Breadbasket

Regional Climate Variability & Change, EESC 4403

Gina Stovall, Spring 2014

Egypt's Nile delta is considered the "breadbasket" of the country. Agriculture produced in the region accounts for over 65% of the country's total production, but relies primarily on the river not rain [8]. The delta discharges on the northern coast of Egypt into the Mediterranean Sea and is located between 35°00' E & 28°00' W and 32°00' N & 22°00' S'. The region underwent rapid urbanization in the past decades, and the population is expected to grow to 123 million people (from approximately 80 million currently) by 2050 [8]. Population expansion of this scale will increase water resource requirements. Additionally, as Egypt continues to develop per capita water use will most likely increase.

The waters of the Nile are highly important to the economy and social welfare of Egypt. But water rights to this river have long been contested. Currently Egypt and Ethiopia are disputing the construction of downstream dams that will likely reduce the volume of water reaching Egypt's banks [10]. As an overall arid nation, the climatology of the delta region affords between 100-200 mm of precipitation annually; insufficient amounts to support the food supply demands among other demands of a growing population. Migration to coastal areas due to climate change impacts inland has been proposed, which would further increase burdens on water supply [5]. The impacts and uncertainties of climate change are threatening this minimal precipitation and other sources of water for the region [5]. The delta is experiencing multiple physical coastal risks that are being exacerbated by a changing climate: sea level rise (SLR), saltwater intrusion of groundwater aquifers, land subsidence, and coastal erosion further exacerbated by the construction of the Aswan Dam. The political climate, physical environmental threats, and social issues including urbanization, poverty, and stunted development weave a complex issue for the Egypt's breadbasket.

In this report, the climatological precipitation patterns are examined in hopes to identify hydrological adaptation opportunities that will reduce the reliance on the River Nile waters, and alleviating current and impending water stress in the wake of climate change and urbanization.

## CLIMATOLOGY + CHANGE

Egypt maintains an arid to semi arid climate; the mouth of the Nile River enjoys a Mediterranean climate north of the Sahara Desert. Seasonal climate includes long dry summers and short temperate winters [11]. The Nile Delta experiences the most precipitation during northern hemisphere winter, the majority of which is experienced December through February (DJF) as shown in Figure 1. This region experienced approximately 80mm/yr over the 30-year period climatological during DJF.

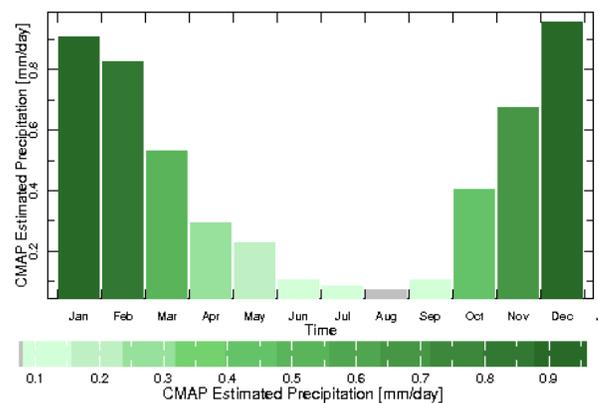
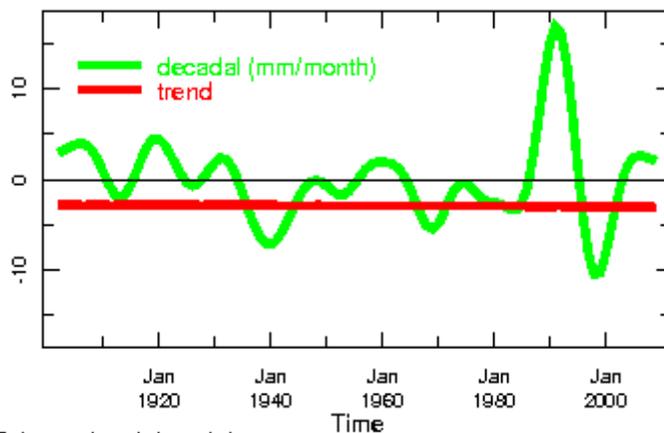


Figure 1: 30-year climatological precipitation of the Nile Delta region using CMAP monthly rainfall data.

Most areas of the northern Mediterranean coast of Africa, particularly in the west (e.g. Tunisia and Algeria), have already observed drier conditions due to anthropogenic climate change [5]. The International Panel on Climate Change projects the same drying trend for the Mediterranean areas in Egypt. And “the annual and seasonal drying/warming signal over the Northern African region is a consistent feature in the global and the regional climate change projections for the 21<sup>st</sup> Century under the A1B and A2 scenarios.” These drying trends correspond to the theoretically implied implications for a warming atmosphere and are seen during the wet winter season; “rich get richer, poor get poorer” axiom that implies pluvial regions should experience more wetness, while dry regions will receive less[6]. In addition, according to the Clausius-Clayperon relationship, Dr. Kevin Trenberth, a climate researcher at the US National Center for Atmospheric Research, predicts that intense precipitation events will become more frequent in many regions (“it never rains, it pours”) [13]. The fifth IPCC assessment report disclosed that a reduction in precipitation is very likely by 2100 in Northern Africa under warming scenarios. This, along with other climate change related factors, would increase the pressure on water availability across the continent and particularly in quickly developing coastal zones [5].

### NATURAL CLIMATE VARIABILITY



Dec-Feb trend and decadal components

Figure 2: DJF Variance explained by decadal and interannual phenomena

Analysis of precipitation for the DJF period using the IRI Map Room *timescales tool* revealed that the climate change trend has not been detected in the Nile delta (Figure 2). Variance explained by the decadal variability amounted to 18% and 79% of variance was attributed to interannual. The interaction between temporal scales of climate variability and the anthropogenically forced climate change trend are necessary to make credible forecasts for future precipitation and water resources.

Figure 3 displays the correlation between mean sea level pressure and an empirical orthogonal function (EOF), appended as Figure A, for the subject region’s precipitation. Maps (a) and (c) of the third figure is the first and primary mode of the EOF, which explained 22.8% of precipitation variability. As seen in the global view, DJF precipitation for the Nile delta is highly positively correlated to sea level pressure over North Africa, the Mediterranean Sea, Western Europe and the North Atlantic. Precipitation for the subject region is inversely related to sea level pressure over Scandinavia, Greenland, and the Greenland Sea. This pressure pattern for the primary mode of precipitation resembles the wintertime North Atlantic Oscillation (NAO). The winter NAO, appended as Figure B, has a teleconnection producing anomalously

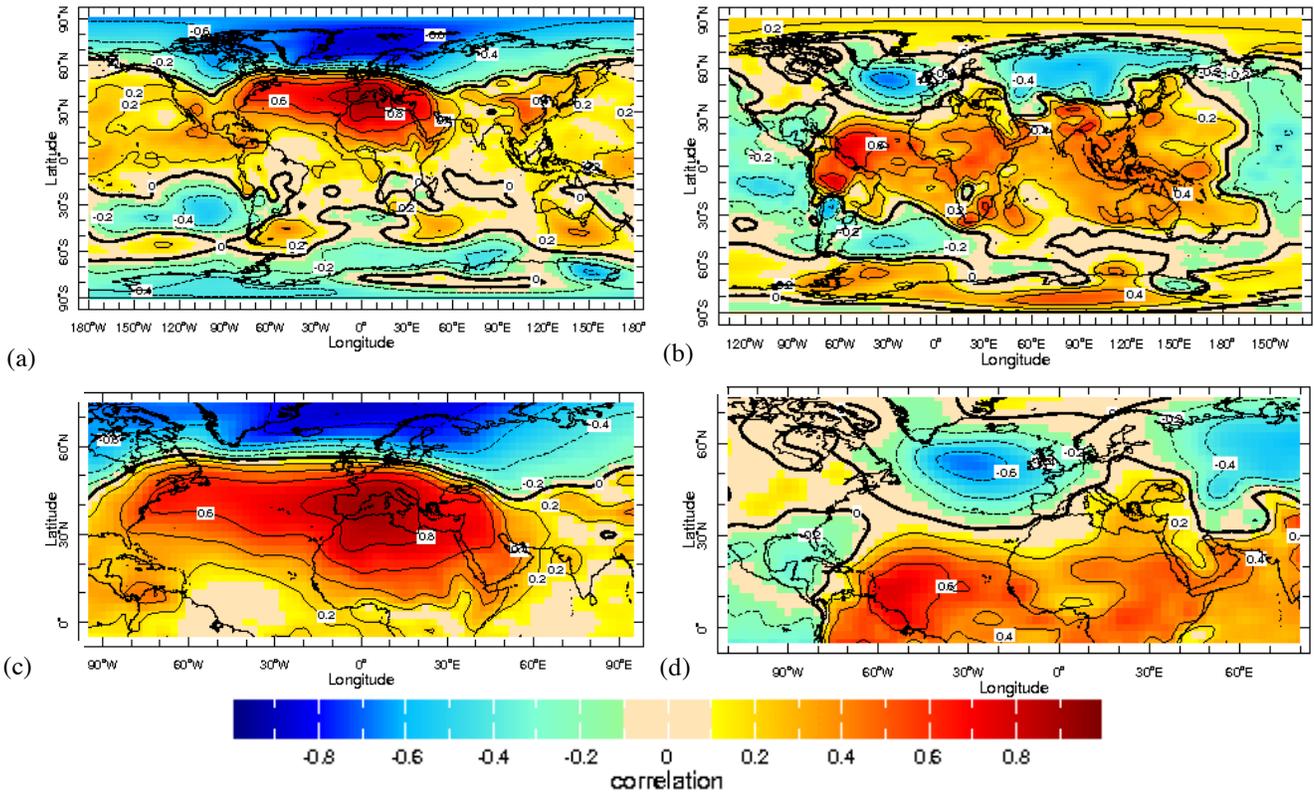


Figure 3: Correlation of SLP and precipitation EOF for the Nile Delta; (a) global view of mode 1 with SLP, (b) global view of mode 2 with SLP, (c) regional North Atlantic view of (a), (d) regional North Atlantic view of (b).

low pressure in the Nile basin (during the positive phase), enabling wet conditions. The positive phase of NAO is characterized by a stronger pressure north-south dipole, whereas the negative phase involves a weaker low over Greenland and weaker high in the north Atlantic. The NAO index was correlated to the first mode of the precipitation EOF for the region as an attempt to attribute some interannual (and interseasonal) variability for the Nile delta; the correlation was calculated as 0.855 (detrended analysis yields the same result), which is over 99% significant. This indicates a less than 1% probability that the correlation is false. Figure 4(a) shows a comparison of the NAO index timeseries with Nile delta precipitation anomalies for the period 1979 to 2014. According to Dr. Kelley and others at Lamont Doherty Earth Observatory at Columbia University, the drying trend is only seen during the winter season, yet the CMIP5 multimodel mean distributes the trend throughout all seasons. Kelley postulates this could denote that multidecadal internal variability from the NAO dominates the trend.

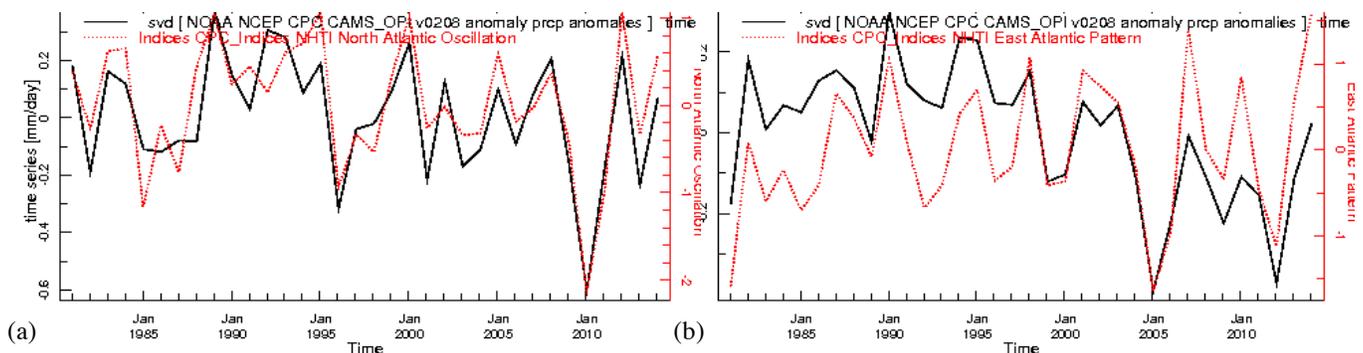


Figure 4: EOF mode 1 with NAO DJF index (a), and mode 2 with EA DJF index (b)

Maps (b) and (d) of Figure 3 demonstrate the second mode of the EOF which explained approximately **16.3%** of variability for the delta. The second mode demonstrates strongly resembles the East Atlantic (EA) winter pattern appended as Figure C. Similar to the NAO with a north-south pressure anomaly dipole, the EA pattern is shifted further southeast than the NAO. The main difference between NAO and EA is that the latter has a strong subtropical connection [1]. The EA pattern is known to comprise some of the NAO pattern, and therefore there could be covariance occurring within this analysis. When correlated with the region of interest's precipitation EOF, the EA index has a 0.580 correlation (detrended analysis yields the same result). This correlation is significant above the 99% level. The cross correlation between the NAO and EA indices was computed at 0.314 for the period of 1979-2014, and was not found to be significant at the 95% level. Therefore, there is a possibility that the two oscillations are statistically independent for the Nile Delta region.

Further analysis would include evaluating the oscillations for clustered periodicity and investigating synchronization of the modes as performed in the 2009 study of NAO and the Ethiopian plateau using proxy data of Nile flooding. Complete synchronization in both phase and amplitude was found between the north Atlantic and eastern Mediterranean during the winter [3]. The explanation for this teleconnection was follows: during "during the winter, a low pressure anomaly extends from Northern Europe to the southern and eastern part of the eastern Mediterranean. The NAO index determines the strength of this low pressure anomaly and, therewith, the amount of rain in the eastern and southern part of the eastern Mediterranean"[3]. In the case of winter precipitation for the Nile delta and the study presented here, understanding the complex nonlinear feedbacks and forcings between the interannual/interseasonal variability of the NAO and decadal variability of EA could enable the development of models to reproduce and forecast climate for the region.

## **POSITIVE PRECIPITATION ANOMALIES**

A December 2012 press release from the World Bank on climate change in the Middle East and North African (MENA) region reported that climate disasters have cost over \$50 million USD directly and indirectly [12]. Specifically, an increasing trend in dry conditions for arid areas and more frequent flash flooding were cited. The 2006 flash flood in the Nile basin resulted in 600 fatalities and nearly 120,000 additional affected people [12]. Flash flood hazards indicate rapid onset precipitation events, with little time for warning, in which peak water levels are reached within hours or less. Impermeable land that is a condition of the urban landscape, or severely dry land exacerbates these natural phenomena. The speed of this flooding imposes great danger to human life and severe damage to infrastructure, particularly due to a lack of traditional knowledge regarding flooding in arid areas [11]. Flash floods manifest in the climatological record as dramatic positive precipitation anomalies on highly resolved temporal scales.

Sudden flooding in January 2013 of the City of Alexandria, Egypt (the largest, most populous city in the Nile delta) highlighted infrastructure inadequacies in the form of extensive flooding resulting in damages to commercial and residential structures and limiting access and mobility of the city. As seen in Figure 5, the 2013 event was among the top three positive January precipitation anomalies of the past 35 years. Protests erupted in the strip city in response to the inundated roads [9]. It was reported that the stormwater infrastructure could not accommodate the unexpected excess of rainwater, and protesters demanded a remedy from the municipal government, who were reluctant and unprepared to address

the massive volumes of water. This type of civil unrest was likely worsened by general political unrest taking place among young people across the country since the Arab Spring in 2010 [6] and general disappointment with the new government of Mohamed Morsi at that time [14]. Additionally, as sea level rise continues to threaten the already “sinking” city [4] that drives the delta region, flooding events and subsequently tensions will continue to grow. In the 2014 Working Group 2 report, *Impacts, Adaptation, and Vulnerability*, the IPCC noted several drivers of conflict induced by climate change and variability. Despite the difficulty attributing unrest and conflict to climate change, it is known that environmental factors can aggravate or multiply existing threats to human security.

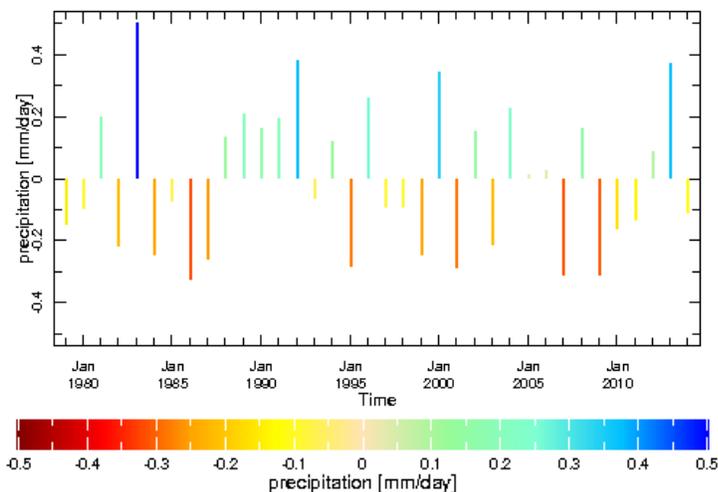


Figure 5: January Precipitation Anomaly Index, 1979-2014

## OPPORTUNITIES + ADAPTATION

There is immense value in being able to, even modestly, predict seasonal precipitation for the Nile delta region. Both water stress and flooding could be alleviated and anticipated with seasonal forecasts (although flash flooding is very hard to forecast), assuming flooding events are confirmed to occur more frequently during wetter seasons. Additionally, there may be opportunities to develop alternative water sources necessary for the region as the climate dries, aquifers are salinized, development continues, and the population grows.

Infrastructure investments that deserve consideration range from long-term and high-cost to near-term and inexpensive. Large-scale reservoir construction to take advantage of intense rain events are a challenging investment for developing countries to undertake due to lack of economic assets. Likewise, desalination plants are suitable for the delta’s location on the Mediterranean Sea, but are very expensive. Particularly in countries without stable political leadership like Egypt currently, big projects and plans are difficult to implement. Compounding the feasibility issues of major water management infrastructure is the uncertainty of precipitation trends with climate change and national pride. Conflict with upstream countries regarding the Nile water rights incites patriotism and Egyptians tend to resist accommodating alternative water supplies.

Although large scale water harvesting is challenging, individual rainwater harvesting systems are relatively inexpensive and could be accompanied with education to improve behavioral usage. Although capitalizing on the climatological and positive rainfall anomalies could not yield volumes of water to replace dependence on the Nile waters, it could supplement domestic use and reduce demand on the delta waters. Water capture and storage systems improve the adaptive capacity of a water stressed region by creating redundancy in water supply.

Probabilistic predictions would enable disaster risk reduction plans and actions and creation of early warning systems. Developing response units within local governments or other governing bodies to take action during flooding events is a necessary component of this type of action. Risk reduction could include preemptive infrastructure maintenance and improvements such as stormwater system drainage testing and clearing. Yet a challenge is that the development of prediction tools, for example hydrological models, requires more robust observational data [11]. Seasonal forecasts require more in depth research of regional climate phenomena. Adding more precipitation monitoring stations will enhance the existing network for early warning and expand the currently limited local knowledge for the region. And training and consistent maintenance and record keeping at the stations would be necessary and would require stable funding. As seen with in-situ measurements for the region previously, they are inconsistent and potentially unreliable; measurements were only available until the 1980s.

Egypt first requires political stability first to begin integrating adaptation into all levels of planning as recommended by the IPCC: "Strategies that integrate land and water management, and disaster risk reduction, within a framework of emerging climate change risks would bolster resilient development in the face of projected impacts of climate change. In the near term, better managing risks associated with climate variability may help to build adaptive capacities for climate change." [5] Without a solid national and municipal plans, the intergovernmental organization's (like the UN and World Bank) work and initiatives mentioned prior will be difficult to implement and adopt and be therefore less effective.

## Appendix

Figure A – Precipitation EOF for Nile Delta Region; *all climate analysis completed using the IRI Data Library and NOAA NCEP Reanalysis monthly data*

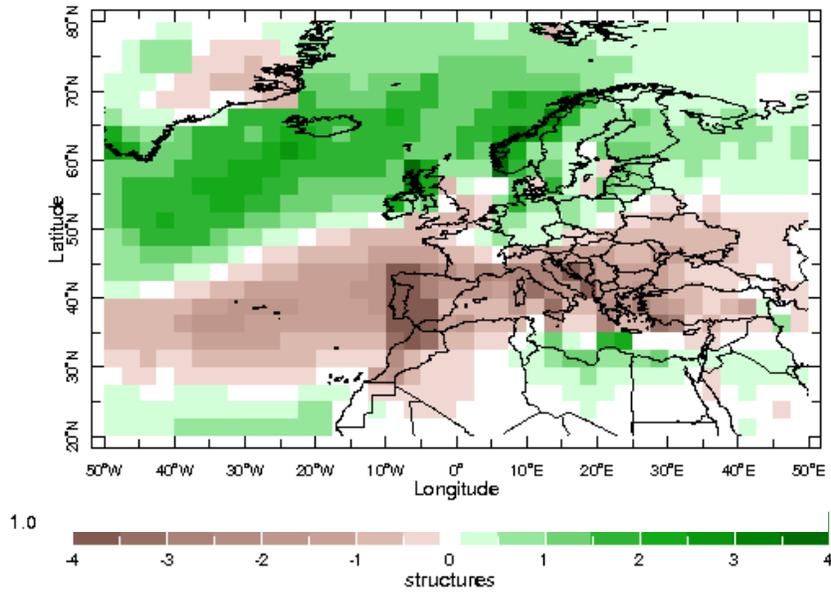


Figure B – Seasonal NAO Map [2]

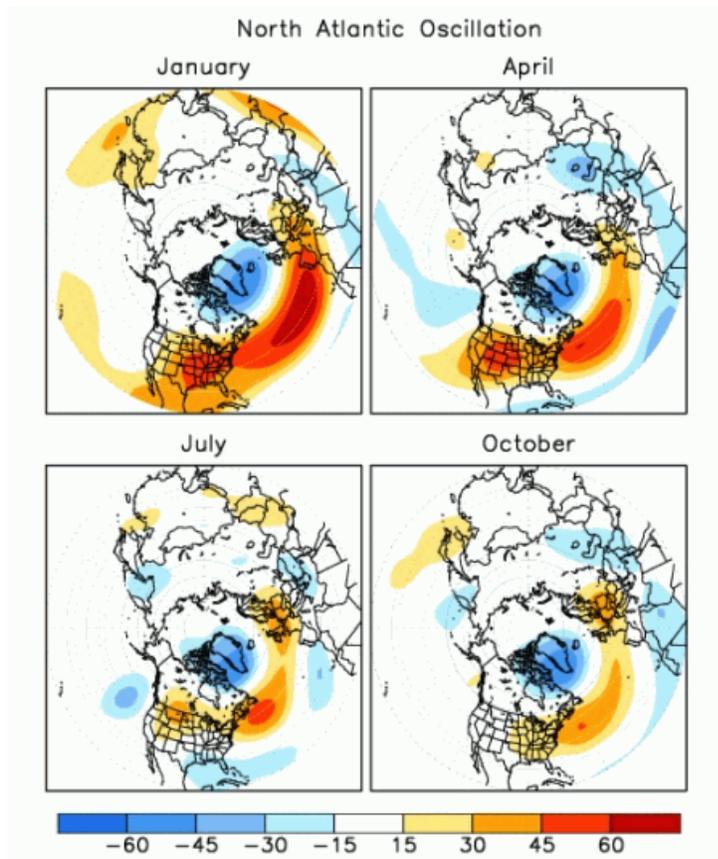
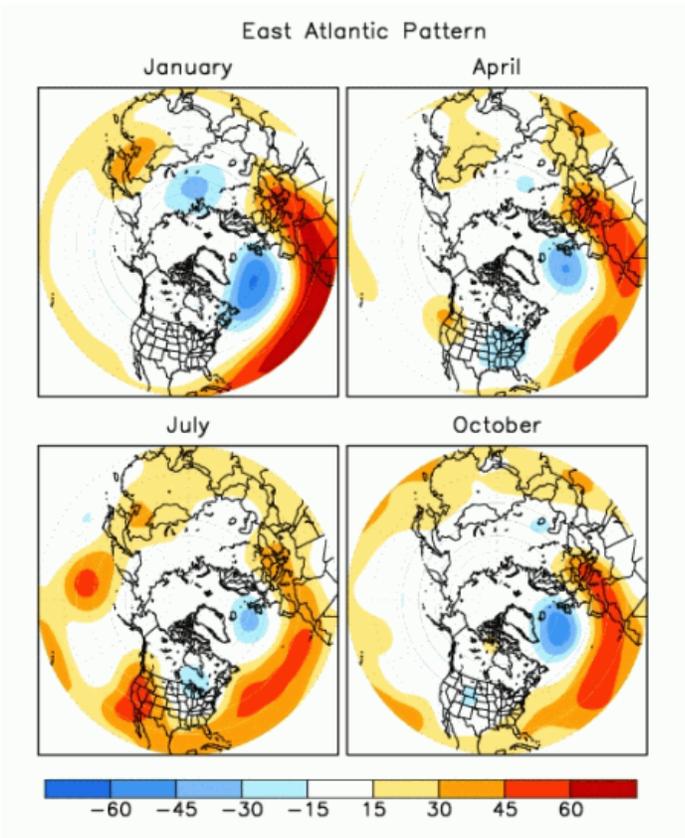


Figure C – Seasonal EA Map [2]



## Works Cited

- [1] Barnston, Anthony G., Robert E. Livezey, 1987: Classification, Seasonality and Persistence of Low-Frequency Atmospheric Circulation Patterns. *Mon. Wea. Rev.*, **115**, 1083–1126. doi: [http://dx.doi.org/10.1175/1520-0493\(1987\)115<1083:CSAPOL>2.0.CO;2](http://dx.doi.org/10.1175/1520-0493(1987)115<1083:CSAPOL>2.0.CO;2)
- [2] Climate Prediction Center - CPC, Northern Hemisphere Teleconnection Patterns- NOAA's National Weather Service. Retrieved May 7, 2014, from <http://www.cpc.ncep.noaa.gov/data/teledoc/telecontents.shtml>
- [3] Feliks, Y., Ghil, M., & Robertson, A. W. (2010). Oscillatory Climate Modes in the Eastern Mediterranean and Their Synchronization with the North Atlantic Oscillation. *Journal of Climate*, *23*(15), 4060–4079.
- [4] Hassaan M. A., & Abdrabo, M. A. (2012). Vulnerability of the Nile Delta coastal areas to inundation by sea level rise. *Environmental Monitoring and Assessment*.
- [5] IPCC, 2014: *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Kelley, C., Ting, M., Seager, R., & Kushnir, Y. (2012). The relative contributions of radiative forcing and internal climate variability to the late 20th Century winter drying of the Mediterranean region. *Climate Dynamics*, *38*(9-10), 2001–2015. doi:10.1007/s00382-011-1221-z
- [6] Kelley, C., Ting, M., Seager, R., & Kushnir, Y. (2012). The relative contributions of radiative forcing and internal climate variability to the late 20th Century winter drying of the Mediterranean region. *Climate Dynamics*, *38*(9-10), 2001–2015. doi:10.1007/s00382-011-1221-z
- [7] Mccann, C. (2011, December 23). Arab Spring. *The New York Times*. Retrieved from <http://www.nytimes.com/2011/12/25/opinion/sunday/arab-spring.html>
- [8] *Population Projection Tables by Country and Group*. HNPStats -. The World Bank, 2012. Web. 09 May 2014.
- [9] Protest in objection to Alexandria's soaked streets. (n.d.). *Daily News Egypt*. Retrieved February 20, 2014, from <http://www.dailynewsegypt.com/2013/01/10/protest-in-objection-to-alexandrias-soaked-streets/>
- [10] Selby, J. (2005). The Geopolitics of Water in the Middle East: Fantasies and Realities. *Third World Quarterly*, *26*(2), 329–349. doi:10.2307/3993731
- [11] Saber, M., Hamaguchi, T., Kojiri, T., Tanaka, K., & Sumi, T. (2013). A physically based distributed hydrological model of wadi system to simulate flash floods in arid regions. *Arabian Journal of Geosciences*, *1*–18. doi:10.1007/s12517-013-1190-0

- [12] Spencer, R. (20:55). Egypt's army drives Mohammed Morsi from presidency and power in dramatic coup. *Telegraph.co.uk*. Retrieved from <http://www.telegraph.co.uk/news/worldnews/africaandindianocean/egypt/10158775/Egypt-s-army-drives-Mohammed-Morsi-from-presidency-and-power-in-dramatic-coup.html>
- [13] Trenberth KE. (2011). Changes in precipitation with climate change. *Climate Research*, 47(1-2), 123–138.
- [14] Urgent Action Needed on Climate Change in Arab World (2012, December 5). *The World Bank News*. Retrieved May 5, 2014 from <http://www.worldbank.org/en/news/press-release/2012/12/05/urgent-action-needed-climate-change-arab-world>