Option B:

Precipitation & Climate Cycle Volatility—Middle East

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Final Assignment

Introduction

Prior to moving any further in seeking to axiomatize the analysis of the region-specific climatic cycle alongside the residual hazards involved, a set of parsimonious yet operational assumptions may have to be stated. To begin with, it will be presumed that the standard climate cycle can be reduced to the hydrological core, with the water balance equation accounting for the bulk of the exogenous or overlooked propagation channels or hazards yet to be integrated.

For that matter, the hydrological part building on precipitation may be confined to the impact of rainfall (insofar as it affects most endogenous variables in the aforementioned equation), with snow (sleeting and the like) making up just under 1% (or less as an ME year average), comparable to the sample or measurement error. [It is for largely the same reason that transpiration is strongly dominated by advection and hence can be assumed away in the interim].

The present report will first outline a consistent and holistic approach to selecting formal theory while informing the experimental or empirical study, followed by applying the prior findings to a region-specific setup.

Analysis of the Consistent Analytical Approach

One flip-side of the previous caveat or scope-qualification would be invoked illustrating just how myopic any annual-cycle averaging could prove, if only insofar as a critical mass of time-concentrated (not necessarily seasonal) precipitation could usher in an impact far exceeding any regular rainfall effect that could be studied with the aid of temperature gradients or spatial distance from the ocean and sea shores (notably for the near-coastal Gulf areas, with the more distant locations plagued by greater dispersion or uncertainty). Therefore, it will be presumed that any hazards (as major deviations from the average expected parameters or regressed coefficients) will have to be gauged as point estimates *[1]*.

The stages of the hydrological cycle (please refer to Figure 1), along with the water phase transfers, may further be qualified with respect to some of the more technically involved tools that may afford but small increments in the predictive (much less explanatory) power, be it R-squared, *p*-value (posterior significance), or effect sizes subject to beta power or design testing. In particular, flow and condensation as well as phase transfers across the atmospheric layers could potentially be tackled with Navier-Stokes equations as applying to general fluids. On the one hand, this need not confine the analysis to the unrealistic case of ideal gases per se. Nor does it call for complex thermodynamic expositions for the system that is far from close, by design. On the other hand, the NS equations for the three-dimensional case hardly allow for analytic solutions, and may inevitably call for numerical approximations, Monte-Carlo simulations, or empirical as well as experimental calibration. This may augment the sensitivity or what-if layer for forecasting purposes albeit without allowing any intuitive or analytical control (or indeed predictive power, as argued at the outset).

By the same token, the precipitation stage (with reference to its infiltration and sedimentation sub-stages mapping into erosion hazards) could be addressed by making partial use of standardized diffusion or mass-transport equations (perhaps by imposing capillarity) with gravity being the driving force in the vertical dimension (i.e. percolation), yet not in horizontal infusion or surface runoff. In other words, the aforementioned qualifications could have the ‘silvery lining,’ in that one need not either draw upon such unwieldy apparatus or replace it with ad-hoc solutions, e.g. finite element methods and related approaches.

One natural starting point would, again, be to refer to the canonical water balance equation accommodating systems (or spatial ranges) that could reasonably amount to closed ones for practical modeling purposes. In order to strike a balance between parsimony and multi-variate validity, the appropriate representation could appear as follows:

The respective variables refer to, *P* for precipitation (followed by condensation or resultant convection), *R* for streamflow (including surface runoff), *E* for evaporation (along with transpiration which will be assumed away for the less moist soil as well as more river-abundant areas as the corner cases), and *delta S* for storage balance (while accounting for groundwater channels, vadose zones and aquifers).

To relax the static exposition, the time parameter can be introduced implicitly (either as an index or parametric representation without explicitly referring to the underlying physics). It can safely be presumed that both the precipitation and the evaporation variables respond equally to temperature without making explicit use of thermodynamic equilibrium (or energy-mass transfer, thermal mass, etc.). At this rate, the remaining variables will offset each other as long as there is no heteroskedasticity in the residual. In other words, the standard deviation can be presumed constant, in which case any differential of the omitted variables will be held anywhere near zero (akin to varying the constant in setups other than calculus of variations). The flipside, however, would be that, whatever holds for differentials or flows need not necessarily carry over to levels or flows.

This may or may not be construed as precipitation being the affine (actually linear, with no free term as an intercept or time-related slope), and nor does this continuous-time or small-differential setup carry over to large differences. Insofar as this does hold, however, it follows that,

The above OLS regression draws upon the solution of the differential or implicit relationship (smooth dependence). While this is a comparative-statics representation, it should (by invoking ergodicity again) accommodate cross-sectional and time-series as well as full-fledged panel studies alike. Although the beta-zero slope would differ, it should oscillate around unity amid there being no free terms (zero intercept) save that all of the omitted or exogenous variables and processes collapsed to a residual (or random effect, which could be time- as well as region-specific in a mixed-effect panel setup).

Incidentally, not only is the effective endogenous variable interactive, it has an inner non-linear structure of its own, thus relaxing the OLS setting.

What this suggests, in line with what has been proposed from the outset, is that complex considerations of thermodynamic impact could safely be collapsed to a residual or error term as exogenous. *Inter alia*, this pertains to the observations of CO_x footprint or its ‘embodied energy’ and ‘exergy’ implications for civil engineering (as part of sustainable or resilient designing response to climate change or extreme amplitudes) on top of the less arcane or more established metrics such as enthalpy. However, even the latter dimension would prove superfluous (along with water discharge based on averaged parameters such as estuary or basin cross-section and velocity of flow as magnified by runoff and/or precipitations), if only because the more extreme outcomes would hardly be point-wise predictable in contrast to the implications of the longer-term warming impacts. In particular, instead of incorporating explicitly its aforementioned correlates, one might benefit enormously from bearing in mind the temperature elasticity of water-cycle intensity ranging anywhere between 3 and 13 (Durack et al., 2012). By assuming ergodicity, this longitudinal implication could carry over to spatial, cross-sectional temperature and cycle volatility gradients, by appropriately adjusting between the Fahrenheit-centigrade scales.

Therefore, unlike time or spatial distances, temperature oscillations can be rather large despite the model still boasting robustness. However, even the smaller oscillations would still account for large (yet predictable) variability—in which light homoscedasticity no longer poses a binding BLUE (best linear unbiased estimate) prerequisite outside OLS testing. In fact, the entire temperature gradient and climate volatility [vector field] matrix collapses to a single [scalar] elasticity metric ranging within the above confidence interval. For instance, a half degree centigrade warming (whether measured temporally or spatially) would be coupled with a 1.5% to 6.5% boost in the likelihood of abnormal climate cycle or volatility effect largely stemming from global warming (yet without assuming any locally closed systems, which turns near meaningless in light of the grand trend looming large). [2]

Regional Application: Data & Results

Since the region under study is the Middle East (please refer to Figure 2 for a climate map), this lends some excessive relevance to the temperature elasticity of climate cycle amid the precipitation-evaporation balance being shifted or skewed dramatically. In other words, precipitation would prove inadequate for practical purposes amid evaporation being excessive in the arid desert zones, with vadose zones largely centered around the oases. While seawater desalination facilities have been at work (in particular pertaining to the cooling-water supply for nuclear reactors in the Abu Dhabi locations of the UAE), this has but second-order impact on melioration programs.

In this light, equation (*1*) could be inapplicable in light of a stable (near-zero) net storage change. Ironically, though, this suggests an extra weight for the augmented version or its tempered term. Since it is the inadequate (or possibly negative as well as unstable) level of runoff or precipitation that applies in the ME area, both would likely reveal a strong correlation (and hence would never need to be accounted for simultaneously, if one is to avoid multicollinearity or violating the independence assumption for the residual with respect to endogenous variables). Moreover, the temperature coefficient (i.e. elasticity) would reasonably be zero, to connote its compensatory function.

Other than this aspect of prediction, the elasticity-based trend can again be analyzed as well as applied in a longitudinal and cross-sectional setup alike—while bearing in mind the impact on the p-value significance feedback. In effect, the entire modeling or prediction set could safely be reduced to inter- as well as intra-regional temperature gradients mapping into the precipitation anomalies on top of the expected levels, based on the above elasticity.

Alternatively, a region-specific elasticity measure could be conceived of and possibly measured, even though one might either turn out more stable regionally despite inter-temporal volatility or fail to apply to precipitation observations in the more densely populated areas that routinely center around the oases as well as coastal lines.

Other than that, issues such as carbon footprint may or may not remain of second-order relevance in the ME region, depending on how well-diversified the economy is beyond the petroleum extraction and processing (which relationship is “positive” formally, i.e. adverse developmentally). Given the downtrend in the oil prices over the past four years or so prior to the recent recovery, the oscillatory nature of the structural impact might only further aggravate the inconclusive role of such extra explanatory variables (with the closed system or endogenous setup pertaining to the global demand, which in turn is derivative of growth projections and reaches beyond the intended scope).

One alternate view on what constitutes a closed system would extend the exposition to account for the entire MENA (Middle East & North Africa) climate horizon, yet this kind of extension will best fare as a direction for future research. In any event, some large-scale recent projections that have been made for the MENA climate have pointed to sustained warming and, more importantly, depressed precipitation—fully in line with the approach as proposed in the present study and in line with the past empirical surveys. In other words, the elasticity based framework as attempted throughout should provide an adequate sensitivity tool, irrespective of how accurate the input data (i.e. temperature gradients or projections) turn out to be. *[3]*

Conclusion (Summary)

It has been argued at the outset that a meaningful study need not embark on either overly sophisticated formal models (which have shown to have but limited applicability, let alone explanatory power for lack of analytical solutions) or on numerical methods and simulations which tend to further trade analytic intuition and control for minor increments in naïve predictive power. On the other hand, since powerful simulation-based researches have been made available recently, there is no need to duplicate or replicate these in the present study. Better yet, their findings prove to be fully in line with the intended scope, in just how the precipitation dynamics as well as anomalies can sparingly be measured with the aid of an elasticity-based approach striking a balance of empirical rigor and analytical scrutiny while builing heavily on sustained, long-run and region-invariant trends such as the more trustworthy as well as crucial impacts of global warming.

ENDNOTES

[1] Along somewhat related lines, it would be awkward to overlook the inland river contribution to rainfall on the sole grounds that oceans account for 97% of water storage while positing an up to 86% to 90% evaporation proportion (Perlman, 2017). After all, it is the impact of rivers and alternative aquifers that is most pronounced in the incidents of excessive surface runoff yet to be studied by the balance equation alongside the total change in the storage net of groundwater impart.

[2] In light of the above, equation *(1)* could further be augmented to incorporate the temperature gradient. On the one hand, this extra variable will formally improve the predictive power by reducing the residual (with the beta-one slope capturing the elasticity). It may appear that the overall model variance has decreased. However, one should be sure to keep in mind that the temperature scaling pertained to the ever more intense climate variability, which may accrue in terms of the effectively *lower* significance of the individual slopes (lower t-statistics despite a high F), or their magnified variances.

[3] One rehashing point would be to point out how some of the more recent, region-specific empirical observations may have seconded all of the key findings in this paper—irrespective of the validity of the stronger yet peripheral implications. For instance, Tabari and Willems (2018) challenge the “wet getting wetter” convention with the kind of reversion that stresses regional seasonality while questioning the merit of averaging. In particular, it happens that, for ME, autumn ushers in the lion’s share of precipitation anomalies, with spring showing on the contrary. This could be a peculiar instance of how seasonality qualifies the temperature gradient—again, as cautioned from the outset.

References

Bucchignani, E. (2018). Climate change projections for the Middle East—North Africa domain with COSMO CLM at different spatial resolutions. *Advances in Climate Change Research, 9*(1), 66-80.

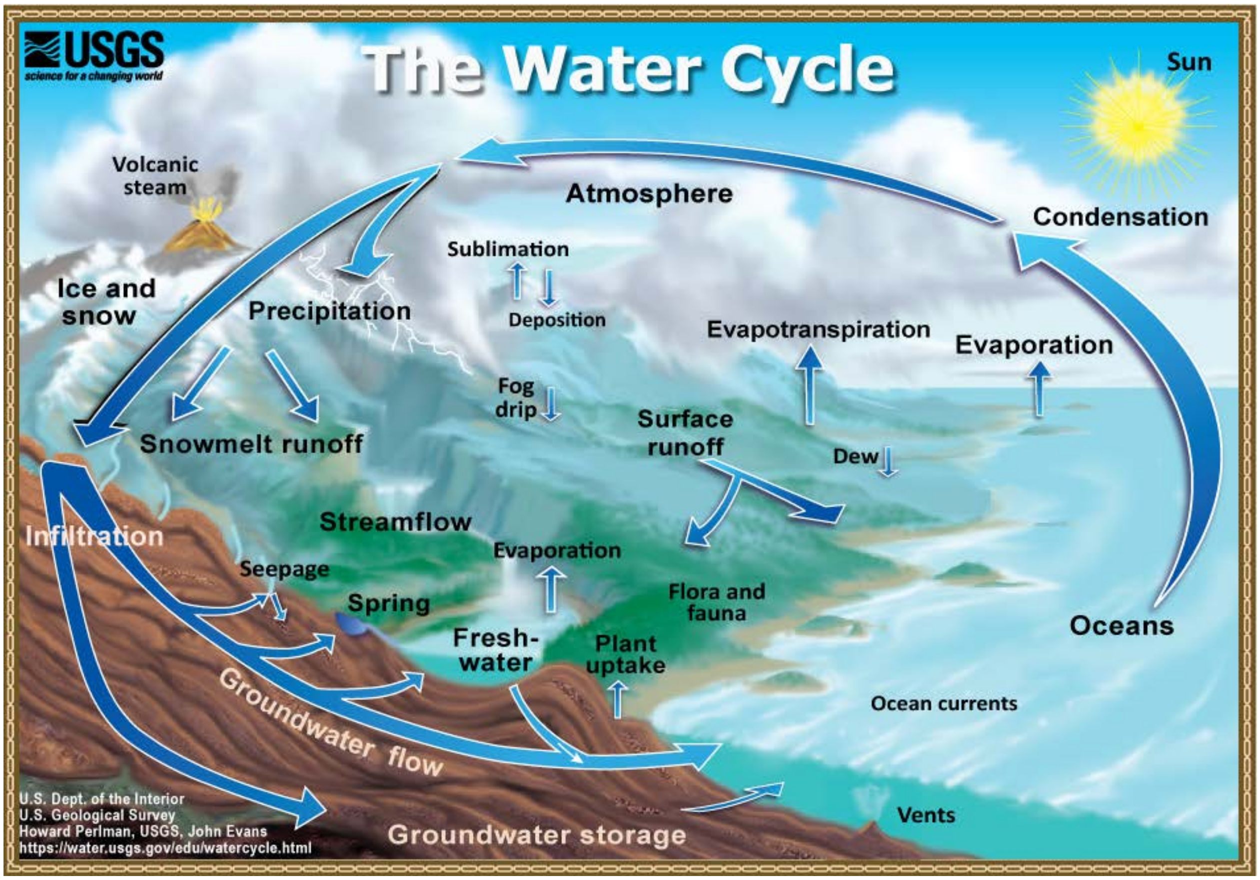
Durack, P., Wijffels, S. & Matear, R. (2012). Ocean salinities reveal strong global water cycle intensification during 1950 to 2000. *Science, 336*(6080), 455-458

Perlman, H. (2017). The water cycle summary. *USGS Water Science School*. Retrieved from https://water.usgs.gov/edu/watercycle.html

Tabari, H. & Willems, P. (2018). Seasonally varying footprint of climate change on precipitation in the Middle East. *Nature, 8* (4435). Retrieved from https://www.nature.com/articles/s41598-018-22795-8

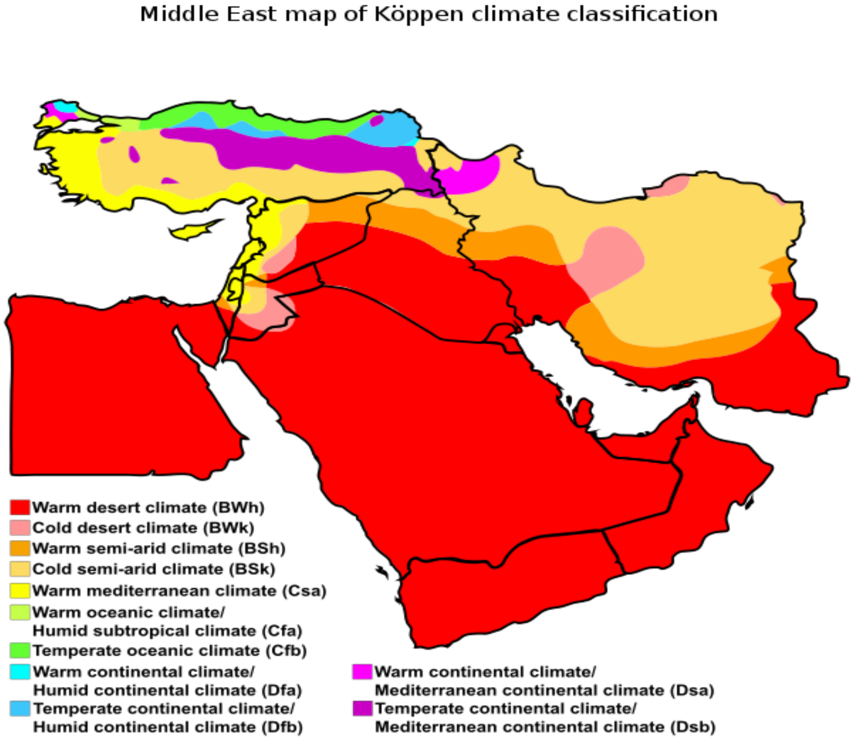
APPENDIX

Figure 1: Water Cycle Visualized



Source: USGS (2017)

Figure 2: A ME Climate Map



Source: Koeppen Maps