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The effect of Atlantic Niño on the Summer Monsoon Rainfall Anomalies in Sri Lanka

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Abstract

Sri Lankan climate is influenced by temperature patterns in the Indian Ocean as well as the Pacific Ocean. El-Niño Southern Oscillation (ENSO) is one of the global scale climate phenomena that have significant influence on the year-to-year variability of the monsoon over South-Asia. There have been numerous studies which explores the connection between the Indian Summer Monsoon (ISM) rainfall and the Atlantic Niño. However, the teleconnections of the Atlantic Ocean with the rainfall of Sri Lanka are not extensively studied. Considering the rainfall over Sri Lanka, Atlantic Niño and the South-west monsoon (summer monsoon) peaks during the June-July-August (JJA) period. Therefore, in this study the connections of the Atlantic Ocean, specifically the Atlantic Niño with regards to the ATL3 region rainfall during June-July-August (JJA) periods were considered. It was found that the JJA rainfall anomaly had significant correlations with the SSTA of ATL3 region (Atlantic Niño/Niña). In this study it was revealed that the Atlantic Niño has a significant positive correlation with rainfall over Sri Lanka with the Niño (positive phase) resulting in increasing JJA seasonal rainfalls over Sri Lanka while the Niña (negative phase) reduces the rainfall. Then the potential mechanism of how the Atlantic Niño/Niña is linked to the seasonal rainfall JJA was studied. In doing so, Relative Humidity (RH) at lower levels of the atmosphere, Outgoing Longwave Radiation (OLR), Divergence at different levels, Zonal and Meridional wind components at different levels of the atmosphere, Moisture Flux and Moisture Flux Divergence, streamline analysis were extensively studied. In this analysis, it was revealed that low pressure areas associated with the SSTA anomaly over the Tropical Atlantic Ocean during the Niño phase has drawn the zonal winds at lower-levels of the atmosphere towards the Atlantic Ocean which has strengthened the latter part of the cross-equatorial flow prevalent during the south-west monsoon period. Cross-equatorial flow plays a vital role during the south-west monsoon period. In addition to that, the extra water vapor that is evaporated during the Niño phase is then transported over the North African continent to the Indian Ocean by the strong westerly zonal wind anomaly prevalent over the Atlantic Ocean. This moisture is then fed to the westerly flowing upper part of the cross-equatorial flow which will further enhance the rainfall over south-western part of Sri Lanka. This wind formation also has resulted in keeping the Inter Tropical Convergence Zone (ITCZ) or the Monsoon Trough (MT) over Sri Lanka for an extended period.

Keywords: Atlantic Nino; Sri Lanka, Rainfall; Teleconnection; Indian Ocean

Introduction

Newly revealed, differentiated, atypical, karst landforms are recognized / identified in the current study while other typical, non-karst landforms in the study are rightfully accorded to geomorphological processes within the Piedmont physiographic province of Pennsylvania (PA), specifically Chester County. This was prompted in the current study because a series of landforms were misinterpreted by Clausen in which he claimed these were ultimately created by a speculative paleo-glacial margin and paleo-flooding. The current study looked over the geological medium that published Clausen and did not see anywhere in it about if it was peer-reviewed or not peer-reviewed, but nevertheless, Clausen still remains a part of the geological literature. Thus, a justifiable reinterpretation of his hypothesis will be proven in the current study while instead, a suggested, reasonable, alternative hypothesis is offered. One simple outlined strategy is to express contentions made here in the same sequence as Clausen's hypothetical assertions were sequenced, so that comparisons between both published papers (his and mine) can be easily made and judged by the reader. Hence, the non-karst landforms are discussed first, followed by newly discovered, karst landforms which are then followed by a discussion about an atypical non-karst, landform. It will be proven that the set of karst landforms is identified / recognized as an elongated polje enclosing either a nested polje or a nested uvala while a relationship to the non-karst, landform assemblage will be shown in the current study. The related non-karst landforms discussed later are water gaps, wind gaps, drainage divides and barbed tributaries, all formed by stream piracy. The remaining, atypical, non-karst landform that is not related to the above landform assemblage happens to be an old but actively persisting landform that envelopes a set of numerous, SE-trending watercourses, formed during the time of the Mesozoic Period. Thus, after weighing all of the facts associated with the cumulative landforms, a credible resolution will be offered here that provides an adequate, elucidation for all of the landforms and their formative processes vs. the paleo-glacial and paleo-flooding hypothesis suggested by Clausen.

Background

The whole conglomeration of landforms that will be discussed in the study is pointed out in USGS topographic maps by Clausen. Those landforms are all reflected by topographic contours in Clausen's maps while all of these are located in Chester County, PA. The focal point of the debate takes place in this county of PA which is located far south

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of both the late Wisconsinan glacial border and both the Illinoian and Pre-Illinoian till limits mapped out by Sevon and Braun [1-2] (Figure 1). The position of Chester County, PA located within un-glaciated terrain is an integral part of the whole debate, while it is counter to Clausen's rationale of his studied landforms being created either directly or indirectly by a speculative or hypothetical paleo-glacial margin that lies far south of the aforementioned glacial and till limits in PA. It is deemed necessary to first describe the geomorphology of each landscape unit, followed by arguments raised about the origin of them.

Methodology

The writer bases the current study on scientific data and facts gathered from: primary, literature sources such as many, scholarly, peer-reviewed journal papers, monographs, published geological survey reports, etc. which support the study's thesis. The cumulative data is complemented by employing bedrock, topographic, and surficial material maps that provide additional evidence and credence. Established, geomorphological models are borrowed,

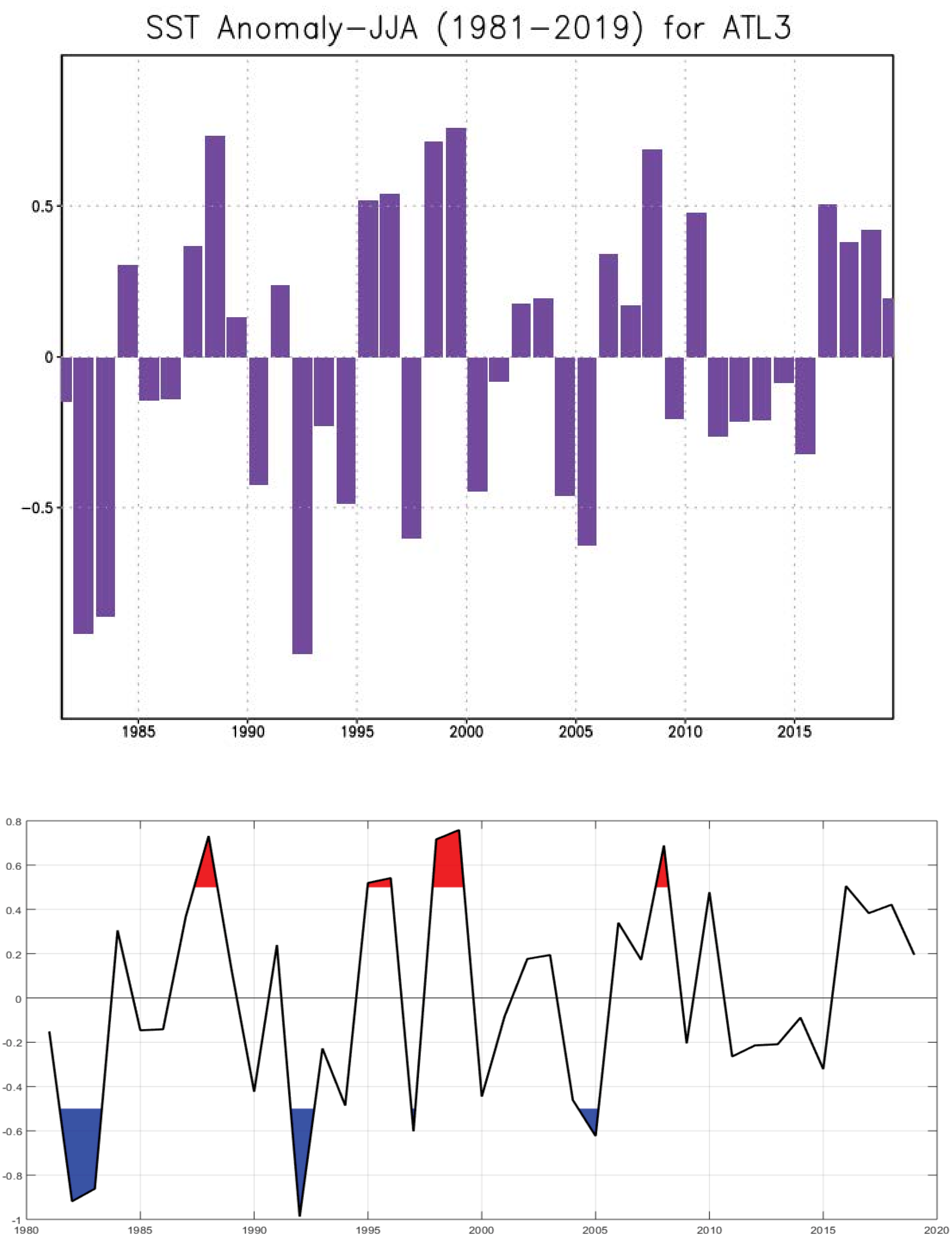

Figure 1: (a) SST Anomalies of the ATL3 region for the period June-July-August during the years 1981-2019 in Co (bar graph) (b) represents the same in a line graph. Years that exceed 0.5 Co(-0.5Co) is identified as Atlantic Niño (Niña).

correlated and applied to the study area, which happen to fittingly match up to observational landforms. The combined preceding ultimately accomplishes a skillful rationalization that leads to a valid reinterpretation of Clausen.

Discussion: Landform Units and Geomorphic Processes

Water and wind gaps

Water gaps and wind gaps are sizable landforms that distinctively stand out within a landscape while they've been well-known for a long time by geomorphologists [3]. Bates and Jackson [4] define a water gap as "A deep pass in a mountain ridge through which a stream flows, especially a narrow gorge or ravine cut through resistant rock by an antecedent stream". Although not specifically mentioned in the preceding definition, it is noted that this definition includes the type of stream running through the ridge, which is simply a transverse stream (as opposed to a parallel stream). A wind gap is a former water gap that does not have a stream running through it at the present time. A popular concept that explains the reason for both a present-day watercourse and only a former watercourse running through it, is head ward erosion on both sides of the ridge (or a drainage divide) until a pass is lowered enough to allow a transverse stream to flow through a present-day, deepened pass. The preceding implies "stream piracy or capture" while the primary mechanism of it is when one stream's base level is lower than the base level of the captured stream at a point of intersection. Clausen discussed stream piracy and head ward erosion within a framework of paleo-flooding as the reason that caused these types of erosional landforms in the Piedmont province. For instance, Clausen claimed that East Branch Brandywine Creek eroded across geological structure (which is a water gap) instead of the creek having an affinity for flowage only upon and within soft bedrock. But the current study prefers the work of Clark as a wise explanation for this controversial piece. Without connotating any association with paleo-flooding, Clark calculated the water gaps and wind gaps of the Piedmont Province were not only formed by transverse fluvial drainage, stream piracy and head ward erosion, but that these were determined by other combinatorial factors such as tectonics and local superposition upon non-resistant cover-masses onto structural weaknesses.

Barbed tributaries, drainage divides, and negligible paleo flooding

The hypothesis of Clausen attempted to explain the origin of barbed tributaries and drainage divides in Chester County, PA by correlating these to an external agent such as paleo-flooding that later initiated stream piracy. But stream piracy can result during or just after an internal agent such as a tectonic / seismic pulse that ultimately forced a degree of crustal deformation, while examples of this will be given later. Barbed drainage is a fluvial landform created from stream piracy while the standard sequential definition of it is a stream pattern consisting of tributaries forming obtuse angles to their main stream due to these going in the opposite direction but still emptying into their main stream Figure 2. Here, afterwards, the stream reversal ultimately pirates the adjacent stream valley when head ward erosion lowered and opened up the drainage divide to the advancing, reversed stream Figure 2 which inevitably results in a new drainage divide. When we add Clausen's flooding dynamics to the equation without any tectonic implication, then sequential, hypothetical flooding of a bottomland, master, Trunk River (not shown in (Figure 2) causes a fluvial "push" into a tributary in the upstream direction which ultimately forces it to

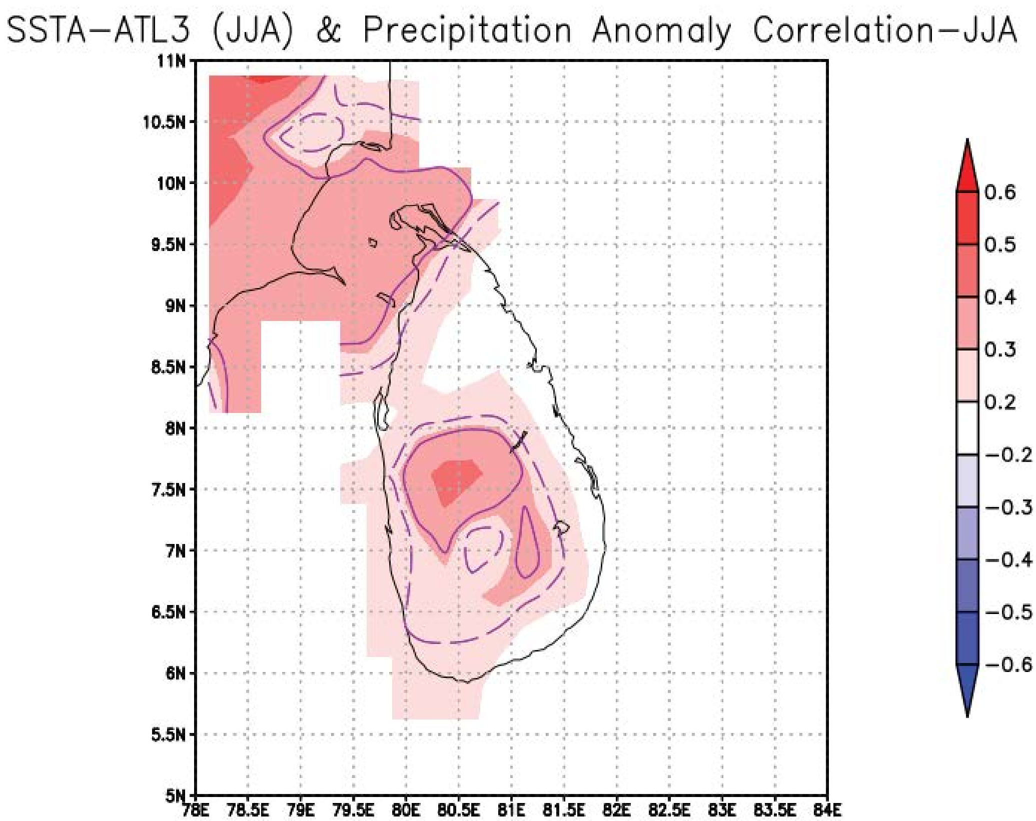

Figure 2: CC of SSTA for JJA and GPCC (0.25x0.25) monthly rainfall anomaly over Sri Lanka for JJA period. The dashed purple line shows the significance of CC at 90% and the solid purple line shows the significance of CC at 95%.

flow in a reverse direction. Then, after head ward erosion breaches a drainage divide, the reversed stream flows through it which captures the neighboring stream. Hence, in this fashion, he implies that a newly formed drainage basin with a drainage divide is started. However, in the case of Chester County, PA, Clausen did not support his own belief with any sedimentary evidence, including potential slack water deposits usually created by most flooding events as it proceeds upslope / upstream along the tributary that was eventually reversed. Slack water evidence would also record the paleo-altitude of heightened floodwaters [5, 6]. Further supporting the evidence against Clausen are other investigators who don't even attribute paleo-flooding as a cause, instead, they prefer other reasons for stream piracy, stream reversal and new drainage divides such as tectonic uplift: Segar & Alexander [7] favored regional tectonic uplift for stream piracy in southeastern Tibet [8] Blamed neo tectonics and litho-structural patterns for both stream piracy and stream reversal in southeast Brazil [9] concluded that active tectonics are still today responsible for perpetual, drainage-divide mobility and stream capture in Bhutan, Himalaya.

Hypothetical paleo-glacier = unlikely paleo-glacier

To account for why paleo-flood sediments are absent in Clausen's hypothesis, he says in a long quotation (verbatim): "Further, most melt water from such a 1 to 3 mile thick or thicker continental ice sheet would contain little or no sediment as it flowed from the ice sheet upper layers. Such melt water would deeply erode regions over which it flowed and leave little or no sediment evidence to indicate the water source. Logically massive floods of such melt water could have crossed the Schuylkill River-East Brandywine Creek drainage divide and represent the most likely erosion agent responsible for erosion events this paper describes". But Clausen's rationale is grossly implausible because of a couple of reasons: Sevon [10] calculated that paleo-continental glaciers were only < 0.48 km thick at Hudson Bay, Canada before moving down to Pennsylvania; while many mountain heights are > 0.48 km in the northeastern-half of the USA which would have made nunataks out of those mountains when ice flowed around them but not over them. This tenable scenario then provides a big natural chance for mobile glaciers to collect supraglacial, unconsolidated sediment due to mass movements and rock falls from frost-wedging / frost-shattering of mountainsides. In addition, atmospheric dust (loess) would have settled onto glacial surfaces [11] during wind-diminishment and dry intervals of time, while afterwards, simple snowfalls would have buried the dust during wet times. Altogether, this then contradicts Clausen because supraglacial melt water would have transported the supraglacial sediment from off the surficial part of the glacier while fluvioglacially depositing at least some of it onto the terrain, especially in slack water-deposit positions within a paleo-flooding scenario which wasn't the case here.

An elongated polje and nested poljes and uvalas

Clauson says two streams run parallel to one another within the NE-SW- trending, mesoscale-size, lowland of Chester Valley in PA [12] (Figure 3), while each one flows in opposite directions, one (Valley Creek West) towards the W and the other (Valley Creek East) towards the E both separated by a divide (Figure 4). The landform "through-valley" was designated for these valleys in Clausen but he did not differentiate it from two different types of landforms that are both known as a "through-valley". Thus, the current study analyzes both landform types to cover both possible versions of the through-valleys in the study area. Clausen claimed that a hypothetical paleo-glacial margin operated closely in the study area, which motivates the current

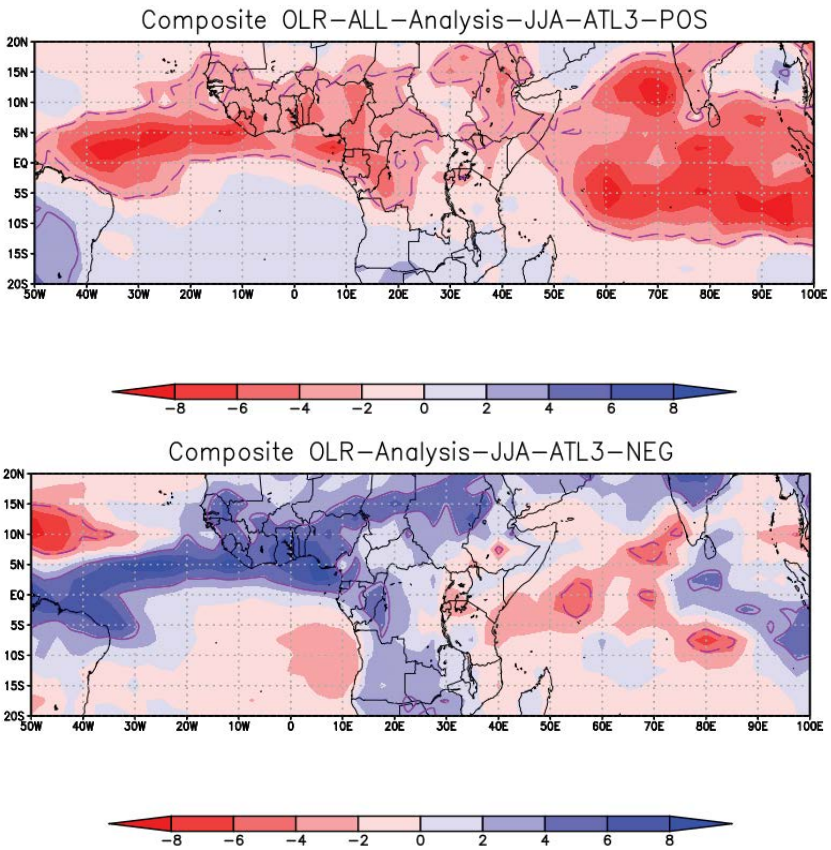

Figure 3: Composite seasonal OLR anomalies during Atlantic Niño (positive, a) years, Atlantic Niña (negative, b) for JJA period within the study period of 1981-2019 in W/m2. Purple line shows 95% significance level.

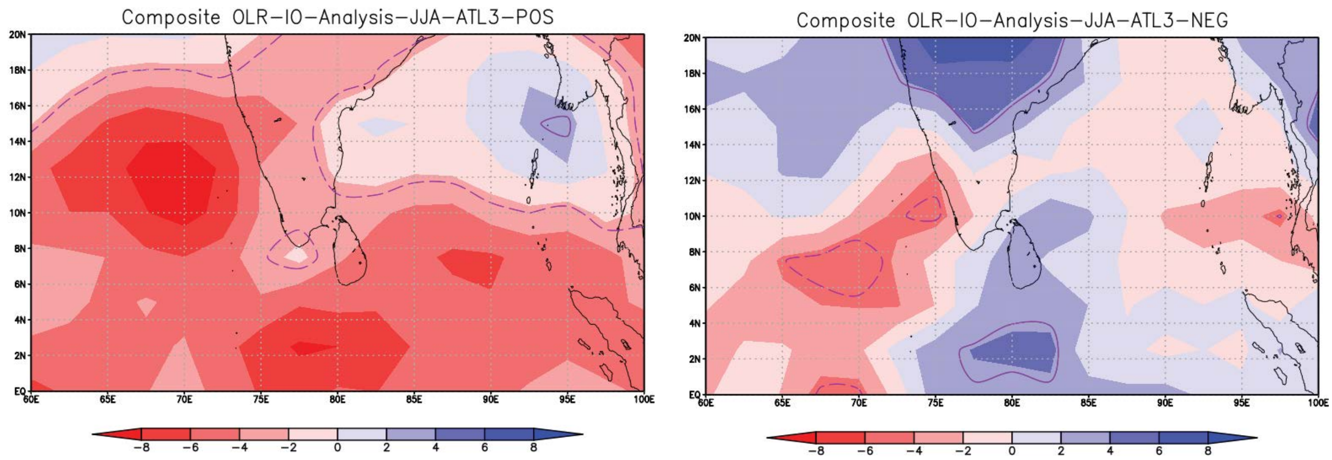

Figure 4: Composite seasonal OLR anomalies during Atlantic Niño (positive, a) years, Atlantic Niña (negative, b) for JJA period for the Indian Ocean region for 1981-2019 period in W/m2. Purple line shows 95% significance level.

study to explain the sub-topic of "glacial through-valleys". This variety of through-valley evolves when glacial ice exploits a divide enough to soften gaps within the divide which results in uniting opposite, oriented streams into one continuous valley as reported by Coates [13]. But one good reason against Clausen's speculation of paleo-glacial ice as being the erosional agent responsible for his through-valley is simply the location of his study area at a very far distance away from the late Wisconsinan glacial limit and the till limit deposited by Illinoian and pre-Illinoian glacial ice Figure 1 thus, both true glacial-ice limits and till limits were not respected by Clausen. The other type of "through-valley" which will now be discussed is correlated to karst or carbonate-rock topography. So, to recapitulate, Clausen discussed the two, parallel creeks that are separated by an N-S divide while flowing in opposite directions which is Valley Creek West and Valley Creek East. Each creek debouches onto Chester Valley via water gaps Figure 4 that transversely cut through the south side, valley wall of Chester Valley underlain by phyllitic-shale of the Octararo Formation that strikes generally ENE - WSW. But Clausen believed that at one time in the past, both creeks flowed in the same direction which convinced him that one of the two streams had to be reversed during the past due to paleo-flooding. Stream reversal and its mechanism of origin have already been discussed and concluded in one of the earlier sections of the current study, so this is applied to here as well, which results in eliminating his belief on this particular matter.

A feasible origin of Valley Creek West and Valley Creek East Figure 4 is ascertained here by first determining an origin for the megascale-size Chester Valley Figure 3 as a whole landscape unit because it may shed light on those two creeks. Kochanov [14] did not offer a reason for the creation of Chester Valley in PA., but Bascom [15] did, since he said that a river never ran through it, but instead, chemical weathering caused dissolution of the carbonate bedrock underlying Chester Valley which resulted in its geomorphic form. The current study agrees with Bascom and now analyzes this megascale-size landform to see if we can deduce a true, complete picture of its origin. First, a description needs to be given about the underlying structure and strata of the study area in Chester Valley. The structural foundation of it is a leveled series of asymmetric and symmetric synclines and anticlines trending transversely across the valley with the inclusion of various types of faults which altogether give the underlying lithostratigraphy of Chester Valley, a slightly complex, deformational pattern. The age of the faults was not determined by Kochanov. The surficial rock lithologies immediately underlying Chester Valley are either one of two carbonate, Cambrian-age, dolostone units which are the Ledger Formation and the Elk brook Formation plus in addition, Ordovician-age limestone bedrock of the Conestoga Formation. These three stratums are overlain by Quaternary sediments of colluvium, alluvium, residuum and saprolite. As mentioned earlier, the lowland of Chester Valley's carbonate bedrock floor is in contact with its own valley walls that are composed of phyllitic shale along its southern side. The lengthy, phyllitic-shale, valley wall was punctuated and completely eroded through by many allogenic creeks, leaving behind a very long, ENE – WSW trending string of ubiquitous, N – S oriented, water gaps Figure 4. This is while Chester Valley's northern side is walled with an unnamed unit - mix of granodiorite and gneisses, plus quartzite of the Chickies Formation. The size of Chester Valley is generally 6 km in width and 88 km in length and it is noted here that the megascale size of it extends beyond Chester County, PA and into neighboring Counties of PA. The current study interprets Chester Valley with its combinatorial characteristics as a "polje". Selby described two different types of poljes: one type is a very large (in areal extent), flat-floored, depression in carbonate bedrock bounded all around by a vertical-walled scarp Figure 5 due to either half-grabens and full grabens that initiated by either gravity faulting or tectonic faulting; another type is also very large in size, having its carbonate bedrock underlain by either a syncline or anticline (Figure 5). Besides the structural influences upon the carbonates involved in the geomorphic development of poljes, other factors are considered as well, such as differential erosional rates between the contact of different bedrock formations through dissolution and both surface drainage and subsurface drainage, as reported by Milanovic.

Poljes are intermontane plains that are well-known in the Balkan countries and in the Middle East such as Turkey, while their sizes can be up to 700 km^2 in area. Dimension-wise, the largest poljes in the world were mapped out by Selby who illustrated lengths of 70 km within the Dinaric Mountains of the Balkan Peninsula. Some poljes are water-filled or flooded due to ponors within their carbonate floors being choked with debris such as alluvium. Traditionally, the general perception of poljes is that they are circular or oval in shape, but in fact, a polje may also be only of an elongated shape or something intermediate in form between a circular and elongated shape (Figure 6). Thornbury besides Selby said poljes do not evolve from karstic "uvala" landforms, but rather, due to structural erosion upon a large-scale anticline / syncline or upon faulted blocks where there is contact between insoluble bedrock and soluble bedrock, as mentioned earlier. Uvalas are either relatively short or long bedrock depressions that develop simply through dissolution

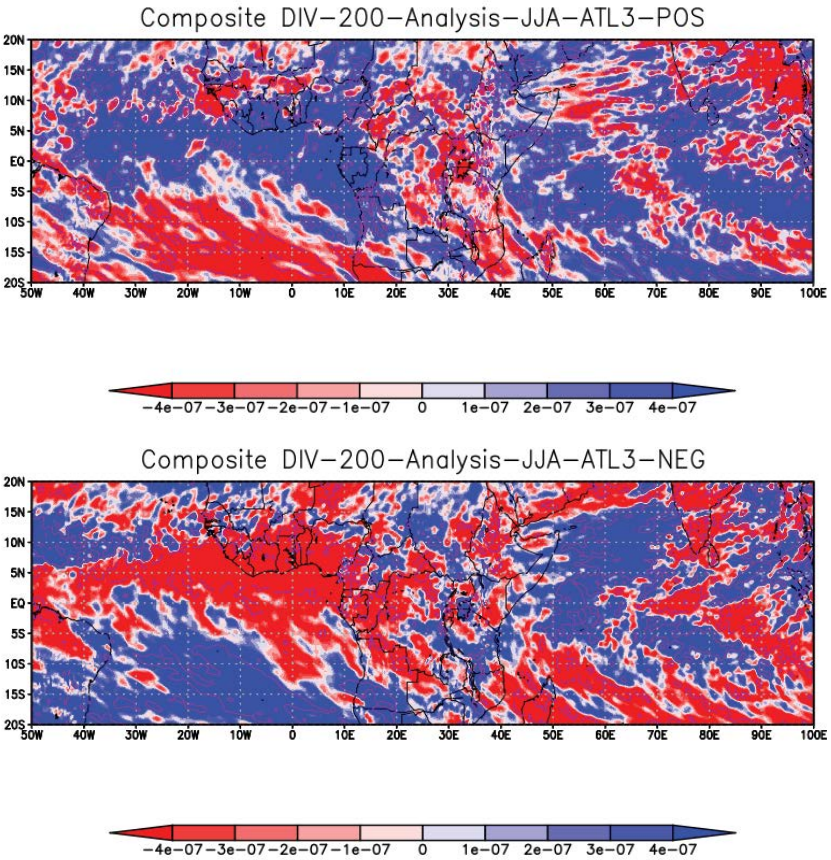

Figure 5: Composite seasonal Divergence anomalies at 200hPa level during Atlantic Niño (positive, a) years, Atlantic Niña (negative, b) for JJA period within the study period of 1981-2019 in s^{-1}. Purple lines shows 95% significance level.

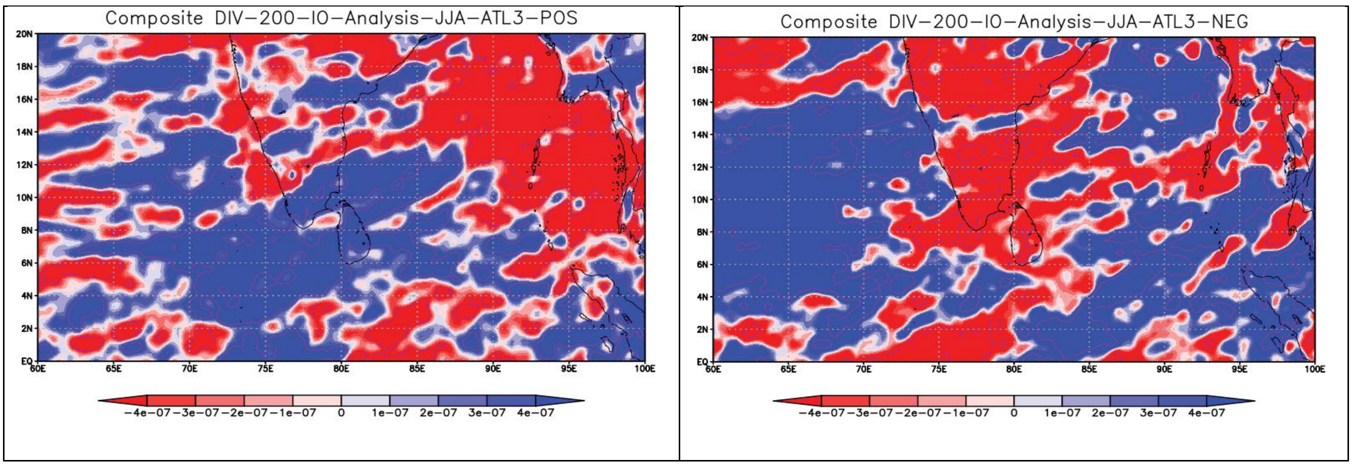

Figure 6: Composite seasonal Divergence anomalies at 200hPa level during Atlantic Niño (positive, a) years, Atlantic Niña (negative, b) for JJA period within Indian Ocean during 1981-2019 in s^{-1}. Purple lines shows 95% significance level.

due to a collapse of many, curving, inter-doline ridges belonging to a string of dolines without the influence of any structural control. It is tempting to say here that Figure 6 represents evolutionary phases of an elongated polje transitioning into a circular polje but this may not be the case because Simsek and Garcia report elongated poljes are dictated by parallel, tectonic, structural control while circular poljes are influenced by fluviokarst. However, it is not certain here how the latter mechanism works in that regard. Anyway, the point of this particular discussion is that the characteristics and the present shape of Chester Valley in PA meet the same criteria as an elongated-shaped polje.

Selby's illustrated model of his first, polje type Figure 5 is very similar to the paleogeomorphic setting of Chester Valley because of insoluble bedrock (the shale) uplifted along the contact with the polje's carbonate floor while allogenic streams head from off the uplifted highland and onto the lowland of the polje. In Chester Valley's case, head ward erosion by allogenic creeks eventually eroded vertically and completely downward upon the paleogeomorphic, phyllitic-shale, and valley's wall in spots which resulted in today's Valley Creek West and Valley Creek East cutting initially and transversely across Chester Valley Figure 4. Hence, it should be stressed again that Figure 5 provides an excellent glimpse into the paleogeomorphology of Chester Valley before the creation of its water gaps. The carbonate lowland of Chester Valley is largely in an inactive phase today by evidence of relict, karst features in it such as: the Port Kennedy Bone Cave (which is actually a large sinkhole of at least Pleistocene age); the surficial dolostone of the Ledger Formation which is a sinkhole-prone, highly-soluble, highly fractured, bedrock; and the inclusion of.5 m – wide ponors. Thus, it's reasonable to presume that the paleoclimate in the region was more humid than today when it generated those erosional, carbonate-rock features.

Before we round out an accurate origin for the previously-discussed, confounded, "through-valley" containing Valley Creek West and Valley Creek East within the megascale size Chester Valley, an additional discussion is imperative. The through-valley is perceived in the current study as one or both of the following karst landforms which are a "nested polje and uvala". A nested polje is defined by Sauro as simply a small polje enclosed by a large polje as illustrated by him Figure7. The smaller landform there is indeed nested, but it is doubtful about it being a smaller polje because there is no structural influence associated with this nested landform seen in the cross-section of Figure 7. Instead, it is most probably an uvala that is erosionally superimposed over the polje simply through dissolutional processes of the limestone bedrock in Sauro's illustration (Figure 7). A detailed description presented here now of the topography associated with Valley Creek West and Valley Creek East may help us affirm minutiae of their genesis. As seen in Figure 4, each creek flows through their own water gap that is partitioned by an N-S divide (labeled as "South Valley Hills" on the map) that extends from the highland of the valley wall and continuing onto the vast lowland of Chester Valley. Here, Valley Creek West enters the lowland in an N direction but then abruptly curves toward the W and runs down a gentle slope. In slight contrast, Valley Creek East enters the lowland in a N direction but then flows over a semi-circular, one-sided collapse-depression (karst?) that seemingly causes it to abruptly curve towards the E, followed by flowage over a slender-shaped, collapse-depression (karst?) and then down a declivitous slope. The study interprets the characteristics of both creeks may be related to stream flowage guided over the previously-mentioned, series of asymmetric and symmetric synclines attached to a chain of synclines and anticlines that transversely underlie Chester Valley. If this is truly the expected association, then Valley Creek West and Valley Creek East are identified as "nested poljes" situated within the megascale size, elongated polje which is Chester Valley. Alternatively, if we take into account about the existence of two collapse-depressions underlying small parts of Valley Creek East, then we cannot rule out an uvala origin, which actually means that a "nested uvala" is erosionally overprinting a portion of the much bigger, elongated-shaped polje that constitutes Chester Valley.

The literature about poljes in the USA

The literature's identification of poljes in the USA is somewhat muddled. According to Milanovic, he was told by a prominent geomorphologist (Richard Parizek) that poljes exist in both Centre County and Lycoming County of Pennsylvania while the largest of these is Phantom Lake. Much farther south, Klindinger and Flocks said there is a peculiar, irregular-shaped, active polje named Orange Lake, in north Florida which sits on the Florida Upland physiographic region flanked on both sides of it by the Coastal Plain. They said it formed through: dissolutional erosion of Florida's Tertiary-age, carbonate platform caused by a deep, 50 m-wide, collapsed sinkhole (with small-scale faulting) and an adjacent, surrounding, subsidence sinkhole that forced a shallower de-elevation of the surficial, limestone bedrock containing thick vertical, solution pipes within bedrock fractures, altogether without any associated, structural folding. But in the case of Orange Lake, the term "polje" may be a misnomer in Klindinger and Flocks because even though it has down faulted limestone, it lacks any contact with insoluble rock nor does it possess any folded bedrock which altogether contradicts a polje definition for it. As a side note, they also said that Orange Lake is colloquially known only as a "drowned prairie". Closer to the strict definition of "poljes", are the oval-shaped type of poljes in the USA which are assigned here to the "coves" (and not "piedmont coves", *sensu stricto*, in the Blue Ridge province, see Mills, his Figure2 such as "Cades Cove" within the Great Smoky Mountains of Tennessee. This is because besides it having nearly the same circulat to oval, geomorphic shape as a polje in Turkey, it also possesses the same properties because of subsurface folds, and different types of faults including similar lithological bedrock units. So, Cades Cove is comparable to Chester Valley in PA, but there are a few differences

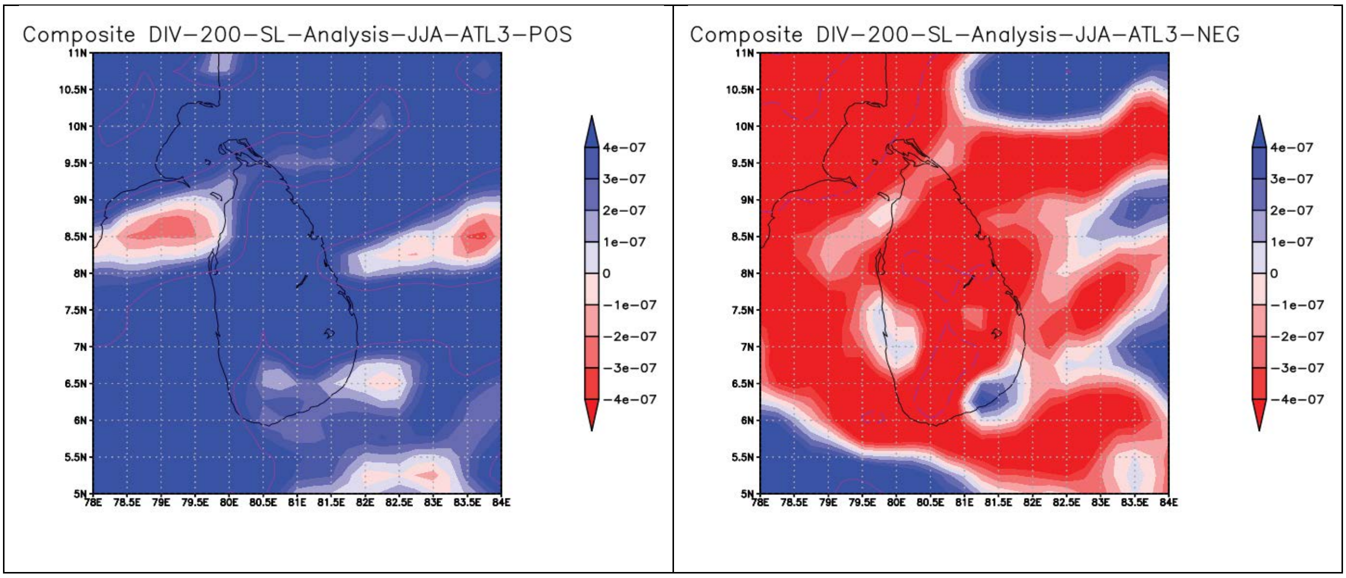

Figure 7: Composite seasonal Divergence anomalies at 200hPa level during Atlantic Niño (positive, a) years, Atlantic Niña (negative, b) for JJA period around Sri Lanka during 1981-2019 in s^{-1}. Purple lines shows 95% significance level.

here which are: the former has an oval shape while being located in the Blue Ridge province vs. the latter which has an elongated shape while being located in the Piedmont province; and dimensions between the two are significantly different. It should be noted that in the adjacent, structural province to the Blue Ridge, which is the Ridge and Valley province, there is the "Dungannon Polje", as only mentioned by Clark. Also, it's worth mentioning here about a similar landform known as a tectonic window or fenster, but here, the standard definition of it does not necessarily include any association to soluble bedrock lithologies.

In summing up here, we can rule out paleo-glacial ice of any age in creating the E – W, narrow and shallow valleys of both Valley Creek West and Valley Creek East, while designating these as either “nested poljes”, or in the case of Valley Creek East, only as a “nested uvala” which is another appropriate possibility. The erosional landforms underlying both creeks are encompassed by the whole landscape unit called Chester Valley while it is formally identified here in the current study as an elongated polje.

SE-trending watercourses

Clausen’s hypothesis includes “valley orientations” (termed by him), for example, the following SE-trending, rivers, streams, creeks and tributaries: the Schuylkill River, East Branch Brandywine Creek, West Branch Brandywine Creek, Wissahickon Creek (north of Philadelphia, PA) and several Octoraro Creek tributaries, all within Chester County, PA. He believed these resulted from SW-flowing, floodwaters originating from a fast-melting, paleo-glacial margin belonging to a speculative, ancient, continental ice sheet that operated far beyond (south of) the late Wisconsinan glacial margin and even far beyond (south of) the till limit of Illinoian and Pre-Illinoian continental glaciers Figure 1. But to the contrary, Clark explains the origin of the SE-trending watercourses by referring to Faill who documented sedimentological evidence supporting a Mesozoic-age, sub-aerial, deltaic, fan which hosted and influenced the previously-mentioned, SE-trending Schuylkill River within the structural Newark-Gettysburg Basin. Clark also included a major trunk valley containing the SE-oriented Susquehanna River (located outside of Chester County and within PA) as flowing on the paleo-deltaic fan too during Mesozoic time. These two rivers do show up on the map of Sevon and Braun although they are not labeled on this map. Thus, both SE-trending watercourses are correlated to all of the above previously-mentioned, modern-day, SE-trending watercourses which inherited their original SE direction from paleo-fluvial flowage upon a deltaic fan that survived through the ages of geologic time, while these simply kept actively flowing within entrenched channels in the same SE direction up to the present time.

Conclusions

The current study gives ample proof negating Clausen’s hypothesis of a paleo-glacial margin and paleo-flooding in Chester County, PA, USA as an origin for the discussed assemblage of different, erosional landforms. It is demonstrated here that other grouped, geological factors were responsible for most of the landforms’ origin such as a combination of tectonics, structure, lithology, and basic geomorphological processes. Even more important, the current study uncovered new revelations by identifying the very large, megascale-size, Chester Valley in PA as an elongated polje. Associated with that, the true nature of the “through-valley” (termed by Clausen) is identified as either a “nested polje” or a “nested uvala”. Nested poljes most probably embody both Valley Creek East and Valley Creek West because of a series of small, leveled, symmetric and asymmetric synclines underlying Chester Valley even while Chester Valley’s origin is structurally controlled by only a fault, rather than to the underlying synforms associated with the creeks. Meanwhile, an alternate explanation is considered for only Valley Creek East because it may be a “nested uvala” since the possibility of only paleo-dissolutional processes overprinted a part of Chester Valley’s polje. It’s emphasized here that the key to comprehending the genesis of Chester Valley was originally hinted at by Bascom because they were the first investigators to say the megascale size valley was not formed by a river running through it, but instead, formed by wholesale, carbonate dissolution of it. Overall, both the discussed karst landforms and non-karst landforms of the current study are all related to tectonics, structure and particular geomorphological processes. Only one of the discussed landforms in the current study do not share the same, above, geological characteristics which is the grouped, SE-trending watercourses that have a remarkable, inherited, persisting quality to them, ongoing ever since Mesozoic times. Clausen was honest enough to admit having many unanswered questions about his own hypothesis, in which case, supplements the nullification given here, as verified by the current study.

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