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Comparative Systematic Analysis of Milankovitch Cycles to Identify Variations of Glaciers and Interglacial Periods of Late Pleistocene in South Asia

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Abstract

Variations in the first Euler angle known as Earth precession phenomenon which is described as a change in the Earth's orbit; found to have strong impact on the climate of Earth. These observations of climate changes were connected with the behavior of the global ice sheets, including their advancing and retreating movements which have been recorded. In fact, Earth's climate depends essentially on the cycle of glaciers' growth and reduction. The alternative glacial periods and the interglacial periods coincide with the variations in Earth's orbit known as "Milankovitch cycles", which affect the insolation, and the sunlight exposure of different regions of the world and thus ultimately the behavior of ice formation. This paper aims to document the variations of the Earth's axis orientation and to discuss how these changes have affected to the sea-level fluctuation of the South Asian Region during late Pleistocene. Experiment methodology consists of compelling a standardized dataset of the sea-level index (Data SET 01-Radiocarbon Journal, Katupotha. J, Data SET 02- SEAMIS database and selected 35 number of carbon dating values recorded and published in the literature of the South Asian Region) and then compare it with the data of Milankovitch Cycles. The discussed results show that the sea-level variations occurred mainly between 12,500 ± 1,500 $_{YBP}$ to 11,000± 1,500 $_{YBP}$, indicating that $25_m \pm 5_m$ recorded to be the lower sea level documented than the current sea level found around the South Asian region. This has been resulted by a quick glacier transition that happened in the Late Pleistocene.

***Keywords**: Milankovitch cycles, Sri Lanka, Sea Level, Carbon dating, Late Pleistocene.*

Introduction

The glacial-interglacial cycles over the late Pleistocene provide a strong framework for understanding the evolution of the climate events over the Holocene. The main objective is to study factors that effecting to changes of interglacial to glaciers environment and glaciers to the interglacial environment mainly focusing on Milankovitch cycles and sea-level fluctuation. However, 'Milankovitch cycles' are insufficient to explain the full range of late "Quaternary climate change, which is also required to compare with the influence of the greenhouse gas and the albedo variations, but they are a primary forcing that must be accounted (Milankovitch,1930). 'Milankovitch cycles' are classically divided into three components as the earth's precession, the earth's obliquity, and the earth's eccentricity cycles. These cycles modulate the solar insolation or its geographic distribution. Orbital and precession variations are also likely to be a generic feature of the other planets, with significant implications for the fate of planetary atmospheres and tend to help us understand the potential of habitability on the other planets. Especially, considering the partial harbour life environment of quaternary habitats in *Sabaragamuwa basin* observed during the late Pleistocene in Sri Lanka (Sumanarathna,2017). In fact, many proxy's data show that Earth's climate has under process the glacial-interglacial cycle with semiregular periodicity, with phases strongly linked to orbital variations (Hays et al., 1976; Huybers and Curry, 2006; Imbrie, 1984; Imbrie et al., 1992; Lisiecki and Raymo, 2005). For the past ~0.80 Ma, the main periodicity has been described as the eccentricity (~100 kyr) embedded with the precession (~21 kyr) and the obliquity (~40 kyr) signals (El Kibbi et al., 2001). Before ~0.8 Ma, the main signal was obliquity with weak eccentricity and precession signals (Imbrie, 1984; Lisiecki and Raymo, 2005), and this shift has been happened in the late to mid - Pleistocene transition that leads to amplify the initial cooling (Fig. 1).

Due to the predominance of northern hemispheric glaciers, the northern hemispheric insolation is usually the assumed driver of the glacial-interglacial cycle (Milankovitch, 1930). Having the strong signal of eccentricity during the past 0.8

Myr since the present has been puzzled because the effect of eccentricity on seasonal insolation is small (Imbrie et al., 1992), although eccentricity modulates precession (Lisiecki, 2010). However, it has been proposed that the 100 kyr cycle may be a modulation of the obliquity signal because the integrated seasonal insolation at a given location does not change with precession (Huybers, 2003, 2006). While numerous studies link paleo proxies to insolation forcing, there is yet no broadly accepted explanation for how ice ages started as well as why they follow a 100 kyr cycle, and why the pace of the glacial cycle changes in Quaternary.

Materials & Methodology

The methodology that has been applied for this study was to compile standardized datasets (https://github.com/Alerovere/SEAMIS) of the sea-level index and limiting points which meet the criteria recently summarized. It includes Data SET 01-Radio Carbon Journal, Katupotha. J (Ref: 10-14) carbon dating values in the west coast of Sri Lanka. Data SET 02- SEAMIS database, including another random carbon dating from India, Singapore, Malaysia, Maldives, Thailand, Vietnam, and Cambodia (Ref :8). In this paper, these geochronological data have been compared with the data of Milankovitch cycles.

Results

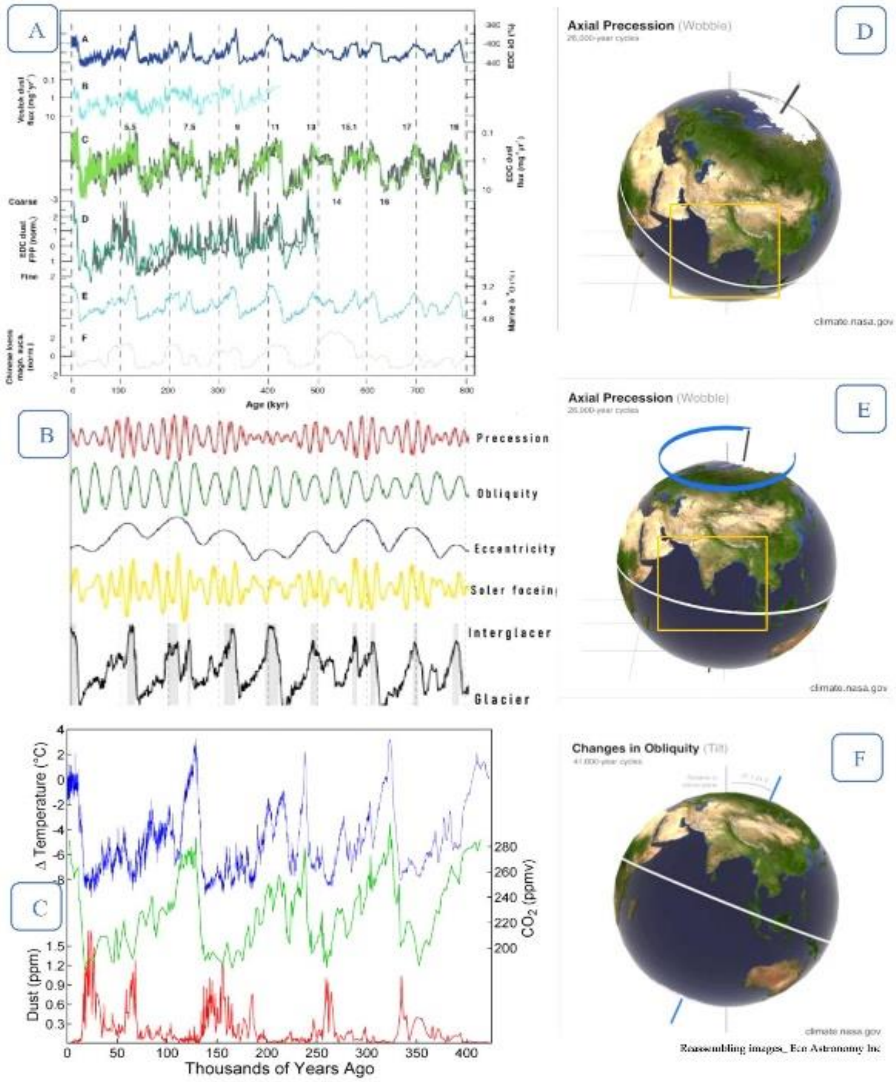


Figure 1. *(A) Variables of proxies in the last 0.8Ma and (B) Graph depicting orbital variations, solar energy changes, and resulting glacial cycles, as a consequence of Milankovitch cycles, demonstrating solar and orbital forcing of climate on 800kyr intervals; Adapted from Quinn et al. (1991) and Lisiecki and Raymo (2005). (C) Temperature Variations (blue), CO 2 (green), and Dust content (red) in an ice core dated 12kyr; Willy and Walter (2012). (D) and (E) Axial precession's stages via one cycle representing the Sun light exposure into the South Asian region; (Buis., 2020). (F) The Earth's axis angle of rotation is tilted as it travels around the Sun which is known as obliquity; (Buis., 2020).*

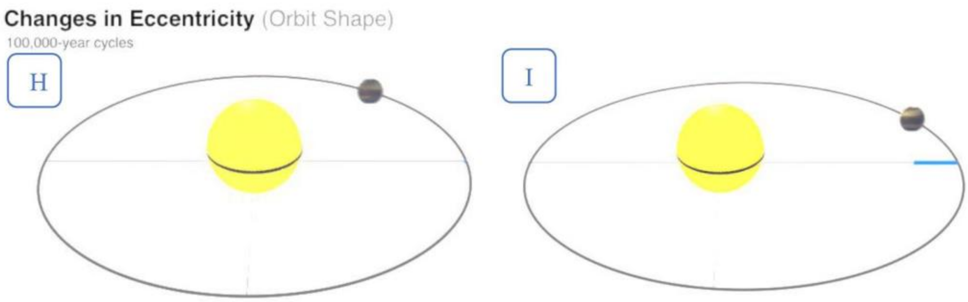


Figure 2: *(H) & (I)The shape of Earth's orbit, known as eccentricity, and its effectivity on surface temperature variation (Buis., 2020).*

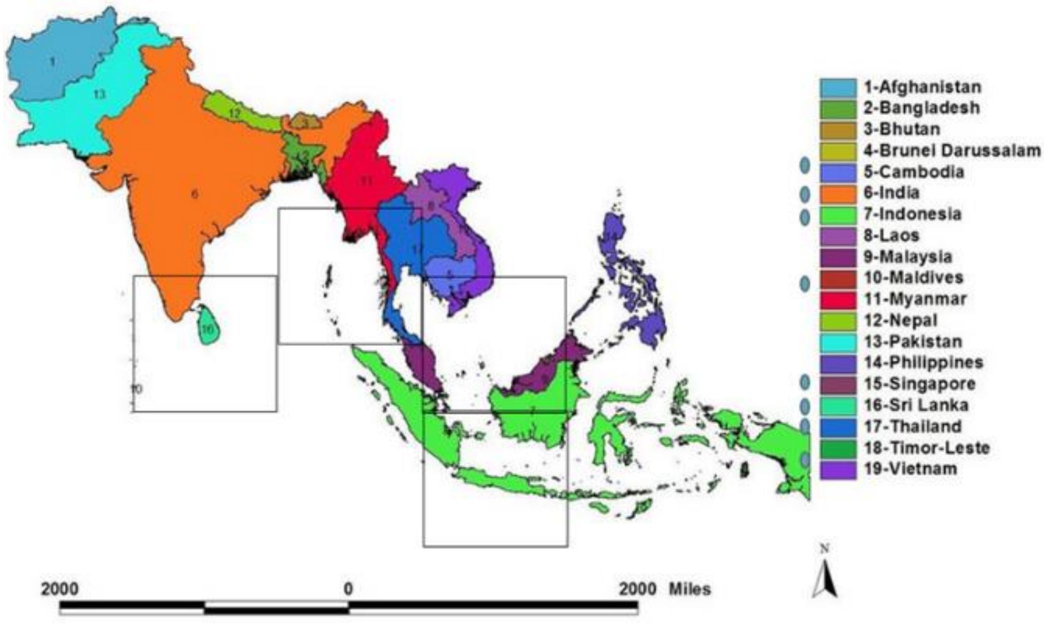
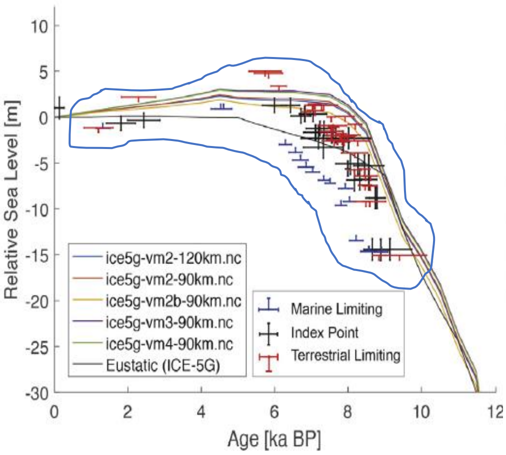


Figure 3: *Map representing region and counties of the sea-level index and limiting points meet the criteria recently summarized (https://github.com/Alerovere/SEAMIS).*

Model short name	Ice model	Earth model parameters
ice5g-vm2-90km.nc	ICE-5G	Upper Mantle = 0.25 × 10^{21} Pa•s Transition Zone = 0.5 × 10^{21} Pa•s Lower Mantle = 5 × 10^{21} Pa•s Lithosphere Thickness = 90 km
ice5g-vm2b-90km.nc	ICE-5G	Upper Mantle = 0.25 × 10^{21} Pa•s Transition Zone = 0.25 × 10^{21} Pa•s Lower Mantle = 5 × 10^{21} Pa•s Lithosphere Thickness = 90 km
ice5g-vm2-120km.nc	ICE-5G	Upper Mantle = 0.25 × 10^{21} Pa•s Transition Zone = 0.5 × 10^{21} Pa•s Lower Mantle = 5 × 10^{21} Pa•s Lithosphere Thickness = 120 km
ice5g-vm3-90km.nc	ICE-5G	Upper Mantle = 0.25 × 10^{21} Pa•s Transition Zone = 0.5 × 10^{21} Pa•s Lower Mantle = 10 × 10^{21} Pa•s Lithosphere Thickness = 90 km
ice5g-vm4-90km.nc	ICE-5G	Upper Mantle = 0.25 × 10^{21} Pa•s Transition Zone = 0.5 × 10^{21} Pa•s Lower Mantle = 100 × 10^{21} Pa•s Lithosphere Thickness = 90 km

Table 1: *Details on the Earth model parameters and different mantle viscosity profiles employed to simulate glacial isostatic adjustment combined with the Ice model ICE-5G in the areas of interest(https://github.com/Alerovere/SEAMIS). Model short names refer to the different model curves in graph A and B*



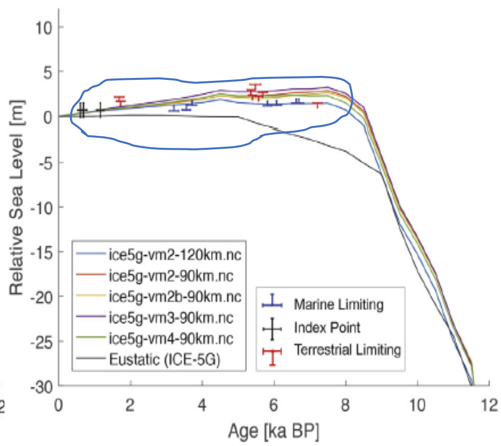


Figure 4: *Graph A (Left) Average values of relative sea-level data index (https://github.com/Alerovere/SEAMIS) relevant to observed countries, as mentioned in fig.3. Graph B (Right) Average values of relative sea-level data index; Katupotha. J (Ref: 10-14) Sri Lanka (Mann et al, 2019 and Sumanarathna et al, 2021)*

Discussion

Interpreting "Fig.1-B" the grey represents the peaks of global variations in temperature that identify interglacial periods of relatively warm climate typical recorded over the past thousands' years; the ice periods are represented by the valleys between peaks of grey areas; the three curves on the top are the Milankovitch cycles of Earth's orbital changes caused by the precession, the obliquity of polar axes, as well as the eccentricity of the orbit these cycles where changes to orbital eccentricity occur at 400,000 and 100,000yr intervals; the variations in axial tilt occur at 40,000yr intervals, and the changes in the axial precession occur at 25,000yrs (Wanner et al., 2008; Bennet, 1990; Imbrie and Imbrie, 1979, Dawson, 1992; Raymo and Nisancioglu, 2003); in addition, the fourth curve is the changes documented for the solar forcing; finally, the bottom curve is the temperature changes which get impacted by these other influences. The orbital variations, solar energy changes and resulting glacial cycles, as a consequence of Milankovitch cycles, demonstrating solar and orbital forcing of climate on 100kyr intervals (Fig.1-B) shows the effects of Precession, Obliquity, Eccentricity, and Solar Forcing which refers to the quantity of solar radiation that reaches the Earth's atmosphere as a result of both solar and astronomical forcing (Berger et al., 2013), which includes axial orientation and positioning relative to the Sun on Glacial Interglacial cycles.

Earth's orbit wobbles shown in "Fig.1-D, E," called Precession cycles, result in a change of the amount of sunlight at middle latitudes by up to 25% and cause the climate to oscillate. Using deep-sea sediment cores found that Milankovitch cycles correspond with periods of major climate change over the past 450,000 years, with Ice Ages occurring when Earth was undergoing different stages of orbital variation (Buis., 2020). When Earth's orbit made northern summers warmer than average, huge pieces of ice were melted through North America, Europe, and Asia; but then when the orbit cooled northern summers, those ice sheets started to advance again. In fact, oceans dissolve less carbon dioxide when it reaches low temperatures, which will lead to a reduction in the atmospheric carbon dioxide levels (Fig.1-C), and this will fall in concert with these orbital wobbles, multiplying their impacts. Also, as mentioned in Fig .1-C, the amount of dusty particle has been increased around 10.5ka to 12.5 ka. It could be a result of a meteorite impact more specifically; it could take place during the younger dryas condition.

After measuring (Fig. 2 and 3) the centricity of how circular a curve is with e=0 describing a circular orbit, $0 < e < 1$ is an elliptic orbit, e=1 describing a parabolic trajectory, and $e > 1$ is for hyperbolic trajectory; taking in consideration the timescale of Earth's eccentricity variation during the 100,000-year cycle as it is represented in "Fig. 2" the orbital eccentricity characterizes in this case how circular e=0.0034 (Fig. 2-H) or slightly elliptical-shaped e=0.058 (Fig. 2-I) our planet Earth orbit around the Sun. Moreover, this orbital eccentricity could explain and even be considered to have directly impacted the climate change recorded in the Asian region. Due to the variations in the quantity of the solar energy received on Earth, as the northern hemisphere winters become relatively longer and the summers become shorter; which will have effects in the sea-level index represented in "Fig. 3". This case observed in the glacial and the interglacial cycles that have driven immense variation in the mean sea level globally (Lambeck and Chappell 2001). These cycles are controlled by eccentricity, which brings us to assume that Milankovitch orbital cycles are the reason for the Earth's glacial and interglacial cycles and the first-order climatic changes, which have caused sea-level oscillations that were important during the Quaternary (Hays, Imbrie & Shackleton, 1976; Muller & MacDonald, 1997; Wunsch, 2004).

(Table. 1 and fig. 4) Graph A (Left) represent the average values of relative sea-level index relevant to observed countries and Graph B (Right) of "fig.4" created based on data mentioned in "table. 1" indicate the average values of relative sea-level data index in Sri Lanka, after analyzing the curves on both graphs it is obvious that during years the average sea-level has been changed, the driving force behind these large-scale changes is 'orbital forcing'. Considering the past period globally speaking so far in the previous 18,000 years ago, the Earth's temperature has risen approximately 9 °F that results in a risen of sea level by 300 feet. 18,000 years ago, the climate begins to warm up (Smith et al., 2013), then 15,000 years ago advance of glaciers halts and sea levels begin to rise, followed by the ice age megafauna that goes extinct

10,000 years ago, still, 8,000 years ago Bering Strait land bridge becomes drowned, stopping the migration of men and animals (Sumanarathna,2017). Collectively, variations in Earth's orbit which are known as eccentricity, obliquity, and precession, can either reinforce signatures of cooling or warming, much more they can counteract each other and produce less severe or ameliorated climate change.

Conclusion

The above results show that the sea-level variations occurred between 12,500 ± 1,500 $_{\mathrm{YBP}}$ to 11,000± 1,500 $_{\mathrm{YBP}}$, indicating that $25_{\mathrm{m}} \pm 5_{\mathrm{m}}$ recorded to be the lower sea-level documented compared to the current sea-level found around the South Asian region (https://github.com/Alerovere/SEAMIS). Considering the fundamental data of precession, obliquity, and eccentricity, including the glacier cycles data, represent the gradual temperature drop between 13.5ka to 10.5ka. When Earth's orbit becomes more eccentric, the semi-minor axis shortens. That will result in an increase of the seasonal changes magnitude. The sea ice growth is concluded to be a rapid—ice increased in the South Asian ocean affecting the precession stage with long-lasting low sunlight and albedo. Though the situation of planet Earth indicate that we are approaching again the minimum amount of sunlight, in other words, we are going towards a new ice age within no less than 14,000 years (Fig. 5). More further studies based on statistical data of those selected countries are needed, which will give us a clear understanding on what has happened.

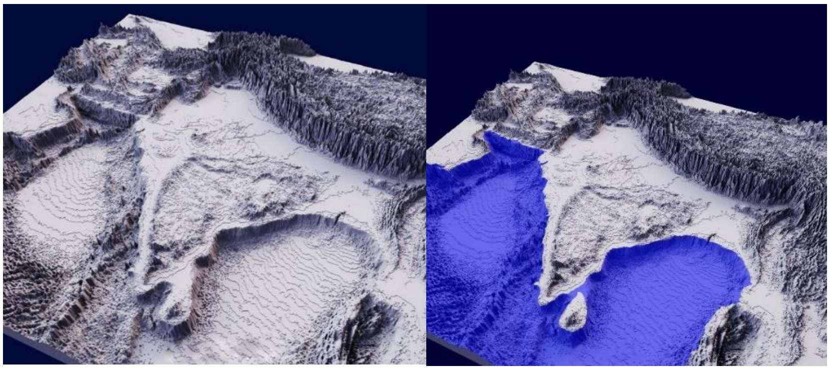


Figure 5: *A simulation model for average sea-level fluctuations in South Asia, around 12,000 yr. BP-12,800yr BP. (Left: Glacier model and Right: Warm and inter glacier model)*

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References

Berger, M.-F. L. and Yin, Q. Z. (2013) 'Glaciation, Causes. Astronomical Theory of Paleoclimates'. In *Encyclopedia of Quaternary Science* (. ed) by S. A. Elias and C. J. Mock. Elsevier: Amsterdam, 136-141.

Elkibbi, M., & Rial, J. A. (2001). An outsider's review of the astronomical theory of the climate: Is the Eccentricity-driven INSOLATION the main driver of the ice ages? *Earth-Science Reviews*, 56(1-4), 161-177. doi:10.1016/s0012-8252(01)00061-7.

Huybers, P., Curry, W. (2006). Links between annual, Milankovitch and continuum temperature variability. *Nature*, 441, 329–332.

Huybers, Peter J. (2006). Early Pleistocene glacial cycles and the integrated summer insolation forcing. *Science*, 313(5786), 508-511.

Lisiecki, L. E., and Raymo, M. E. (2005). A Pliocene-Pleistocene stack of 57 globally distributed benthic d 18O records. *Paleoceanography*, 1-17.

Lisiecki, L. E. (2010). A benthic δ13 C-based proxy for atmospheric pCO 2 over the last 1.5 Myr, *Geophysical Research Letters*,1-5

Lambeck, K. and J. Chappell. (2001). 'Sea Level Change Through the Last Glacial Cycle'. *Science,* 292, 679 – 686.

Mann, T., Bender, M., Lorscheid, T., Stocchi, P., Vacchi, M., Switzer, A. A. (2019). Rovere, Holocene sea levels in Southeast Asia, Maldives, India and Sri Lanka: the SEAMIS database. *Quat. Sci. Rev*.112: 125.

Milankovitch, M. (1930). Mathematische Klimalehre und Astronomische Theorie der Klimaschwankungen. *Handbuch der Klimatologie. 1 Teil A. von Gebrüder Borntraeger*

Katupotha, J. (2019). Holocene sea-level changes of the southern coast of Sri Lanka. *Bulletin of the Sri Lanka Association of Geographers,* Volume 1. No.1 2019, 1-31.

Katupotha, J. Evolution and Geological Significance of Holocene Emerged Shell Beds on the Southern Coastal Zone of Sri Lanka. *Journal of Coastal Research*, Vol. 11, No.4, Fall 1995, 1042-1061.

Katupotha, J. (1989). "Coastal landforms during the Holocene Epoch in Sri Lanka: are they comparable to those in Brazil and Venezuela, Ext. Abs." *International Symposium on Global changes in South America during the Quaternary,* Sao Paulo (Brazil), 188-191.

Katupotha, J. (1988a). "Hiroshima University Radiocarbon Dates l: West and South Coasts of Sri Lanka." 30(1), 125-128.

Katupotha, J. (1988b). "Hiroshima University Radiocarbon Dates ll: West and South Coasts of Sri Lanka." 30 (3), 341-346.

Sumanarathna, A.R., Katupotha, J., El Haouari Aouititen, M. (2019). Comparative Systematic Analysis of Proxy to Indicate Younger Dryas Cooling in Late Pleistocene in Sri Lanka. Conference: *First research conference - Ocean University of Sri Lanka*,01.8.

Sumanarathna, A.R., Katupotha, J., Abeywardhana, K., and Madurapperuma, B. (2017). Extinction of Quaternary mammalian habitats of megafauna in Sabaragamu Basin, Sri Lanka. *Journal of Eco Astronomy,* 01,16-31

Smith, D. E., Harrison, S., and Jordan, J. T. (2013). 'Sea level rise and submarine mass failures on open continental margins. *Quaternary Science Reviews* 82, 93-103.

Wanner, H., Beer, J., Butikofer, J., Crowley, T. J., Cubasch, U., Fluckiger, J., Goose, H., Grosejean, M., Joos, F., Kaplan, J. O., Kuttel, M., Muller, S. A., Prentice, I. C., Solomina, O., Sotcker, T. F., Tarasov, P., Wagen, M., and Widmann, M. (2008). 'Mid-to Late Holocene Climate Change: an overview'. *Quaternary Science Reviews* 27 (19-20), 1791-1828

Buis, A. (2020, May 05). Milankovitch (Orbital) cycles and their role in Earth's Climate – climate Change: Vital signs of the planet. Retrieved February 25, 2021, from https://climate.nasa.gov/news/2948/milankovitch-orbital-cycles-and-their-role-in-earths-climate

Sumanarathna, A. R. (2021, February 02). (PDF) comparative systematic analysis of proxy to INDICATE ... Retrieved February 02, 2021, from https://www.researchgate.net/publication/338073575_Comparative_Systematic_Analysis_of_Proxy_to_Indicate_Younger_Dryas_Cooling_in_Late_Pleistocene_in_Sri_Lanka