Paleomonsoon Reconstruction Using Marine Proxies of the Indian Ocean

A THESIS

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By

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CERTIFICATE

I feel great pleasure in certifying that the thesis entitled "Paleomonsoon Reconstruction Using Marine Proxies of the Indian Ocean" by Mr. Pullabhatla Kiran Kumar has been completed under my guidance.
He has completed the following requirements as per Ph.D. regulations of the University:
(a) Completion of the Course Work as per the university rules.
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(c) Regular submission of six monthly progress reports.
(d) Presentation of his work in the Departmental Committee.
(e) Publication of at least one research paper in a referred research journal.

I am satisfied with the analysis of the data, interpretation of the results, and conclusions drawn. I recommend the submission of the thesis.

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DECLARATION

I, Mr. Pullabhatla Kiran Kumar, S/O Mr. (Late) Pullabhatla Nageswara Rao, resident of C-102, Block-1, Navrangpura, Ahmedabad - 380009, hereby declare that the research work incorporated in the present thesis entitled "Paleomonsoon Reconstruction Using Marine Proxies of the Indian Ocean" is my own work and is original. This work (in part or in full) has not been submitted to any University or institute for the award of a degree or a diploma. I have properly acknowledged the material collected from secondary sources wherever required and I have run my entire thesis on the anti-plagiarism software namely "iThenticate".

I solely own the responsibility for the originality of the entire content.

Date: Pullabhatla Kiran Kumar

Place: (Author)

Dedicated to

My parents and

all my mentors

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Finally, my last five years of Ph.D. work has now come to an end; however, I believe this is just the beginning of my scientific research career many more to achieve in future. I owe a lot of people and I pay my sincere gratitude to them for their immense support and motivation, without which it wouldn't have been possible for me to complete this in time.

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Abstract

Stable isotopes of hydrogen, carbon and oxygen are used as a tool to study modern seawater hydrological dynamics (effect of runoff and large-scale ocean mixing) and to reconstruct past climate from ocean sediment cores. Significant variations in the Indian monsoon (IM), at intra-seasonal, annual, centennial to millennial time scales, are observed due to changes in the inter-hemispheric (northern and southern) dynamics, ice sheet extensions (glacial and interglacial) and short term climate processes. This thesis reports results on oceanic changes based on measurements of stable isotopic composition ($\delta^{18}O$, δD) carried out on modern seawater samples and inferences on IM from the stable isotopic composition ($\delta^{18}O$, $\delta^{13}C_{org}$, and $\delta^{15}N$) of three sediment cores over the last ~ 70 ka raised from the northern Indian Ocean (NIO).

Isotopic compositions ($\delta^{18}O$ and δD) of surface seawater samples from NIO show significant spatial and temporal variability. Seasonal variability in the linear $\delta^{18}O$ – S relation (slope and intercept) of surface waters of the NIO are observed with stronger $\delta^{18}O$ – S and δD – $\delta^{18}O$ relations during the winter than the spring time. During winter time, runoff effects dominated on the $\delta^{18}O$ – S. Substantial changes in the slope and intercept of $\delta^{18}O$-S relation for subsurface waters could be a characteristic of water mass dynamics in NIO. Reanalysis of large volume of recently published results on salinity and $\delta^{18}O$ measurements of surface seawater suggests that variation in the $\delta^{18}O$ of the eastern Arabian Sea is mainly controlled by the influx of low salinity water from relatively fresher Bay of Bengal through winter time boundary currents.

Based on the sedimentary records from NIO, significantly strong and weak monsoon periods associated with the global climatic events during the last ~70 ka were observed. Record from the Andaman Sea sediment core shows an abrupt decrease in the ISM during the mid-Holocene (7-4.5 ka). During the Last Glacial Maximum, the Andaman Sea salinity was 2 (psu) higher than the early Holocene. $\delta^{18}O$ analysis of mixed habitat planktonic foraminifera species shows significant variation in the stratification over the NIO during last ~ 70 ka. In contrary to the earlier inferences, the present work based on a compilation of high-resolution $\delta^{18}O$

foraminifera records from the eastern Arabian Sea provides evidence that the south Asian summer monsoon steadily declined during the Holocene. Abrupt variation in the $\delta^{18}O$ values of *G. ruber* in response to short term climatic events were observed: with warm (cold) Dansgaard-Oeschger (Heinrich) events associated with relatively stronger (weaker) monsoon periods. The bulk sediment analysis for $\delta^{15}N$, $\delta^{13}C_{org,}$ and N & C_{org} (wt %) infers a substantial variation in the productivity over the western Bay of Bengal, associated with the variability in the upper ocean stratification during the last ~ 16 ka.

El-Niño Southern Oscillation (ENSO) is known to have affected IM: most of the severe droughts in India are associated with active ENSO periods. Given the heterogeneity in rainfall patterns over India, the ENSO influence on Indian summer monsoon has been revisited. During strong El-Niño events, the multiple isotopic (proxy-based) and satellite data set show a weaker summer monsoon over central India (CI) and relatively stronger summer monsoon over northeast India (NEI). The general circulation model derived $\delta^{18}O_{rain}$ variation over the CI during ENSO events mimic the weaker rainfall conditions. Since these observations were unprecedented and counterintuitive, further verification from paleo-proxy records (speleothem cave deposits) showed a similar dipole nature of rainfall patterns over CI and NEI during ENSO periods, confirming observed ENSO's role on rainfall. Both instrumental and paleoclimate proxy records showed a decadal variability in the ISM concurred with variation in the El-Niño strengths. Armed with this new "calibration" of $\delta^{18}O_{rain}$ and ENSO, we infer that the high-resolution speleothem records from CI an NEI based stronger (weaker) rainfall conditions over CI (NEI) during 1625 – 1715 AD, represents an absence of long term El-Niño or stronger La-Niña like conditions over the central Pacific Ocean.

Keywords: Indian Summer Monsoon, Stable isotopes, ENSO, LGM, Ocean stratification, Foraminifera, Deep-sea sediment, Speleothem, Bay of Bengal, Arabian Sea.

Abbreviations

θ	: Potential Temperature
σ_θ	: Water Density
‰	: per mill
$\delta^{13}C$	: Isotopic composition of carbon with respect to VPDB
$\delta^{15}N$	: Isotopic composition of nitrogen with respect to Air N_2
$\delta^{18}O$	: Isotopic composition of oxygen with respect to (VPDB, VSMOW)
δD	: Isotopic composition of hydrogen with respect to VSMOW
AMS	: Accelerator Mass Spectrometer
AS	: Arabian Sea
ASHSW	: Arabian Sea High Saline Water mass
BOB	: Bay of Bengal
BoBW	: Bay of Bengal Water mass
C	: Carbon
CI	: Central India
CTD	: Conductivity Temperature Depth
D	: Deuterium
DIC	: Dissolved Inorganic Carbon
DO	: Dansgaard Oeschger
E	: Evaporation
EA	: Elemental Analyzer
EICC	: East India Coastal Current
ENSO	: El-Niño Southern Oscillation
FORV	: Fishery Oceanographic Research Vessel
GB	: Gas Bench
GC	: Gas Chromatograph
GCM	: General Circulation Model
GMWL	: Global Meteoric Water Line
GNIP	: Global Network of Isotopes in Precipitation
GPCP	: Global Precipitation Climatology Project
H	: Hydrogen
HE	: Heinrich Event
IAEA	: International Atomic Energy Agency
IAPSO	: International Association for the Physical Sciences of the Oceans
IOD	: Indian Ocean Dipole
IRMS	: Isotope Ratio Mass Spectrometer
ISM	: Indian Summer Monsoon
ITCZ	: Inter Tropical Convergence Zone

LGM	: Last Glacial Maxima
LMWL	: Local Meteoric Water Line
MIS	: Marine Isotopic Stage
MJO	: Madden Julian Oscillation
MLD	: Mixed Layer Depth
MMB	: Makrana Marble
N	: Nitrogen
NARM	: Narmada water
NEI	: North East India
NIO	: Northern Indian Ocean
O	: Oxygen
OMZ	: Oxygen Minimum Zone
P	: Precipitation
PDO	: Pacific Decadal Oscillation
PRL	: Physical Research Laboratory
PGW	: Persian Gulf Water mass
R	: Runoff
RSW	: Red Sea Water mass
S	: Salinity
SC	: Somalia Current
SEAS	: South Eastern Arabian Sea
SST	: Sea Surface Temperature
SLAP	: Southern Light Antarctic Precipitation
SWING	: Stable Water Isotope Intercomparison Group
TD	: Thermocline Depth
TRMM	: Tropical Rainfall Measuring Mission
VPDB	: Vienna Pee Dee Belemnite
VSMOW	: Vienna Standard Mean Ocean Water
WICC	: West India Coastal Current
WICO	: Inter-laboratory comparison exercise for δ^2H and $\delta^{18}O$ analysis of water samples
WMC	: Winter Monsoon Current
WMO	: World Meteorological Organization

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1. **Kumar. P. K**., Ramesh. R. (2017). *Revisiting reconstructed Indian monsoon rainfall variations during the last ~25 ka from planktonic foraminifera $\delta^{18}O$ from the Eastern Arabian Sea*. Quaternary International, 443, 29-38.

2. **Kumar. P. K**., Singh. A., Ramesh. R., Nallathambi. T. (2017). *N_2 fixation in the Eastern Arabian Sea: Probable Role of Heterotrophic Diazotrophs*. Frontiers in Marine Science, 4:80, 1-10.

3. **Kumar. P. K**., Shraddha. B., Ramesh. R., Awasthi. N. (2018). *Monsoon variability and upper ocean stratification during the last ~66 ka over the Andaman Sea: inferences from the $\delta^{18}O$ records of planktonic foraminfera*. Quaternary International, 479, 12-18.

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1. **Kumar. P. K**., Arvind Singh., Ramesh. R. (2019). *Increase in summer monsoon rains in northeast India during ENSO periods*. (Climate Dynamics).

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1. Gautam, P. K., Narayana, A.C., **Kumar. P. K**., Ramesh, R. (2019). *Indian Monsoon variability during last ~46 ka over the southwestern Bay of Bengal: as inferred from planktonic foraminifera isotope studies* (To be submitted: Journal of Quaternary Sciences).
2. **Kumar. P. K**., Singh, A., and Ramesh, R (2019). *Vertical distribution of $\delta^{18}O$ in the Arabian Sea and its implication for water masses dynamics*.

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1. **Kumar. P. K**., *Importance of Paleoceanographic study from Thermocline Ridge of Indian Ocean*, during 16th -17th June, 2016. Recent Trends in Isotope Geochemistry Conference, Physical Research Laboratory, Ahmedabad, India.

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3. **Kumar. P. K**., Arvind Singh, Ramesh, R. *Spatio-temporal variation of rainfall over Indian in response to ENSO:* SISAL's 2nd workshop, 20th - 22nd September, 2017, University of Stockholm, Stockholm, Sweden.

4. **Kumar. P. K**., Shraddha. B., Ramesh. R., Awasthi. N. *Paleomonsoon reconstruction of Andaman Sea: inferences from the $\delta^{18}O$ records of planktonic foraminfera*. GIAN short course on "Reconstruction of the Asian Monsoon System New Approaches and Techniques" during 17th - 27th October, 2017, Indian Institute of Technology, Kanpur, Uttar Pradesh. India.

5. Prateeksha. N., **Kumar. P. K**., Yadava. M.G. *High resolution $\delta^{18}O$ and δD measurements of atmospheric water vapour during end of a monsoon season from western India.* NSSS-2019. 29th - 31st January, 2019, Pune, India.

6. **Kumar. P. K**., Arvind Singh, Ramesh, R. *Spatial variability of $\delta^{18}O$ rainfall and teleconnection with global processes: Implication for paleoclimate studies***.** SPATIAL: International Summer School, 10th - 21st June, 2019, University of Utah, Utah, USA.