Stable Water Isotopologues in the Indian Summer Monsoon Rainfall

A thesis submitted in partial fulfillment of

the requirements for the degree of

Doctor of Philosophy

by

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Declaration

I declare that this written submission represents my ideas in my own words and where others' ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above can cause disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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CERTIFICATE

It is certified that the work contained in the thesis titled **"Stable Water Isotopologues in the Indian Summer Monsoon Rainfall"** by **Midhun M** (IITGn Roll No: 11330015), has been carried out under my supervision and that this work has not been submitted elsewhere for a degree.

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Abstract

Stable oxygen isotope ratios ($\delta^{18}O$) of tree cellulose and speleothem carbonate are useful proxies for past monsoon rain in many tropical regions, as in such region a decrease in rain $\delta^{18}O$ accompanies an increase in rainfall on a monthly time scale. This amount effect varies spatially; therefore a local calibration, with actual measurements of rain amount and its $\delta^{18}O$ is required. Such observations, however, are quite limited in space and time. This thesis is aimed to improve the understanding of factors that control the $\delta^{18}O$ of Indian monsoon rainfall. For the present study water vapor samples were collected from the marine atmosphere over the Bay of Bengal (BoB) and rainfall sampled from Central and Northern India. The multiple simulations from isotope enabled General Circulation Models (GCM) are also used to understand the variability of the $\delta^{18}O$ of the Indian Summer Monsoon (ISM) rainfall on daily to interannual time scales.

Measurements of stable isotopic compositions ($\delta^{18}O$ and δD) of water vapor collected from the BoB helps characterize both ISM vapor and North East Monsoon (NEM) vapor. This study shows that vapor $\delta^{18}O$ is higher during ISM compared to NEM with higher d-excess during NEM. This seasonal difference is possibly due to the seasonality in sea surface conditions, change in circulation pattern and changes in the type of rain forming systems (monsoon depression during ISM vs. tropical cyclones during NEM). The stable isotopic composition of water vapor estimated using Craig and Gordon model with the closure assumption (i.e., evaporation from the BoB is the only source of vapor) matches well with the measured values during non rainy days of ISM, whereas, it shows a large deviation from the model estimate during NEM season. The deviation from model estimate is negatively correlated with the rainfall along parcel trajectory (upstream rainfall) during both the seasons. The convective downdraft associated with tropical cyclones during NEM also plays major role in the lowering of vapor $\delta^{18}O$.

During ISM 2013, rain water samples were collected on a daily basis from six different cities (Ahmedabad, Bhopal, New Delhi, Kanpur, Varanasi and Dhanbad) spread over central and northern India and stable isotopic analyses were carried out. A weak amount effect (negative correlation between local rain and its $\delta^{18}O$) is observed at five out of the six stations, which explains ∼7-22 % of intraseasonal variation of $\delta^{18}O$ of rain. The nudged simulations from an isotope-enabled General Circulation Model (IsoGSM) is compared with the observations. Though the model has some limitation in simulating the accurate spatio-temporal pattern of rainfall, the model simulated rain $\delta^{18}O$ is in good agreement with the observations. This study suggests strong control of moisture transport pathways on daily rain $\delta^{18}O$ at Ahmedabad, Bhopal and New Delhi. At New Delhi this effect is observed on intraseasonal to interannual timescales.

Many isotope enabled General Circulation Models (GCM) are used to aid the interpretation of rainfall-^{18}O based proxies; nevertheless, all such simulations taken together remained to be evaluated against observations over the Indian Summer Monsoon (ISM) region. This study also examine ten such GCM simulations archived by the Stable Water Isotope INtercomparison Group, phase 2 (SWING2). The spatial patterns of simulated ISM rainfall and its $\delta^{18}O$ are in good agreement with the limited observations available. Simulations nudged with observed wind fields show better skill in reproducing the observed spatio-temporal pattern of rainfall and its $\delta^{18}O$. A large discrepancy is observed in the magnitude of the simulated amount effect over the Indian subcontinent between the models and observations, probably because models simulate the spatial distribution of monsoon precipitation differently. Nudged simulations show that interannual variability of rainfall $\delta^{18}O$ at proxy sites are controlled by either regional (rather than local) rainfall or upstream rain out. Interannual variability of rainfall $\delta^{18}O$ over the East Asian region is well correlated with El Niño Southern Oscillation (ENSO), while it is only weakly correlated over the Indian sub-continent.

Key points:

- An important data set of stable isotopic composition of water vapor from Bay of Bengal during ISM and NEM were generated and studied for the first time.
- The role of moisture pathways on ISM rainfall $\delta^{18}O$ variability over central and northern India is addressed using observations and model simulation.
- The present day ISM simulations from ten isotope-enabled GCMs were validated and used to examine the factors that control interannual variability of ISM rainfall $\delta^{18}O$.

Keywords: *Indian Summer Monsoon, Stable water isotopologues, Amount effect, isotope enabled General Circulation Models, Paleomonsoon*

Abbreviations

δD	Stable hydrogen isotopic composition of water relative to VSMOW standard.
δD_p	Stable hydrogen isotopic composition of precipitation relative to VSMOW standard.
δD_v	Stable hydrogen isotopic composition of water vapor relative to VSMOW standard.
$\delta^{18}O$	Stable oxygen isotopic composition of water relative to VSMOW standard.
$\delta^{18}O_p$	Stable oxygen isotopic composition of precipitation relative to VSMOW standard.
$\delta^{18}O_v$	Stable oxygen isotopic composition of water vapor relative to VSMOW standard.
‰	per mil (parts per thousand).
AS	Arabian Sea.
BoB	Bay of Bengal.
CAM	Community Atmosphere Model.
CE	Common Era.
CMAP	CPC Merged Analysis of Precipitation.
ECMWF	The European Center for Medium-Range Weather Forecasts.

ENSO	El Niño Southern Oscillation.
GCM	General Circulation Model.
GISS	Goddard Institute for Space Studies.
GMWL	Global Meteoroic Water Line.
GNIP	Global Network for Isotopes in Precipitation.
GPCP	Global Precipitation Climatology Project.
HadAM	Hadley Center Atmospheric Model.
HYSPLIT	The Hybrid Single Particle Lagrangian Integrated Trajectory Model.
IAEA	International Atomic Energy Agency.
IRMS	Isotopic Ratio Mass Spectrometer.
ISM	Indian Summer Monsoon.
IsoGSM	Isotope-enabled General Spectral Model.
IST	Indian Standard Time.
ITCZ	Inter Tropical Convergence Zone.
JJAS	June, July, August, September.
LLJ	Low Level Jet.
LMDZ	Laboratoire de Meteorologie Dynamique GCM.
MERRA	Modern-Era Retrospective Analysis For Research And Applications.
MIROC	Model for Interdisciplinary Research on Climate.

NARM	Internal laboratory slandered: NARMada river water.
NCEP	National Center for Environmental Prediction.
NEM	North East Monsoon.
NOAA	National Oceanic and Atmospheric Administration.
PCE	Post Condensation Exchange.
SST	Sea Surface Temperature.
SWI	Stable Isotopologueous of Water.
SWING2	Stable Water Isotope INtercomparison Group, phase 2 (SWING2).
TRMM	Tropical Rainfall Measuring Mission.
VSMOW	Vienna Standard Mean Ocean Water.
WMO	World Meteorological Organization.

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List of Publications

Publications in peer reviewed journals

1. Lekshmy P.R, **Midhun M** and R Ramesh 2015; Spatial variation of amount effect over peninsular India and Sri Lanka: role of seasonality, *Geophysical Research Letters, 42* (http://dx.doi.org/10.1002/2015GL064517)

2. **Midhun M** and R Ramesh 2015; Validation of $\delta^{18}O$ as a proxy for past monsoon rain by multi-GCM simulations, *Climate Dynamics* (http://dx.doi.org/10.1007/s00382-015-2652-8)

3. Lekshmy P.R , **Midhun M**, Ramesh R and R A Jani 2014;^{18}O depletion in monsoon rain relates to large scale organized convection rather than the amount of rainfall, *Scientific Reports, 1-5* (http://dx.doi.org/10.1038/srep05661)

4. **Midhun M**, Lekshmy P.R , and R Ramesh 2013; Hydrogen and oxygen isotopic compositions of water vapor over the Bay of Bengal during monsoon,*Geophysical Research Letters 40, 6324-6328* (http://dx.doi.org/10.1002/2013GL058181)

Papers in Conferences proceedings

1. **M.Midhun**, A.Kesarker, R.Ramesh; Simulation of Stable hydrogen and Oxygen Isotopes in Indian Monsoon Precipitation using IsoGSM. *National Space Science Symposium, 2012, Tirupati, India.*

2. **M.Midhun**, P.R.Lekshmy, R.Ramesh and R.A.Jani 2013; Stable Isotopic Composition of Atmospheric vapor over the Bay of Bengal and its Relation with Ocean Surface Conditions, *Proceedings of 12th ISMAS Triennial International Conference on Mass Spectrometry, 2013, Goa, India, pp 318-320.*

3. P.R.Lekshmy, **M.Midhun**, R.Ramesh and R.A.Jani; Is the Isotopic Composition of Rainfall of the South west coast of India Independent of Local Rainfall Amount? *Proceedings of 12th ISMAS Triennial International Conference on Mass Spectrometry-2013,Goa, India pp 306-308.*

4. **M.Midhun**, R.Ramesh; Stable Water Isotopologues in Indian Summer Monsoon Rainfall: A comparison between SWING2 model simulations and observations 13th *International Regional Spectral Model workshop 2014, Yokohama,Japan.*

5. **M.Midhun**, P.R.Lekshmy and R.Ramesh; Short-term Variability of Indian Summer Monsoon Rainfall δ^{18}O, *EGU General Assembly 2015, Vienna, Austria.*

6. P.R.Lekshmy, **M.Midhun** and R.Ramesh; Rain- vapour isotopic interaction over the south-west coast of India, *EGU General Assembly 2015, Vienna, Austria*

Publications attached with thesis

1. **Midhun M**, Lekshmy P.R , and R Ramesh 2013; Hydrogen and oxygen isotopic compositions of water vapor over the Bay of Bengal during monsoon,*Geophysical Research Letters 40, 6324-6328* (http://dx.doi.org/10.1002/2013GL058181)

2. **Midhun M** and R Ramesh 2015; Validation of $\delta^{18}O$ as a proxy for past monsoon rain by multi-GCM simulations, *Climate Dynamics* (http://dx.doi.org/10.1007/s00382-015-2652-8)