How rainwater isotopes are simulated in General Circulation Models during Indian Summer Monsoon?

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Introduction

- Isotope-enabled General Circulation Models (GCMs) simulate stable water isotope ratios $^{18}O/^{16}O$ and $^{2}H/^{1}H$ (expressed as $\delta^{18}O$ and δD) considering various physical processes in the hydrologic cycle.
- Historical simulations of these models are often compared with proxy isotope data to constrain past atmospheric circulation. India is rich in various natural proxies such as tree rings, speleothems etc from which past monsoon rainfall has been reconstructed in multidecadal to centennial time scales.
- The current study provides a thorough analysis for evaluating these GCMs over various parts of India and estimates the contribution of various physical processes controlling isotope biases.

Results

(1) Rain amount-rain isotope correlation in Isotope enabled GCMs

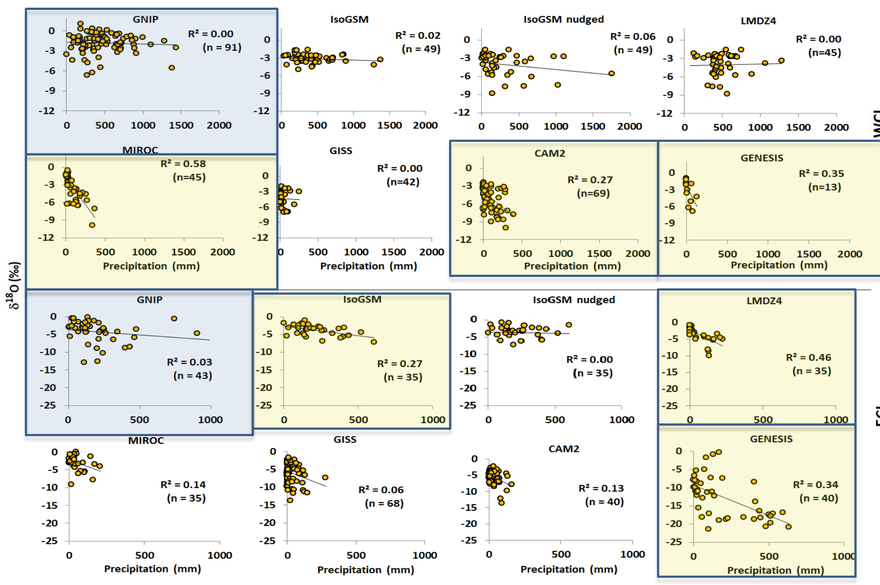

Fig. 2 : Rain amount bias-isotope bias correlation

Observed data
Models with significant amount-isotope correlation

Observed data do not show any amount-isotope correlation but some models do

Does rainfall bias contribute to rain isotope bias ?

(2) Rain/humidity/temperature bias – isotope bias correlation across models

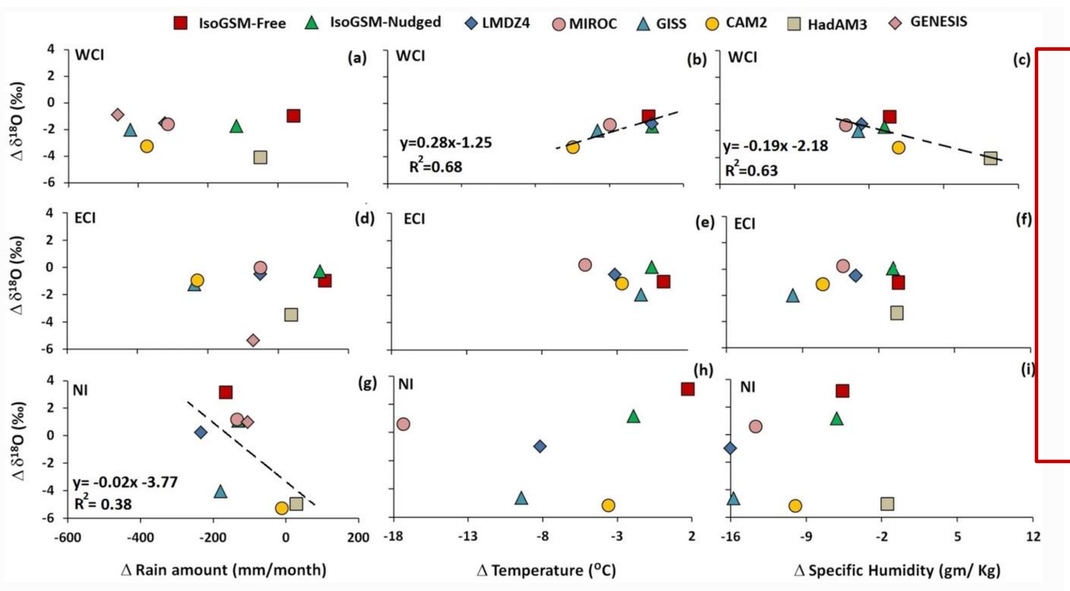

Fig. 3 : Scatter plots showing relationships between the mean biases (Δ = model-observed) in the rain $\delta^{18}O$ values and meteorological parameters

Temperature, humidity and rainfall biases have some region specific control on isotope biases but no general trend

(1)multiple parameters simultaneously control the rain isotope biases which vary from model to model .

(2) isotope biases in a given region result from biases in physical fields in other region.

(3) Linkage between isotope biases and atmospheric circulation (humidity and VIMT biases)

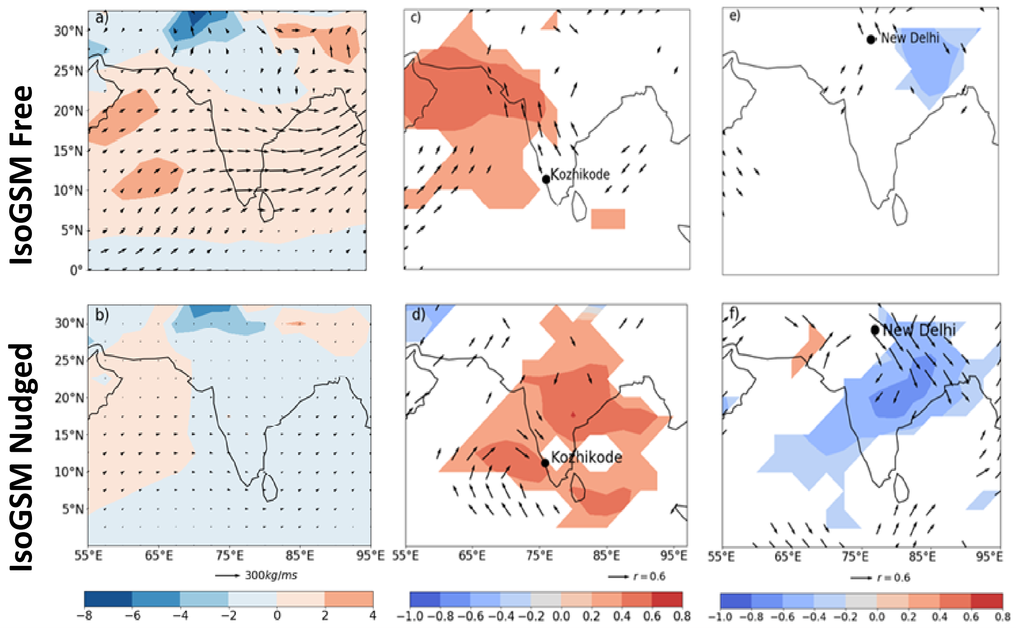

Fig. 4 : Sp. Humidity (shaded; a) and VIMT (vector, b) biases in two models. Their correlations with rain isotope biases at Kozhikode (c,d) and New Delhi (e,f)

- **IsoGSM-Nudged and free models, biases in the meridional component of low-level wind /VIMT over the AS positively affect the rain isotope biases at Kozhikode.**
- **The isotope biases at New Delhi seem to be significantly controlled by the biases in specific humidity, rainfall amount, wind, and moisture transport over the monsoon trough region.**

Data and Methodology

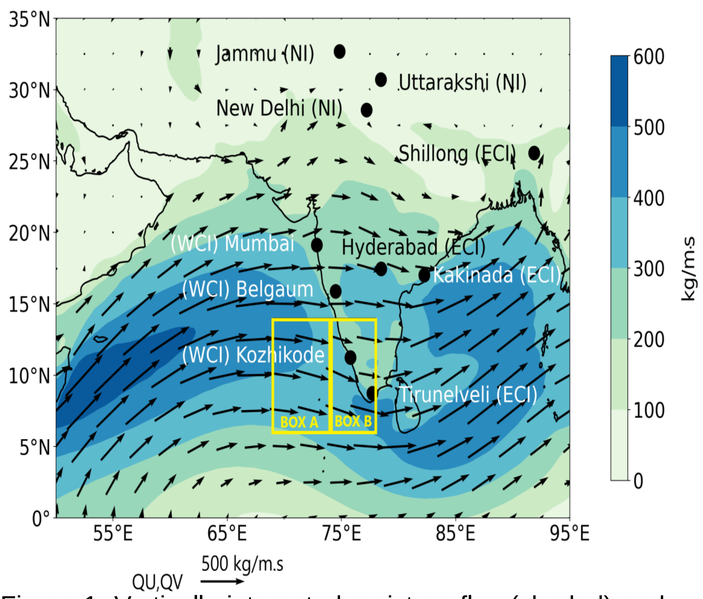

Figure 1: Vertically integrated moisture flux (shaded) and moisture transport (vector) over the studied region and adjoining ocean. 9 locations

GCM	Grid resolution (Latitude × Longitude)	Simulation	Data period	References
IsoGSM	1.91° × 1.875°	Free and Nudged	1980–2008	Yoshimura et al. (2008)[a]
LMDZ4	2.5° × 3.75°	Nudged (u, v) by ECMWF	1977–2006	Risi et al. (2010)[b]
MIROC	2.81° × 2.81°	Free	1977–2006	Kurita et al. (2011)[c]
GISS	2° × 2.5°	Nudged (u, v) by NCEP	1967–2008	Schmidt et al. (2007)[d]
CAM2	2.81° × 2.81°	Free	1966–2003	Lee et al. (2007)[e]
GENESIS	2° × 2.5°	Free	1966–1999	Mathieu et al. (2002)[f]
HadAM3	2.43° × 3.75°	Free	1870–2001	Tindall et al. (2009)[g]

[a]Isotope enabled Global Spectral Model
[b]Laboratoire de Météorologie Dynamique Zoom 4
[c]Model for Interdisciplinary Research on Climate
[d]Goddard Institute for Space Studies Model E version
[e]National Center for Atmospheric Research Community Atmosphere Model
[f]Global Environmental and Ecological Simulation of Interactive Systems
[g]Hadley Centre Atmospheric Model version 3

GCMs used

WCI – Mumbai, Kozhikode, Belgaum
ECI- Shillong, Hyderabad, Kakinada
NI- New Delhi, Jammu, Uttarkashi

Observed rain isotope data – GNIP stations

Observed vapour isotope data – Tropospheric Emission Spectrometer (Level-2)

Discussion

Physical process specific isotope bias decomposition (Kozhikode)

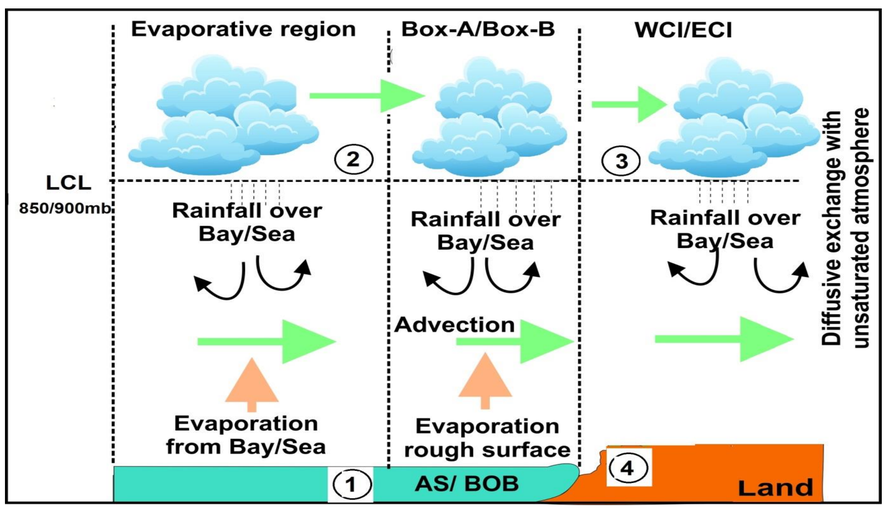

Fig. 5 : Schematic showing the physical processes considered for isotope bias decomposition at Kozhikode

Observed/estimated rain/vapour isotope compared with model outputs at four stages

Models largely over and underestimate mid tropospheric vapour isotope values suggesting inadequate simulation of mixing processes

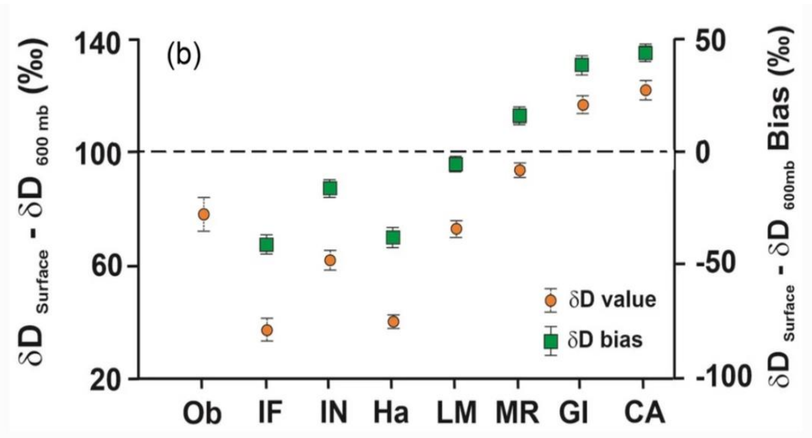

Fig. 6: The difference between surface leveland 600 mb vapour δD values are shown by orange-filled circles for the observation and seven simulations from six models. The corresponding biases (model-observed) in δD values are shown by green-filled rectangles

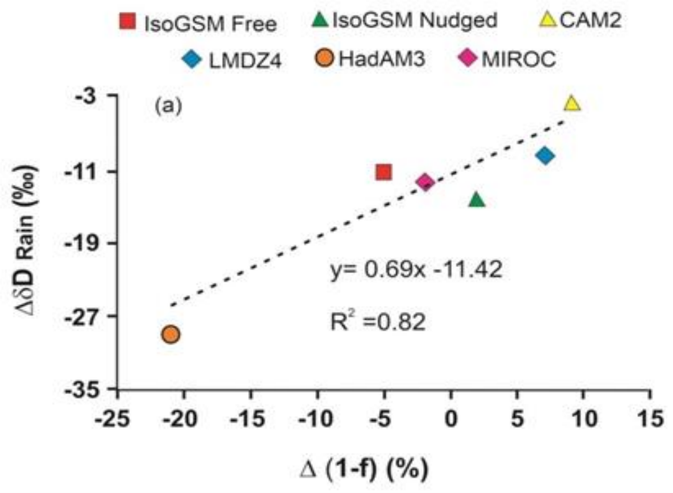

Fig. 7: Rain δD bias (model-observed), ΔδDRain, vs. raindrop evaporation bias Δ(1 – f), (model-observed), each averaged over Kozhikode

The model that simulates higher raindrop evaporation (i.e., higher 1-f) also simulates higher isotope values in the surface rain.

Conclusions

- Eight simulation of 7 isotope enabled GCMs are evaluated over western, eastern and northern India covering several natural proxy locations. ISOGSM-Free and Nudged models perform better among them.
- Rain isotope biases in western and northern India are strongly controlled by specific humidity biases over the AS and rainfall bias over the BoB monsoon trough respectively.
- The efficacy of these models depends on how accurately they simulate (a) mid-tropospheric mixing processes and (b) raindrop evaporation.