An Investigation on Continental Scales and Altitude Effect on Isotopic Composition (δD) of Ground Level Vapour (GLV) in Indian Sub-Continent

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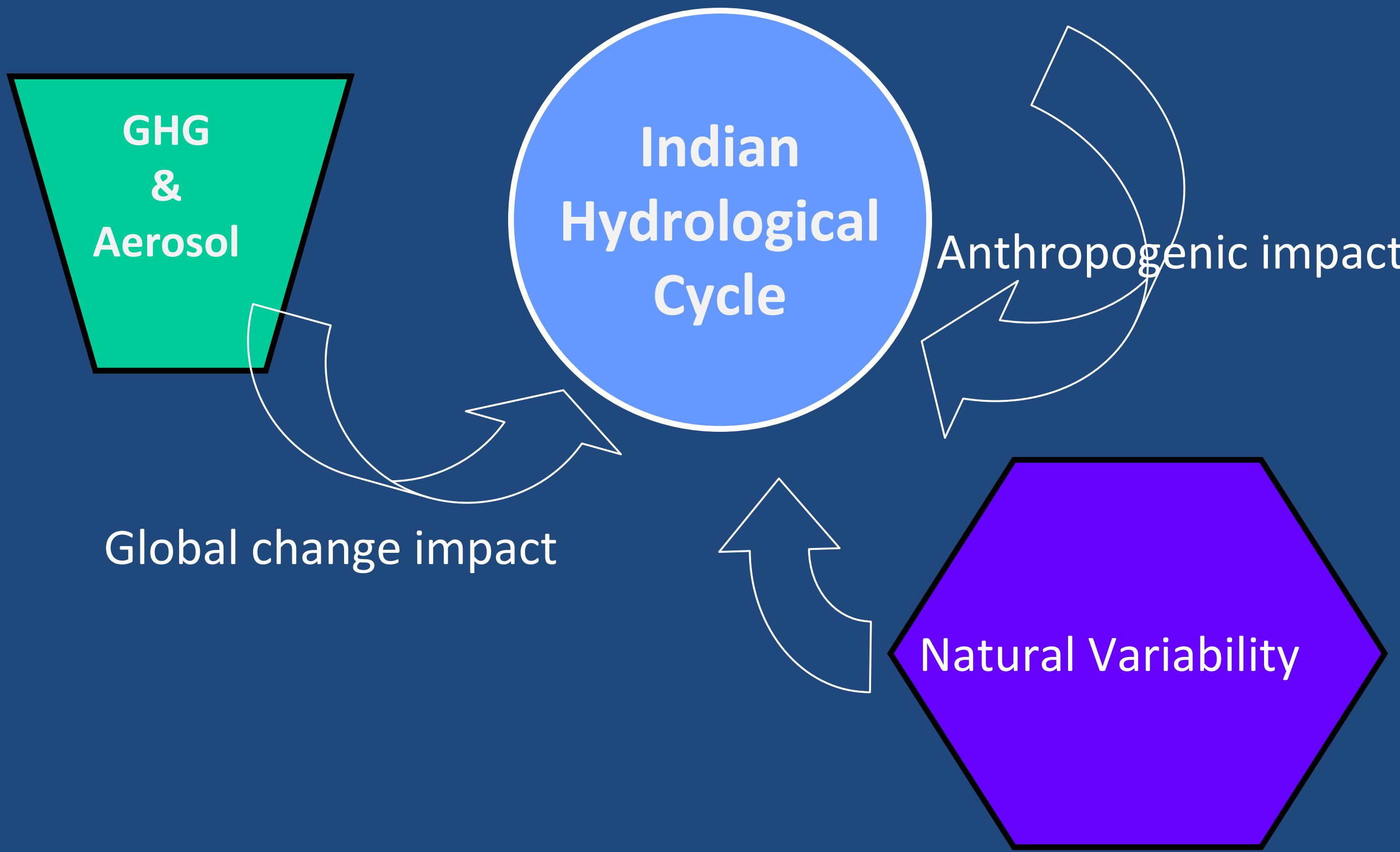
Backdrop

India: Water resource scenario

Utilizable water: ~1200 km^3/yr
current water use: ~700 km^3/yr
Estimated Demand (by 2050): 973 - 1450 km^3/yr

Large scale alterations of hydrological and ecological systems



Isotope tracing can strengthen Hydrometric approach

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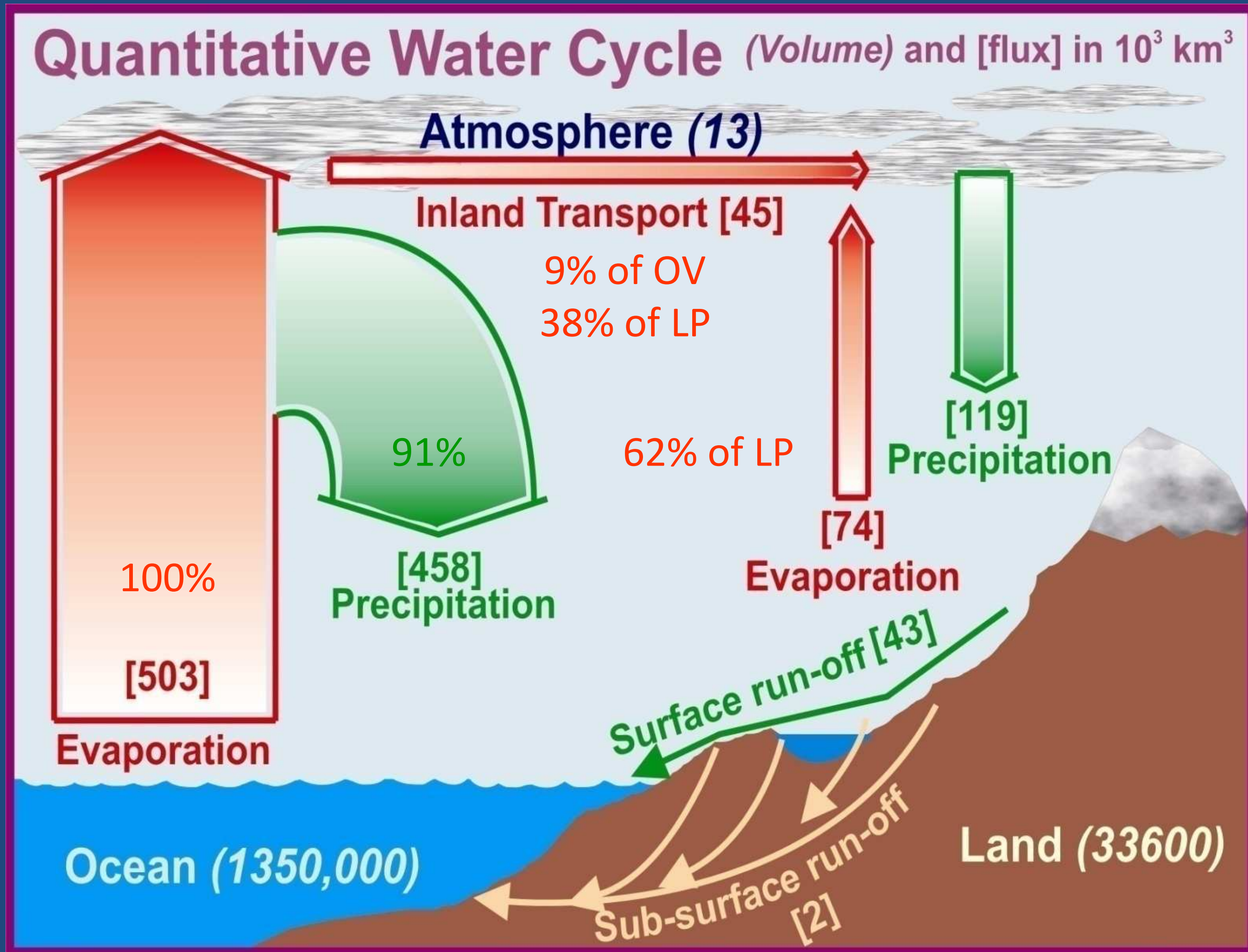

- Quantitative information on components/ processes, their controls and fluxes across hydrological boundaries can help analyse, predict and minimise adverse impacts to our natural, agricultural and urban environments.
- Baseline data on characteristics features is essential for future comparison.

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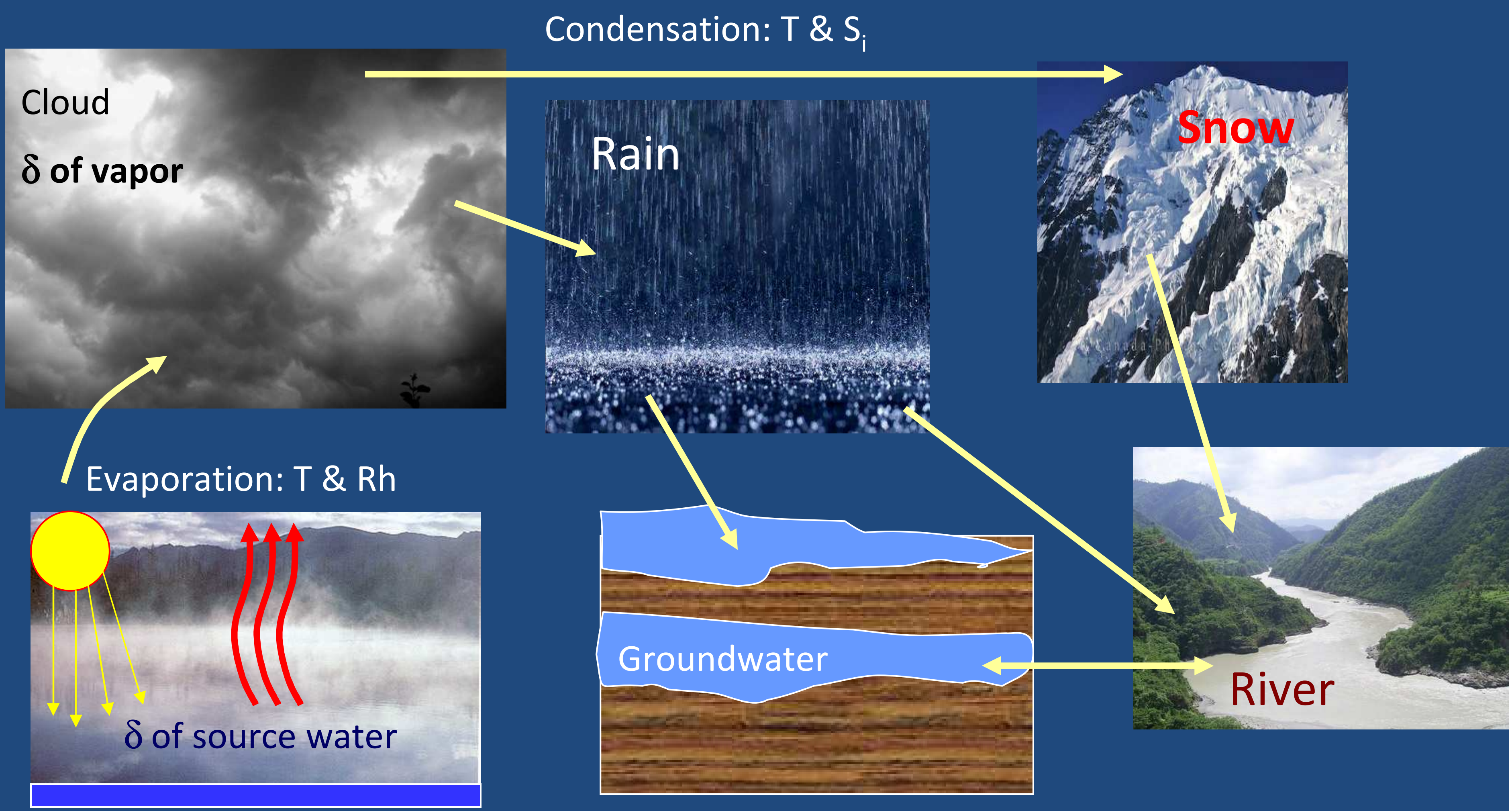
Water molecules record the information about their origin and path in their isotopic composition



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Hydrogen Isotopes !!

Hydrogen 1.00794(7) g·mol^{-1}		
Isotopes	**Natural Abundance**	**Atomic mass**
^{1}H (1p + 0n)	99.985%	1.00782503 u
^{2}H (1p + 1n)	0.015%	2.01410177 u
Abundance Ratio ^{2}H / ^{1}H = 0.0001500225 = 150 × 10^{-6}		
One ^{2}H atom per 6666 atoms of ^{1}H		

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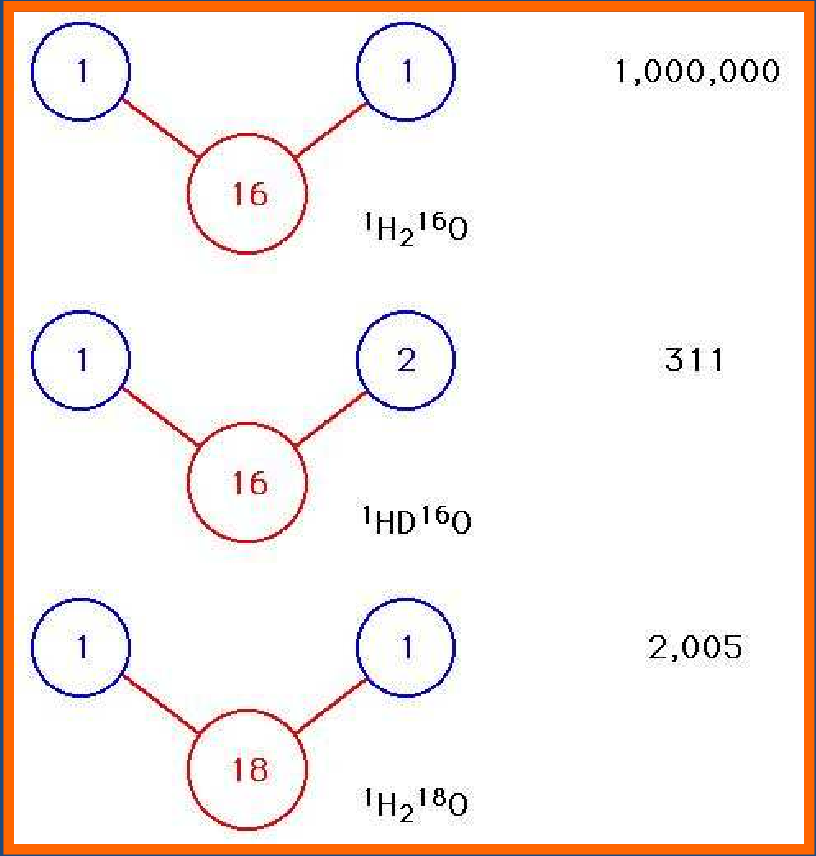
Isotopic Molecular Species
(*isotopologues*)

1. $H_2{}^{16}O$
2. $H_2{}^{17}O$
3. $H_2{}^{18}O$
4. $HD^{16}O$
5. $HD^{17}O$
6. $HD^{18}O$
7. $DD^{16}O$
8. $DD^{17}O$
9. $DD^{18}O$



Relative abundance of isotopic water				
$H_2{}^{16}O$	$H_2{}^{18}O$	$H_2{}^{17}O$	$HD^{16}O$	$D_2{}^{16}O$
99.78%	0.20%	0.03%	0.0149%	0.022 ppm
18	20	19	19	20

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How Isotopic Composition is expressed and why it is done this way?

$$\delta(\text{in } ‰) = \left[\frac{R_{Sample}}{R_{Standard}} - 1\right] \times 1000$$

Why ratio of sample to standard ?

Why multiply by 1000 ?

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Isotope Effects - 1

1. Temperature Effect (δ-T Relationship)
   - Decreasing δ values with decreasing T
2. Latitude Effect
   - Decreasing δ values with increasing Latitude
3. Continental Effect
   - Decreasing δ values with increasing inland distance
4. Amount Effect
   - Increasing δ values with decreasing amount of rain
5. Altitude Effect
   - Decreasing δ values with increasing altitude
6. Seasonal Effect
   - Greater seasonal extremes in T generate strong seasonal variations

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Isotope Effects - 2

δ-T Relationship

Dansgaard (1964) established a linear relationship between surface air temperatures and δ values for mean annual precipitation on a global basis.

$$\delta^{18}O = 0.695\ T_{annual} - 13.6‰\ SMOW$$

$$\delta^{2}H = 5.6\ T_{annual} - 100‰\ SMOW$$

Based on monthly average temperatures the global relationship is:

$$\delta^{18}O = (0.338 \pm 0.028)\ T_{monthly} - 11.99\ ‰\ SMOW$$

On average, a 1‰ decrease in average annual $\delta^{18}O$ corresponds to a decrease of about 1.1 to 1.7 ºC in the average annual temperature.

Departure from global relationship occurs at the regional to local scale due to physiographic variation.

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Isotope Effects - 3

Latitude Effect

Basis:

1. From the δ-T relationship, polar regions should have lower δ values.
2. Polar regions are situated at the end of Rayleigh rainout process therefore, $\delta^{18}O$ gradient is expected to be steeper.

- -0.6‰ for $\delta^{18}O$ per º latitude for continental stations of the North America
- -2‰ for $\delta^{18}O$ per º latitude for the colder Antarctic Stations.
- Very low gradients in the low latitudes where over 60% of atmospheric vapour originates

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Isotope Effects - 4

Altitude Effect (Alpine or Elevation effect)

Basis

1. Orographic precipitation occurs as vapour mass rises over the landscape and cools adiabatically (by expansion) causing rainout.

2. At higher altitudes where the average temperatures are lower, precipitation will be isotopically depleted.

$\delta^{18}O$: -0.15 to -0.5 ‰ per 100 m rise in elevation

δD: -1 to -4 ‰ per 100 m rise in elevation

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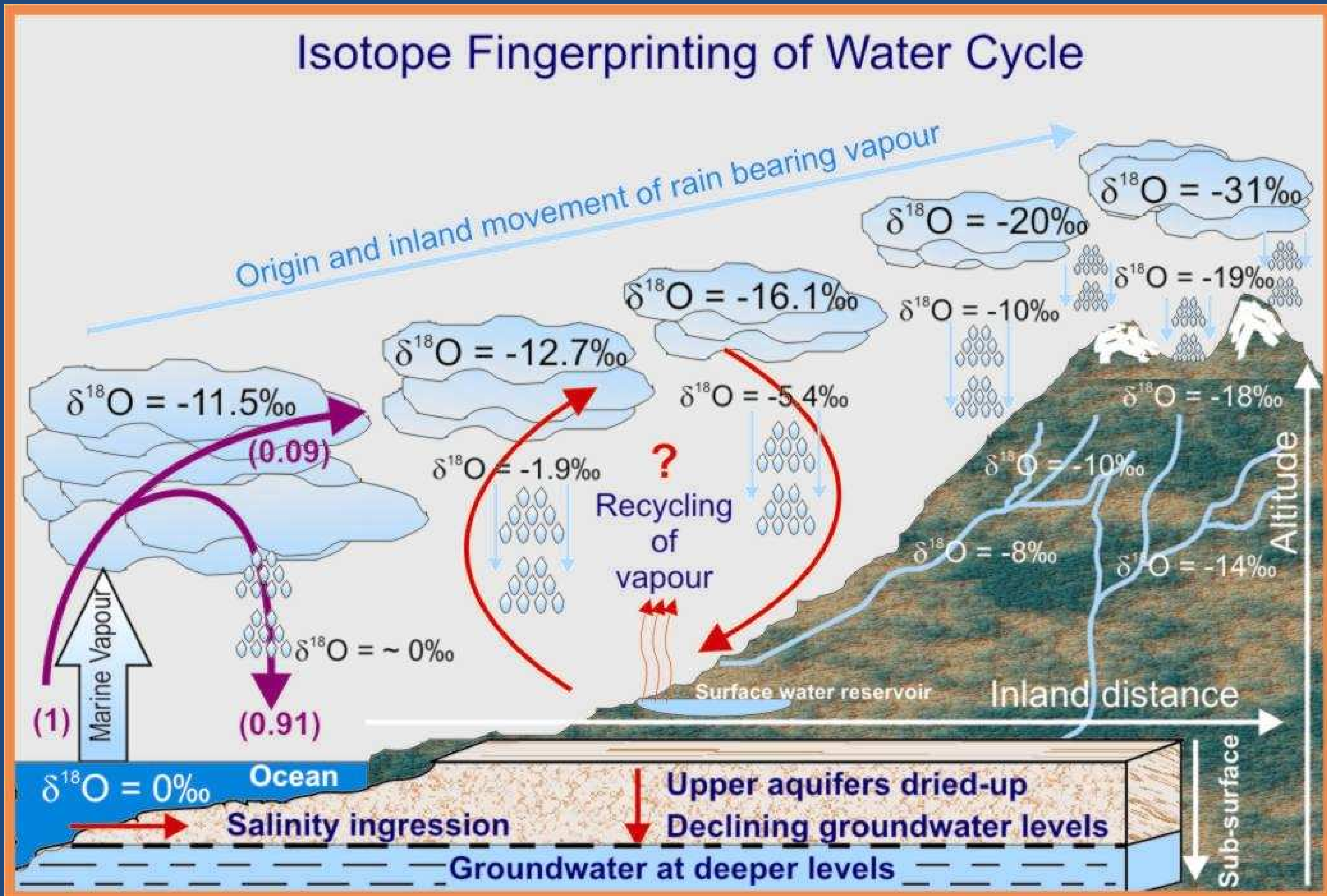

Vapor source region, advancement of vapor front, recycled component, groundwater and snow melt contribution to river etc.

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National Motivation Behind IWIN

- Meeting the estimated water demand (~1450 km^3/yr by 2050 from current 630 km^3/yr) will necessitate large-scale alterations of the hydrological and the associated ecological systems. This will have an impact on Indian hydrological cycle.
- Anthropogenic impacts on hydrological cycle will be superposed on hydrological consequences of global climate change
- Quantified data on hydrological cycle components/ processes and their controls can help predict, analyse and minimise adverse impacts to our natural, agricultural and urban environments.

Origin of IWIN Programme

- It was realized that nation-wide comprehensive isotope investigations, in conjunction with conventional hydrometric methods, can provide more accurate quantitative description of the Indian hydrological cycle. This can also help predict, analyse and minimise the adverse hydrological impacts of engineered interventions and global climate change. In view of the above, a research programme was conceived.
- Isotope hydrologists and water resource related professionals within India discussed the importance and feasibility of a collaborative programme to obtain isotope fingerprints of various water sources of India. In consultation with all the partners, IWIN National Programme was formulated. IWIN is jointly sponsored by DST and PRL. PRL is the nodal agency for implementation of IWIN.

Water records information about its origin and movement in the form of its isotopic signature

Isotopic fingerprints are imparted during:

1. Phase change: fractionation during evaporation and condensation – temperature & humidity dependent.
2. Mixing of different water/ vapour masses.
3. Selection of rain events during runoff and groundwater recharge

Stable Isotopes in Water ($^{1}H_2O$)

$^{1}H_2{}^{18}O$	$\delta^{18}O$(‰)
$^{1}H^{2}H^{16}O$	δD (‰)

δ (‰) = $(R_x/R_s - 1).1000$

R=Ratio ($^{18}O/^{16}O$; $^{2}H/^{1}H$)

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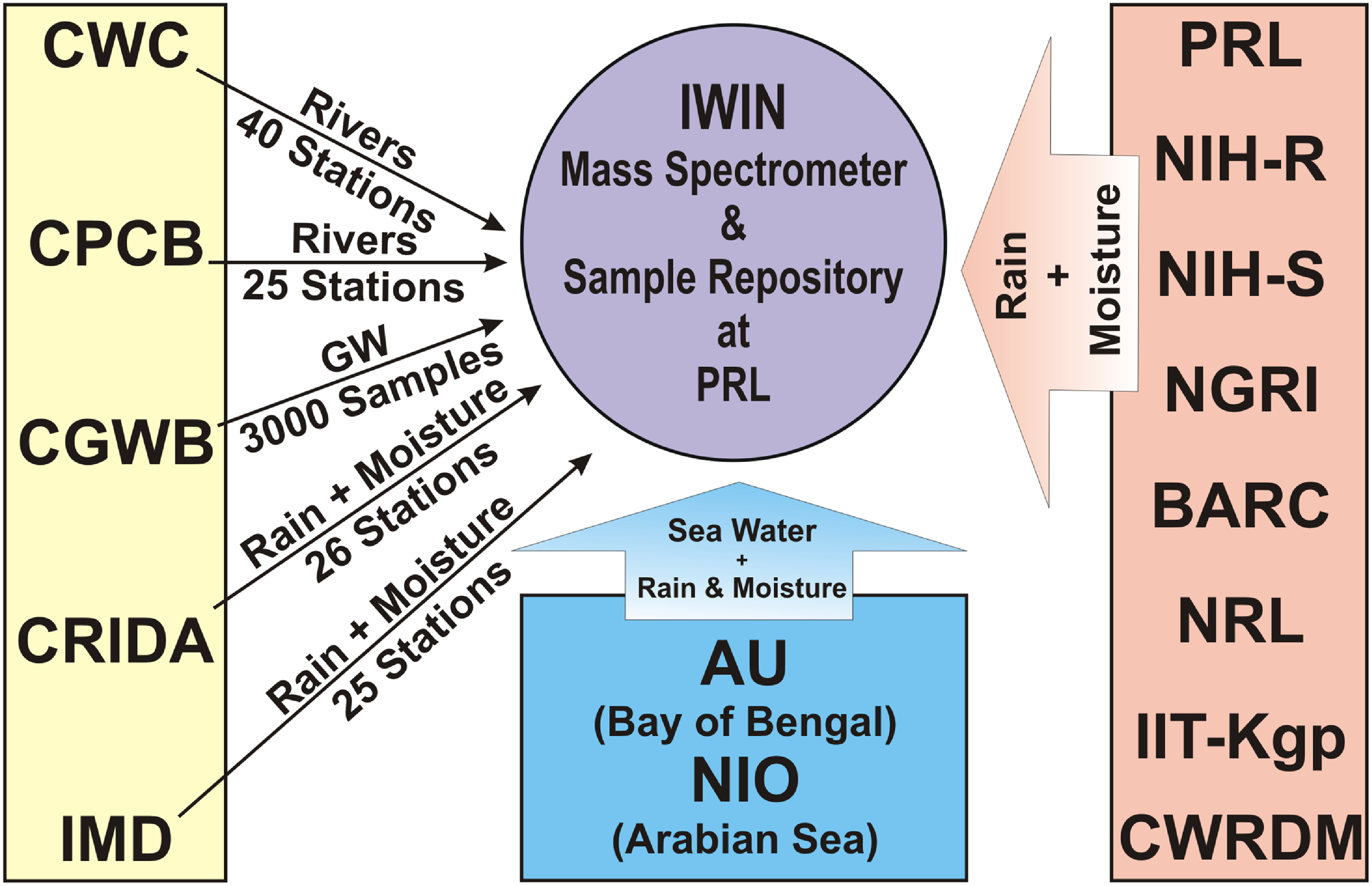
Active IWIN Network



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Specific Objective

To monitor isotopic fingerprints of major water sources in spatial and temporal domain to:

1. **Quantify vapour supply (Arabian Sea/ Bay of Bengal/ Local and long distance oceanic/ continental sources) at different locations during different seasons.**
2. **Estimate the extent and rates of interactions across hydrological boundaries and the controls exercised by geographical and climatic factors.**

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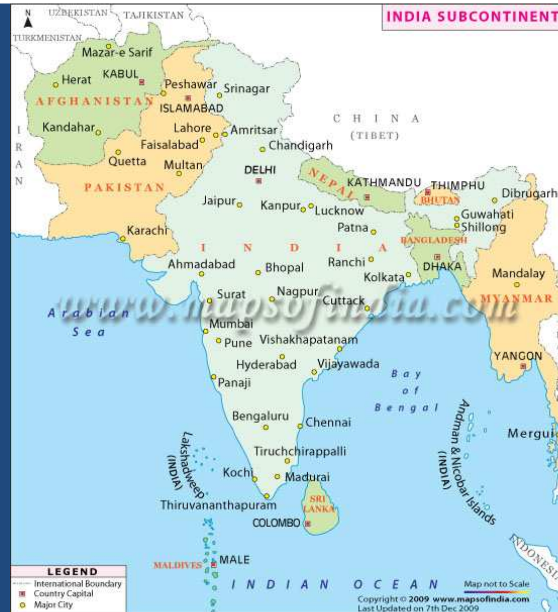
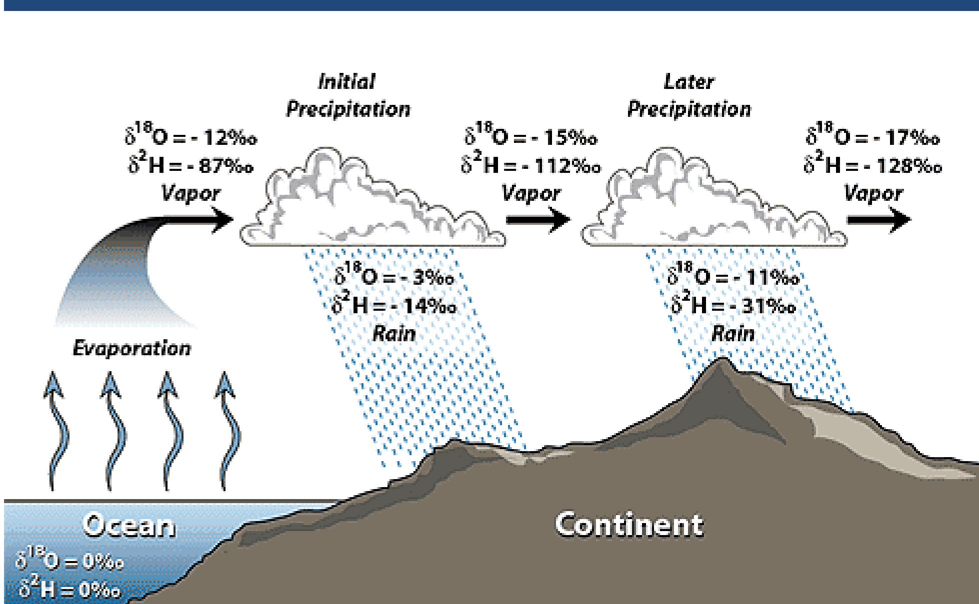
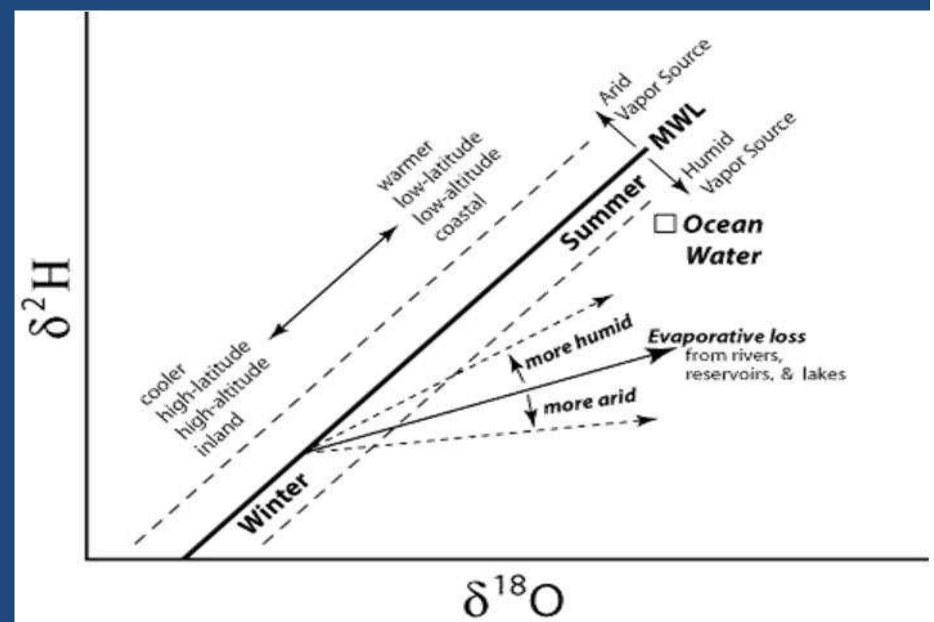


Hoefs 1997 and Coplen et al. 2000





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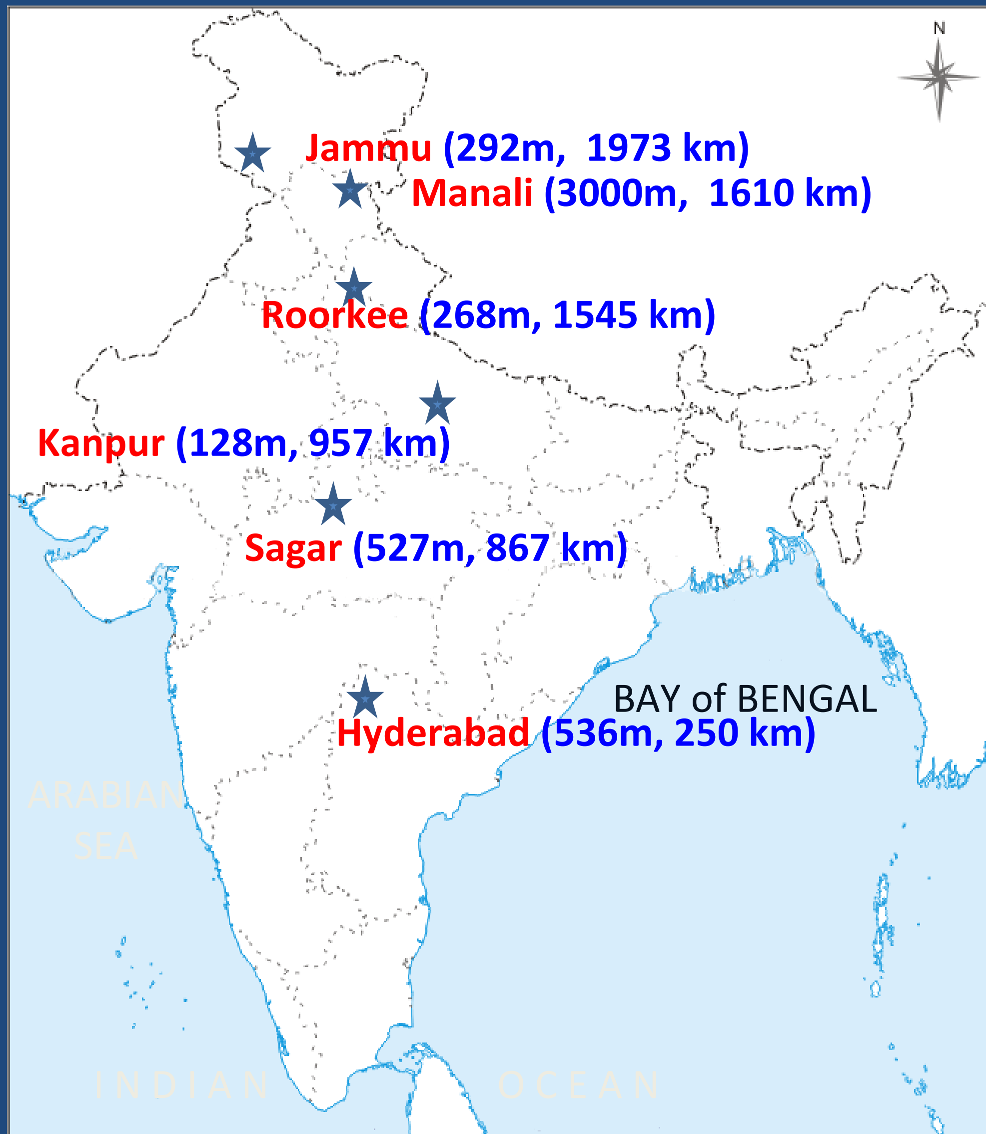
SAMPLING LOCATIONS MAP



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Methodology

Measuring Isotopic Composition of Air Moisture

- Collection of air moisture samples
- Analysis of air moisture samples

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Collection of Ground level Air Moisture Samples

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Components of Conical Condensation Device for Air Moisture Sample Collection

System Components

System in Met-Observatory

System in Operation

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Schematic Model Sample Collection during Condensation

Avg. vapour sampled by Trapping

δD = ~ –71‰

Gas Phase

at T = 0ºC

ε^{18} = 11.7 ‰

ε^{2} = 112 ‰

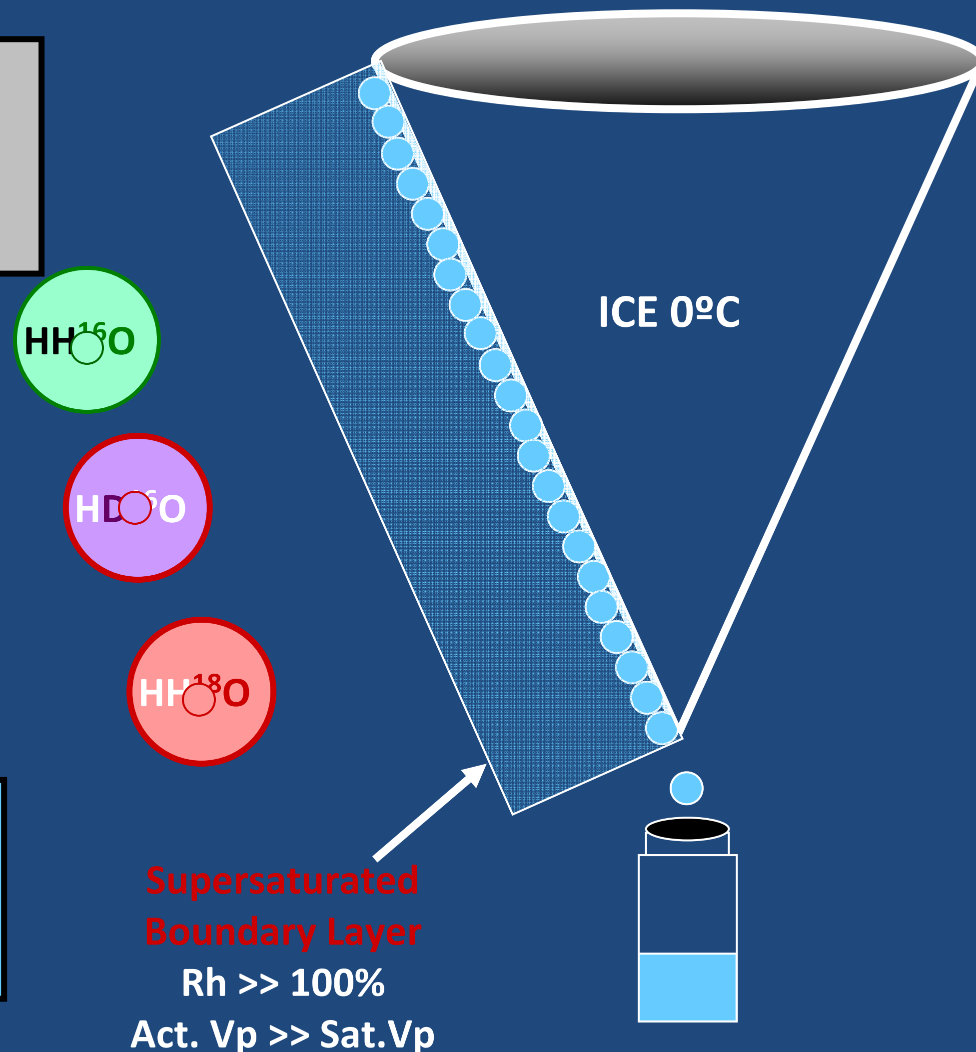
Equilibrium Fractionation

Liquid Phase

Expected Liquid Condensate

$\delta^{18}O$ = ~ 0.4‰

δD = ~41‰



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Isotopic Analysis of Air Moisture Sample using Isotope Ratio Mass Spectrometer (IRMS)

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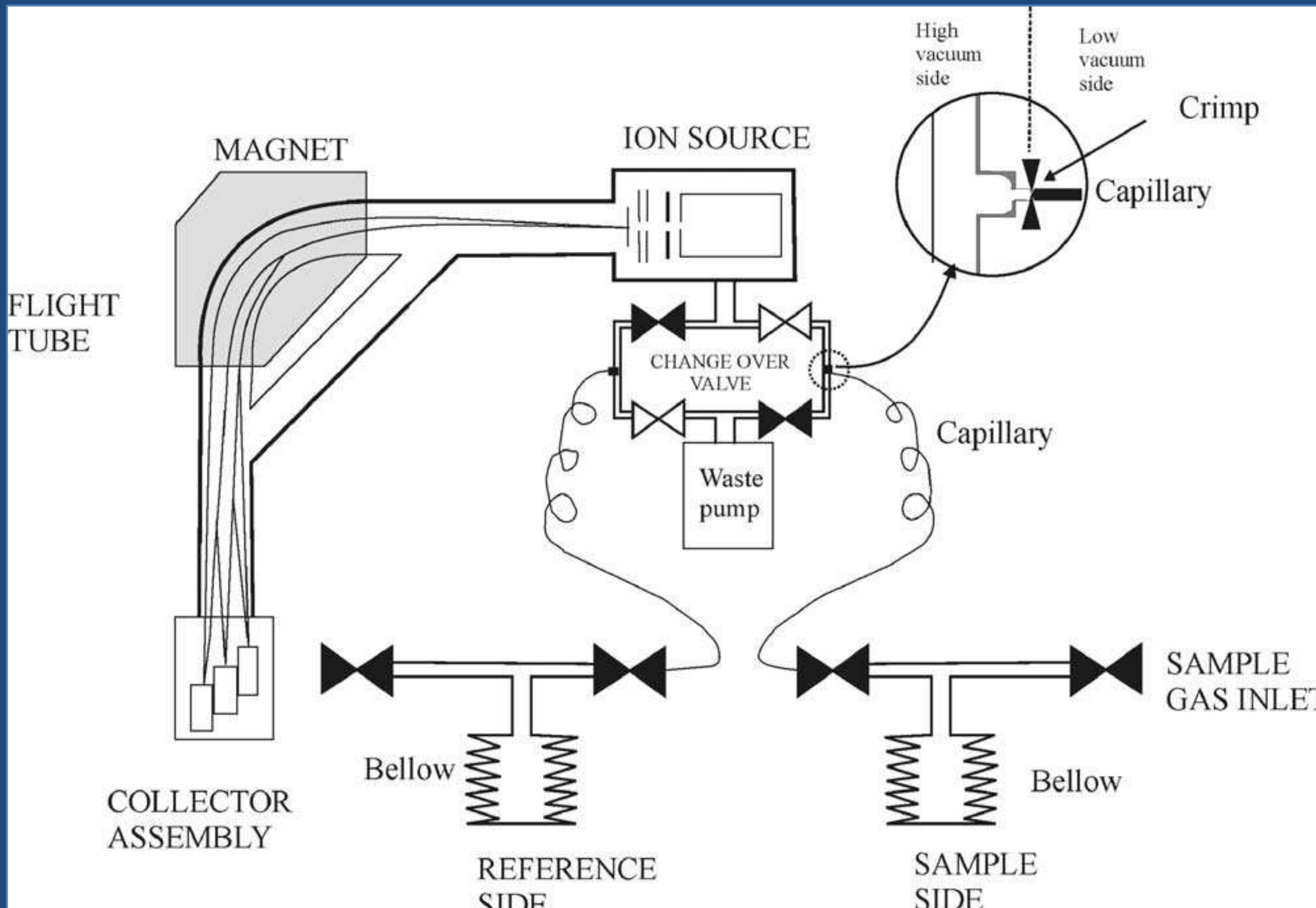

Schematic Diagram of DI-IRMS

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Stable isotopes (^2H or D) in water were analysed using GV-Isoprime Dual Inlet Isotope Ratio Mass Spectrometer. For δ D analysis, 400 μl of the water sample is equilibrated with H_2 along with Pt catalyst at 40°C for 3 hrs. and then the equilibrated gas is introduced into the mass spectrometer. The measured values are reported as delta (δ) values (Coplan, 1996). The precision of measurement for $\delta\ ^2H$ was within ± 1‰

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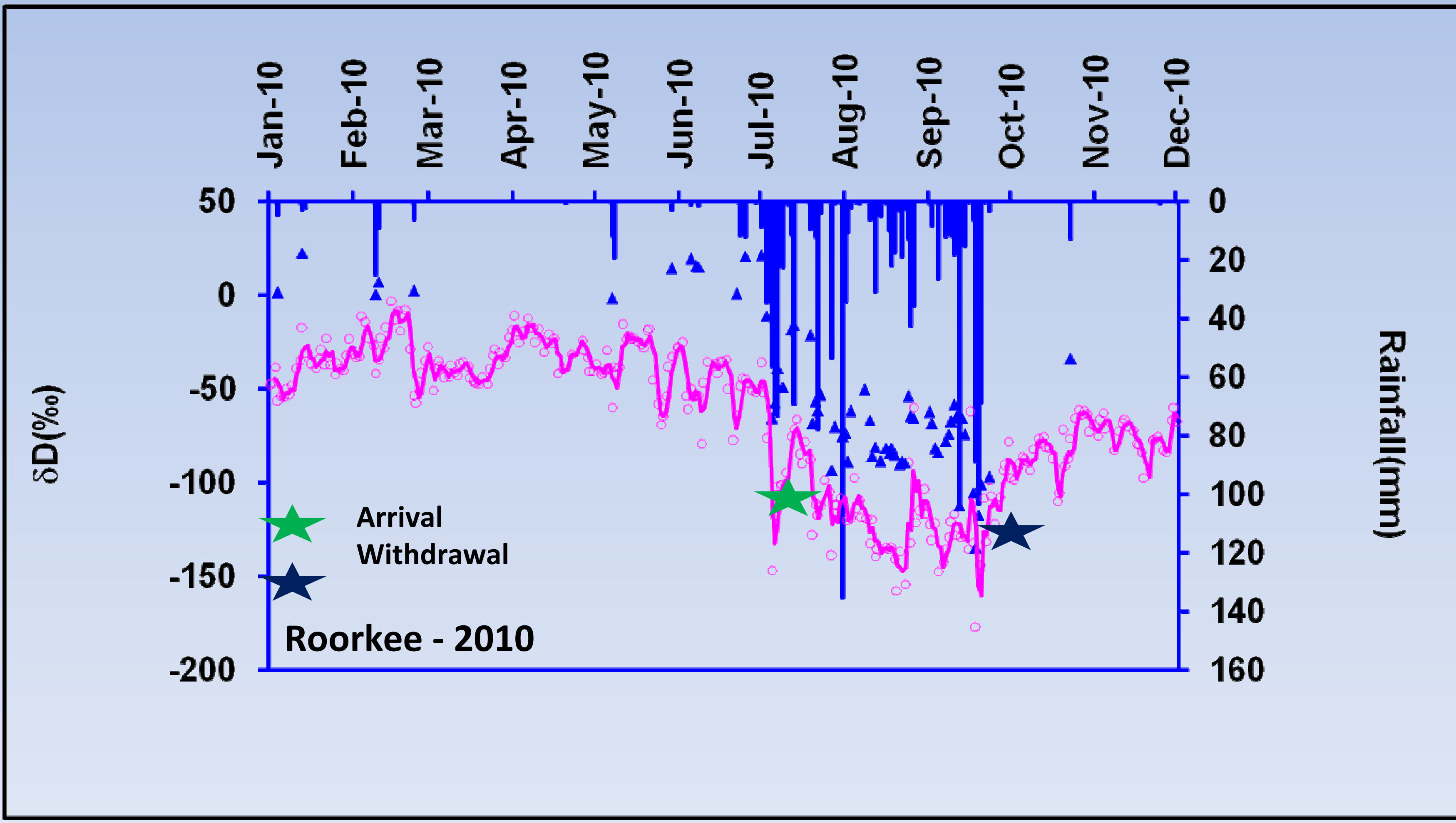
RESULTS

VARIATION OF ISOTOPIC COMPOSITION OF GLV(LIQUID CONDENSATION METHOD) AT ROORKEE



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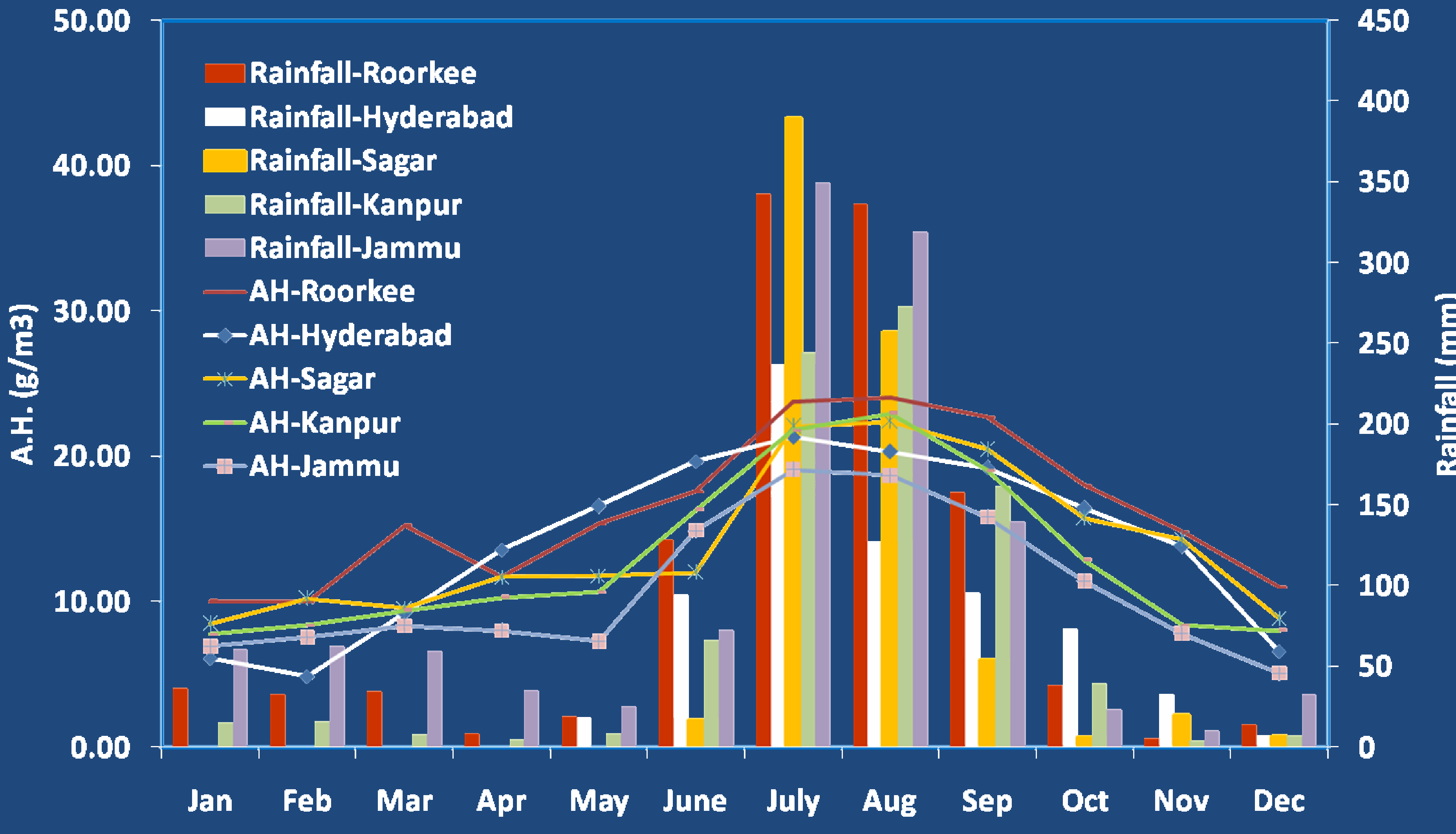
VARIATION IN RAINFALL AND ABSOLUTE HUMIDITY



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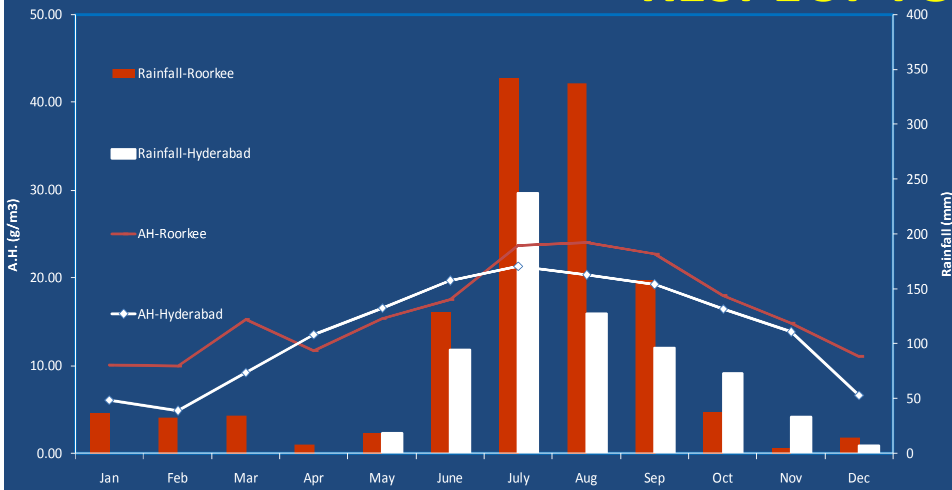
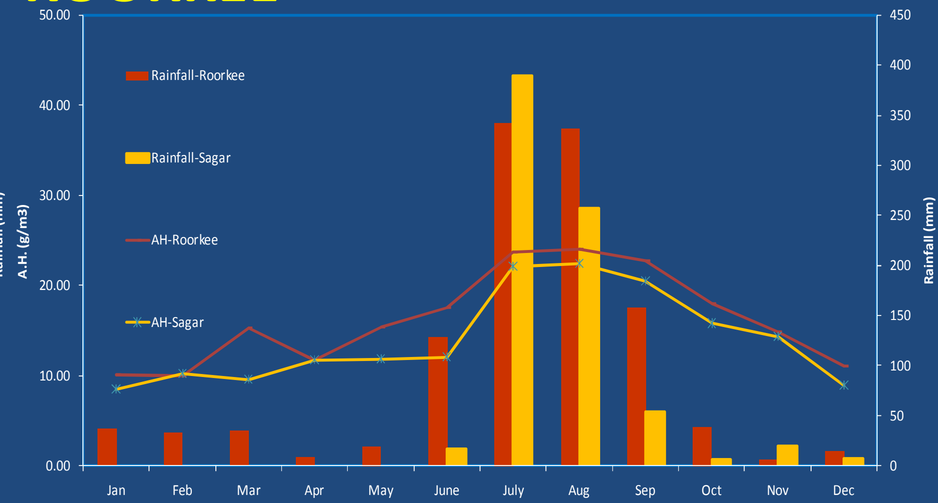
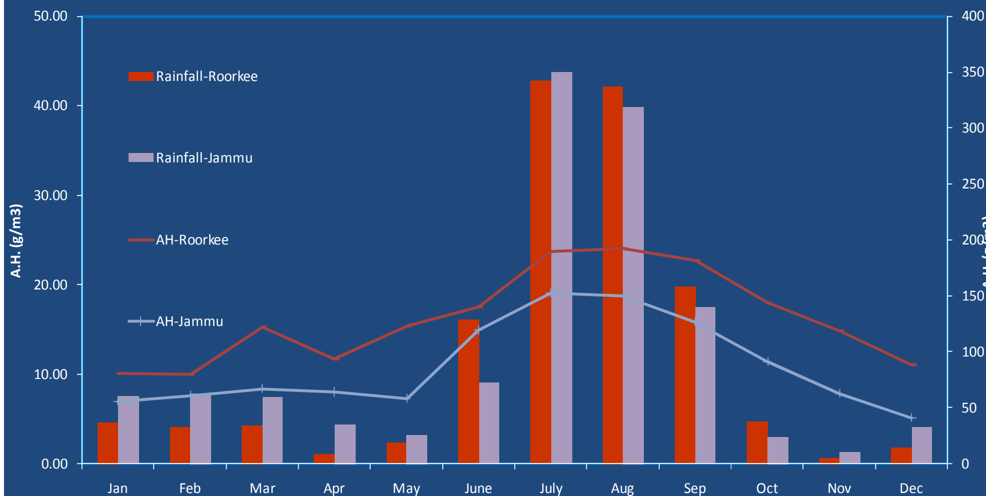
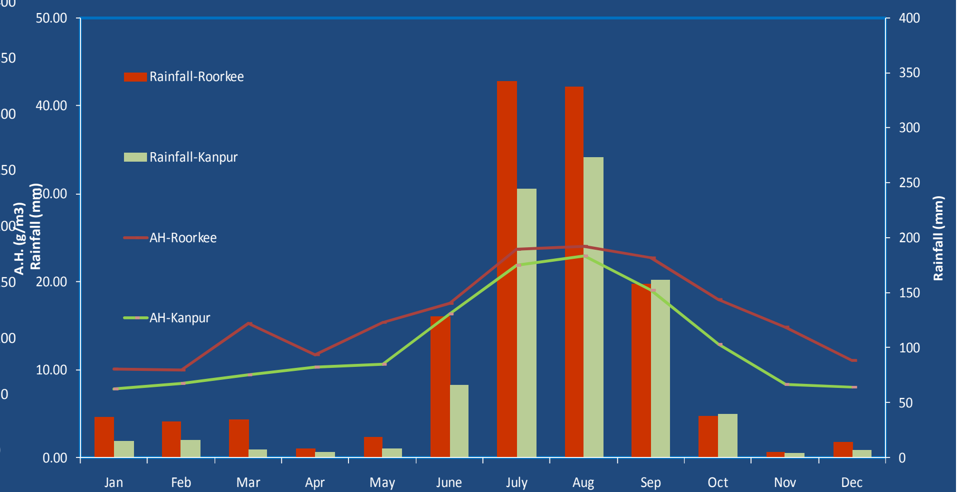
VARIATION IN RAINFALL AND ABSOLUTE HUMIDITY WITH RESPECT TO ROORKEE









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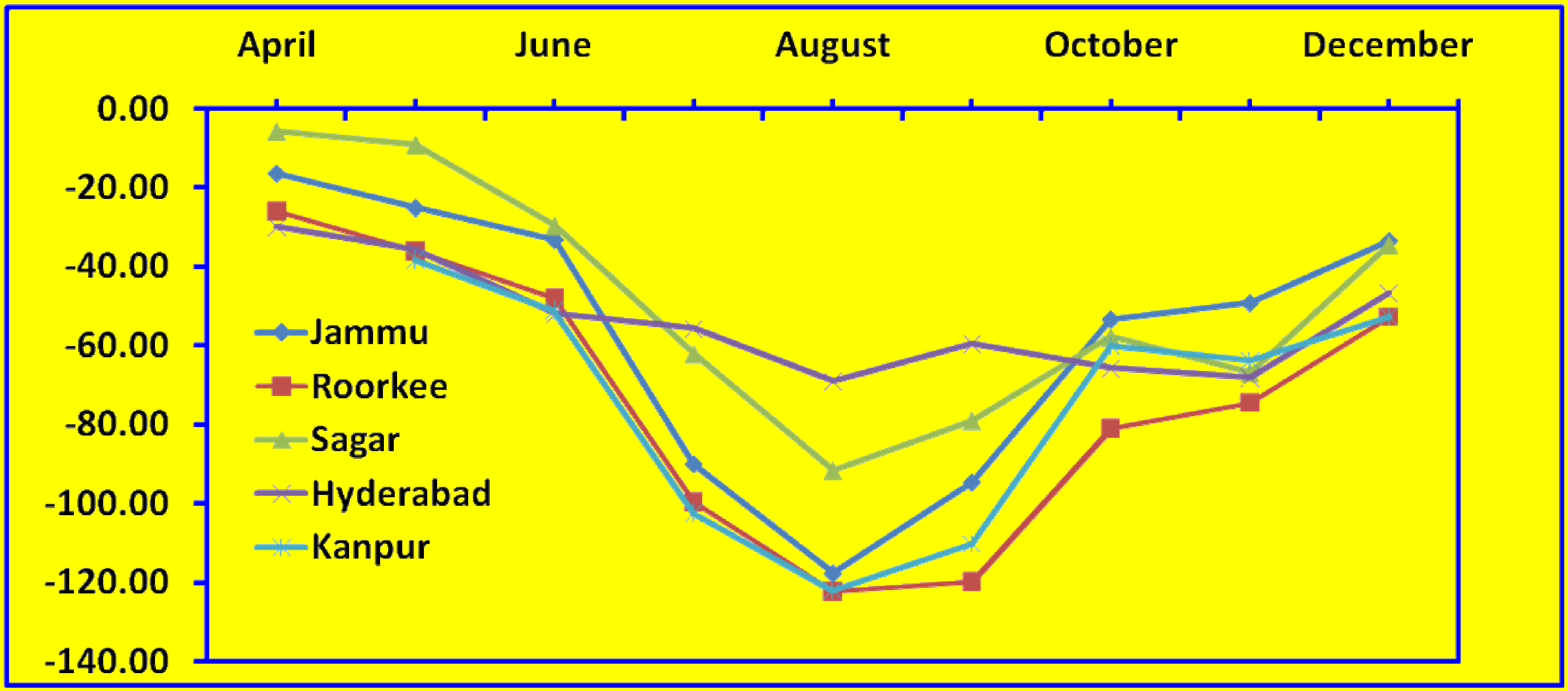
VARIATION OF ISOTOPIC COMPOSITION OF GLV(LIQUID CONDENSATION METHOD)



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VARIATION IN ISOTOPIC COMPOSITION (δD) OF GLV WITH RESPECT TO ROORKEE

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SEASONAL VARIATION IN ISOTOPIC COMPOSITION (δD) OF GLV AT INDIAN STATIONS WITH RESPECT TO ROORKEE

Season	Station Name				
	Hyderabad (2008-10)	Sagar (2008-10)	Kanpur (2011)	Roorkee (2008-11)	Jammu (2010)
Monsoon (June –Sep)	+37.0‰	+32.0‰	+01.0‰	0.0	+16.0‰
Post-monsoon (Oct.-Dec.)	+10.0‰	+17.0‰	+12.0‰	0.0	+25.0‰

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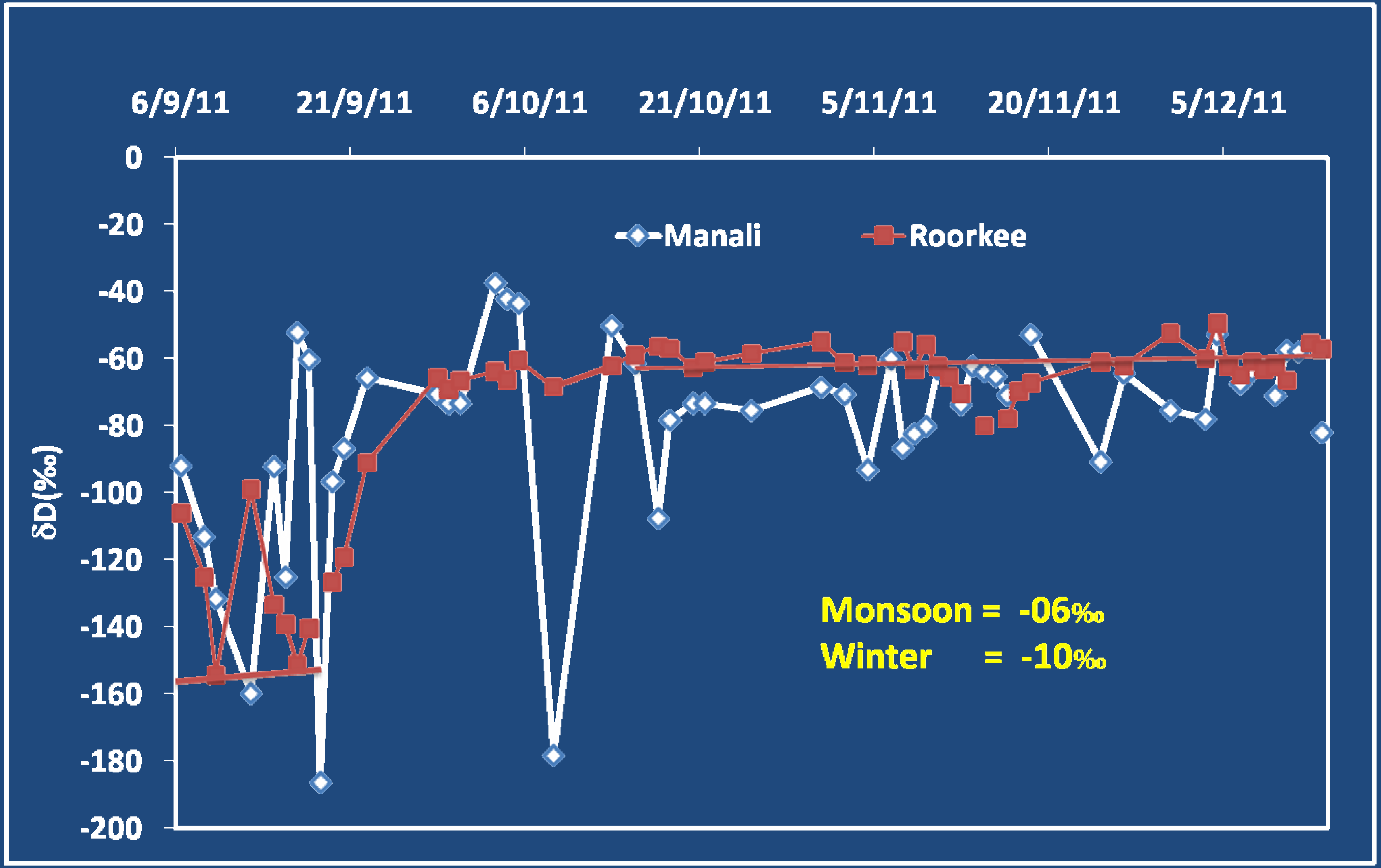
ALTITUDE EFFECT IN ISOTOPIC COMPOSITION (δD) OF GLV AT MANALI WITH RESPECT TO ROORKEE



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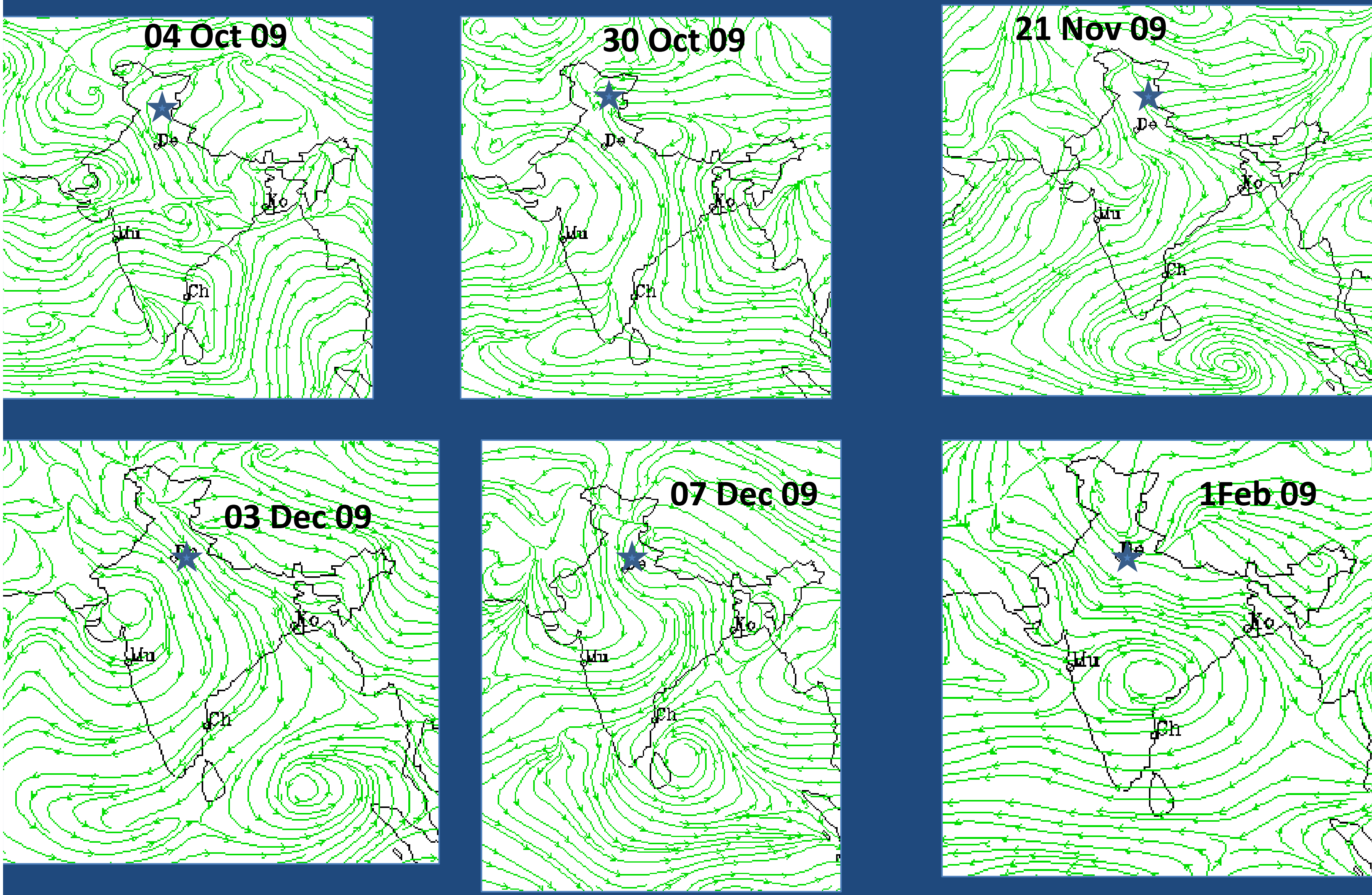
WIND TRAJECTORY DATA



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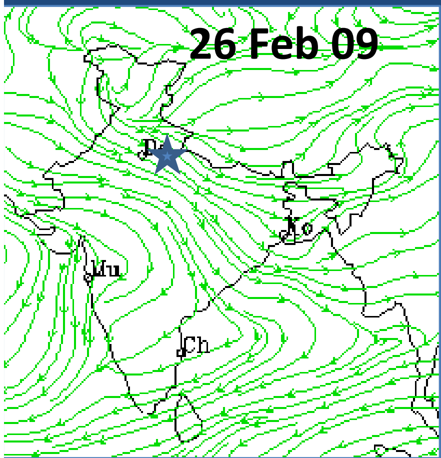

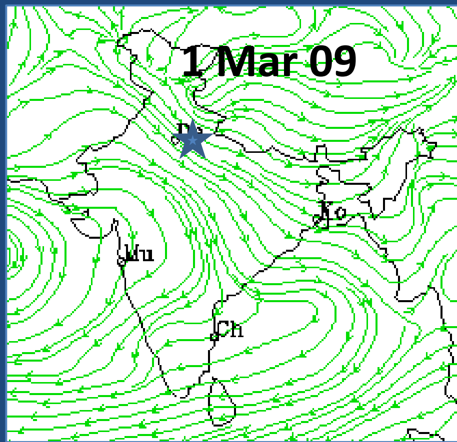

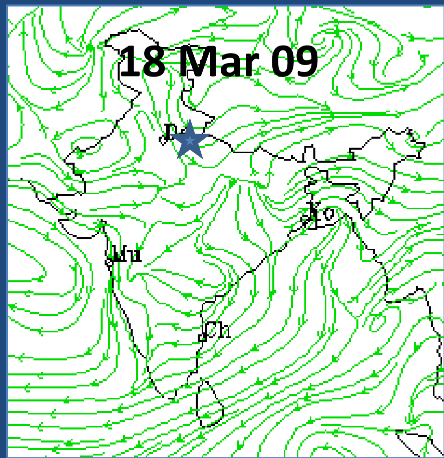

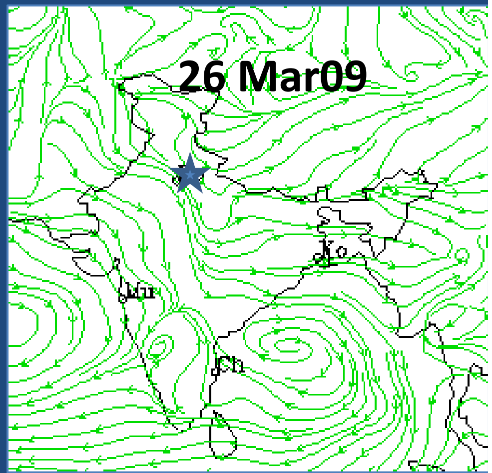

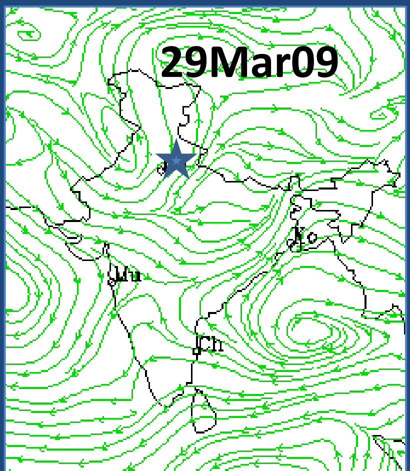

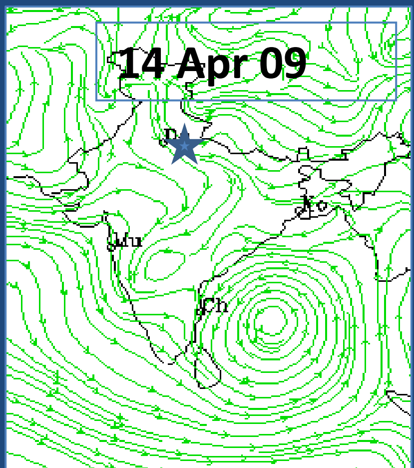

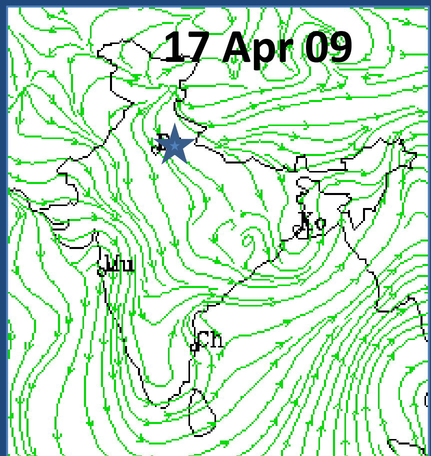

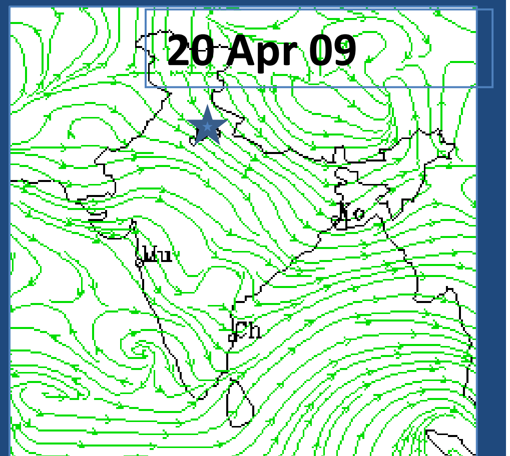

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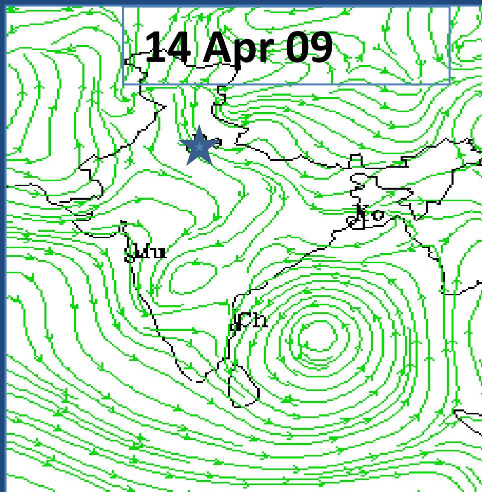

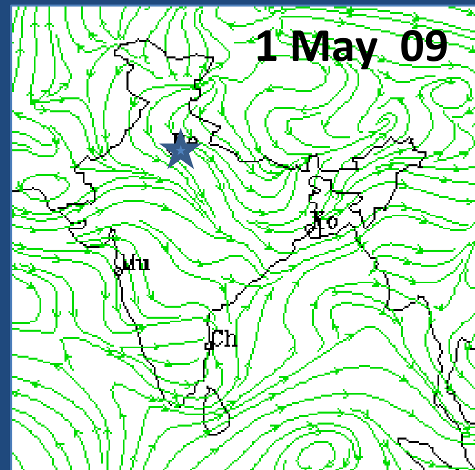

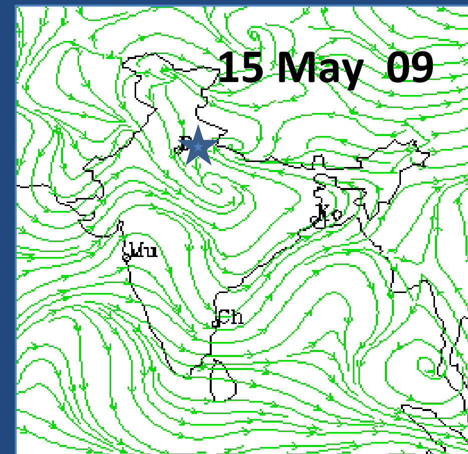

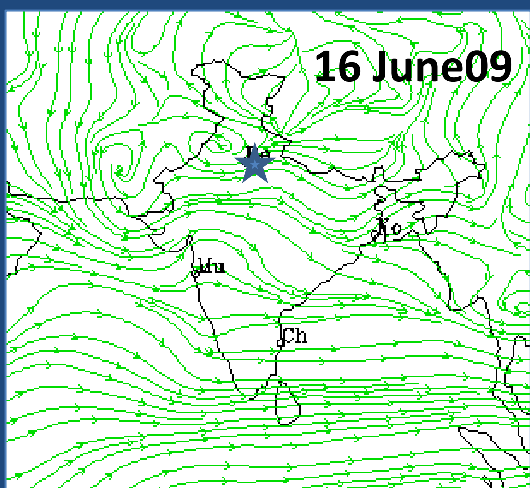

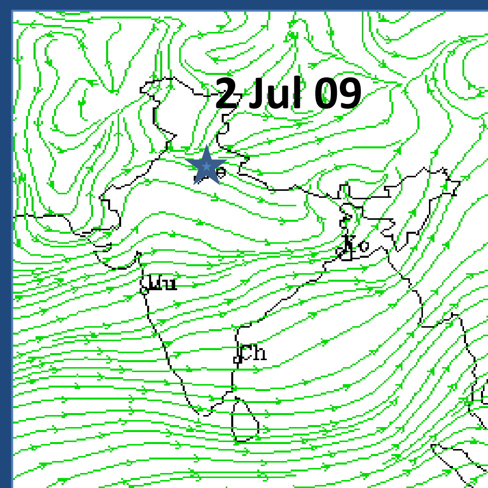

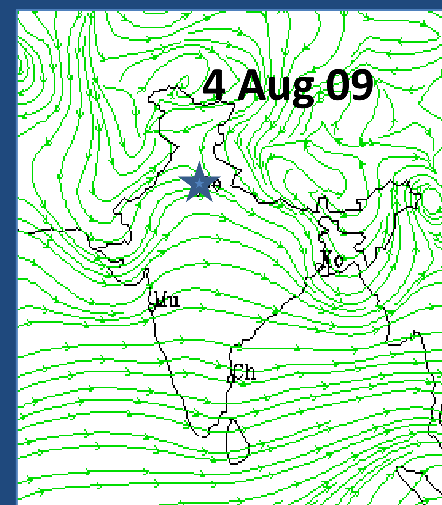

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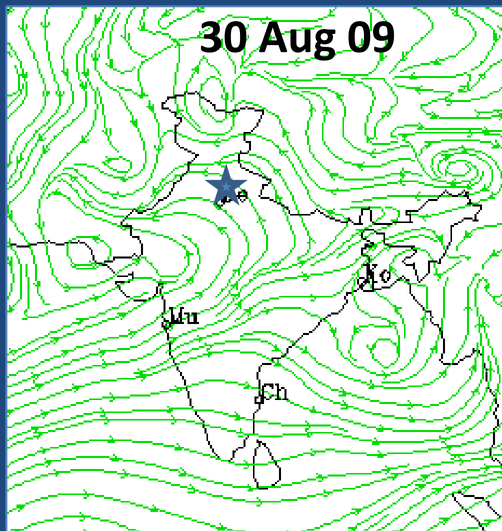

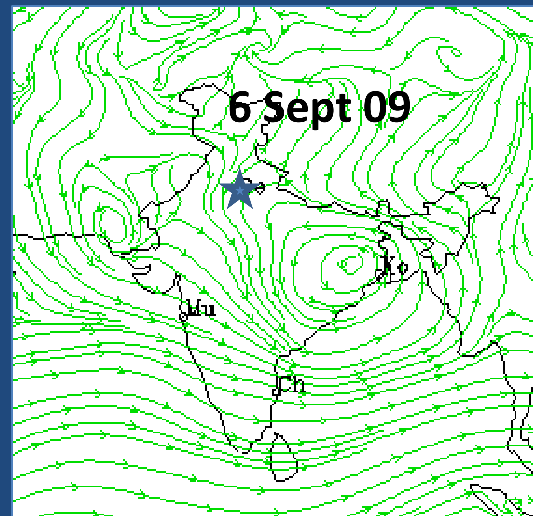

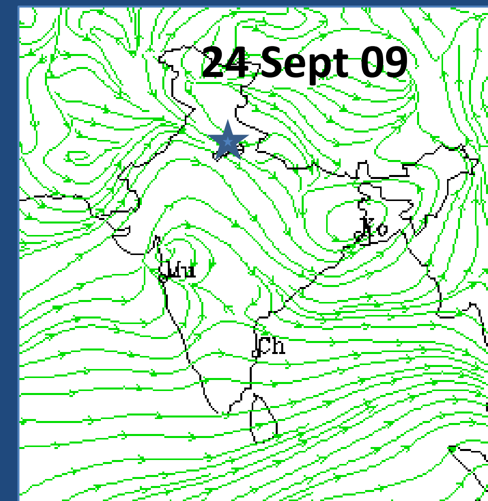

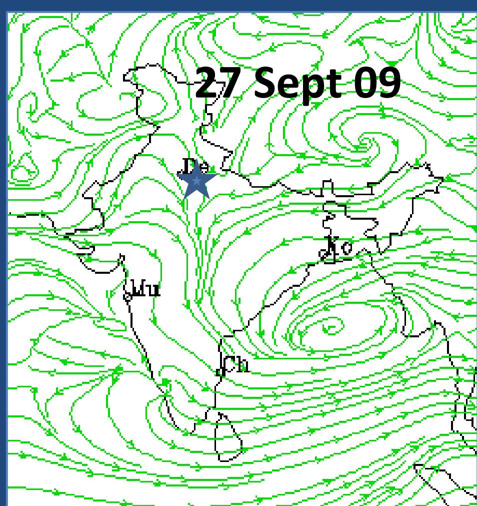

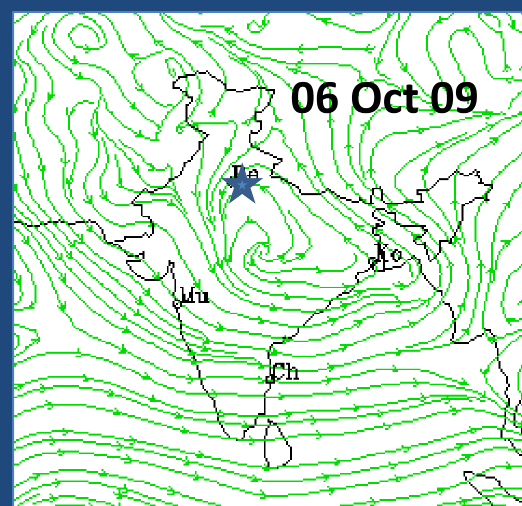

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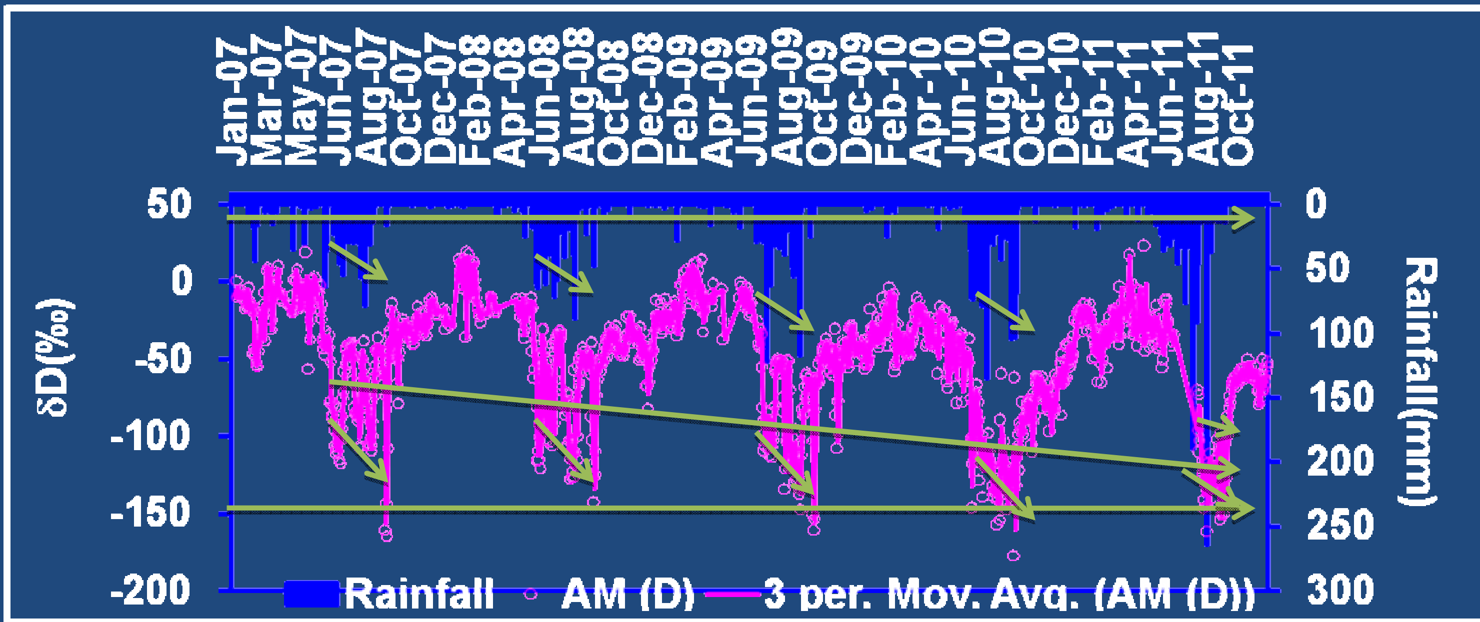
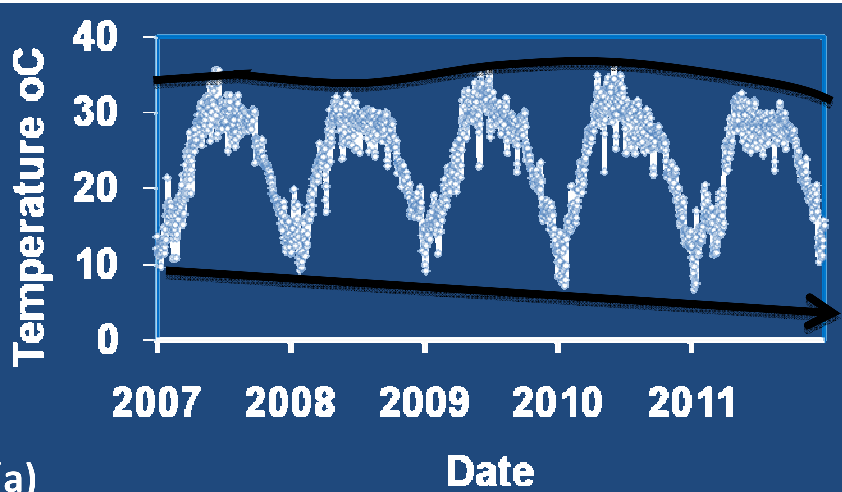
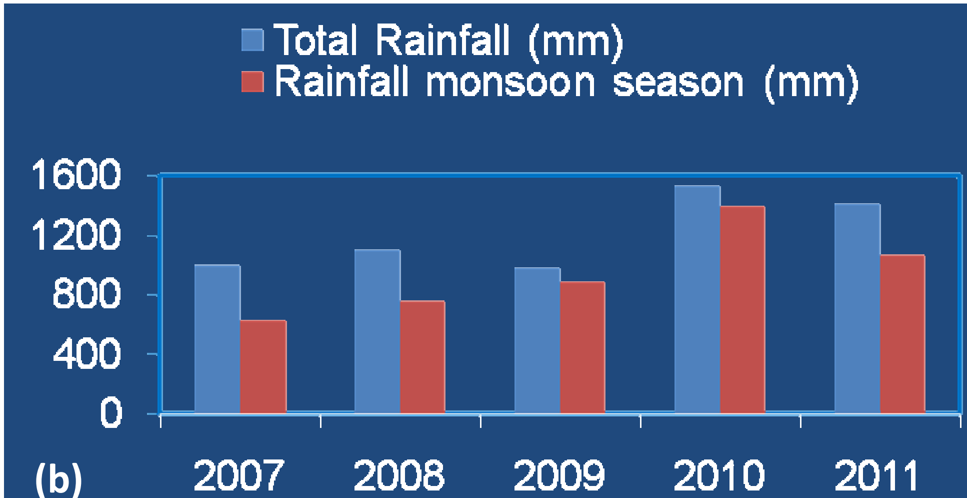
Variation in isotopic composition of air moisture and rainfall at Roorkee for 2007-2011



Variation in Meteorological parameters during 2007-11
(a) temperature (b) rainfall (c) average temperature & average RH
(d) total rainfall and rain in monsoon season



(a)



(b)

CONCLUSIONS

- **Vapours associated with monsoon are always depleted at all the stations with respect to non-monsoon vapours, therefore, isotopes may be used to track movement of monsoon vapours and regional influx of moist vapour.**
- **The difference in isotopic composition is primarily affected by the season and source of variation.**
- **The present data pattern clearly demonstrates the continental effect (decreasing δD values from Hyderabad to Roorkee) and altitude effect in the Indian sub-continent (decreasing δD values from Roorkee to Manali) and can be used in climate studies similar to meteoric water.**

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- Yogesh
- Luxmi
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- Tushar
- Kartik
- Vimla Purohit
- Geetanjali Purohit
- Kailash Purohit

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Thanks for your patience.