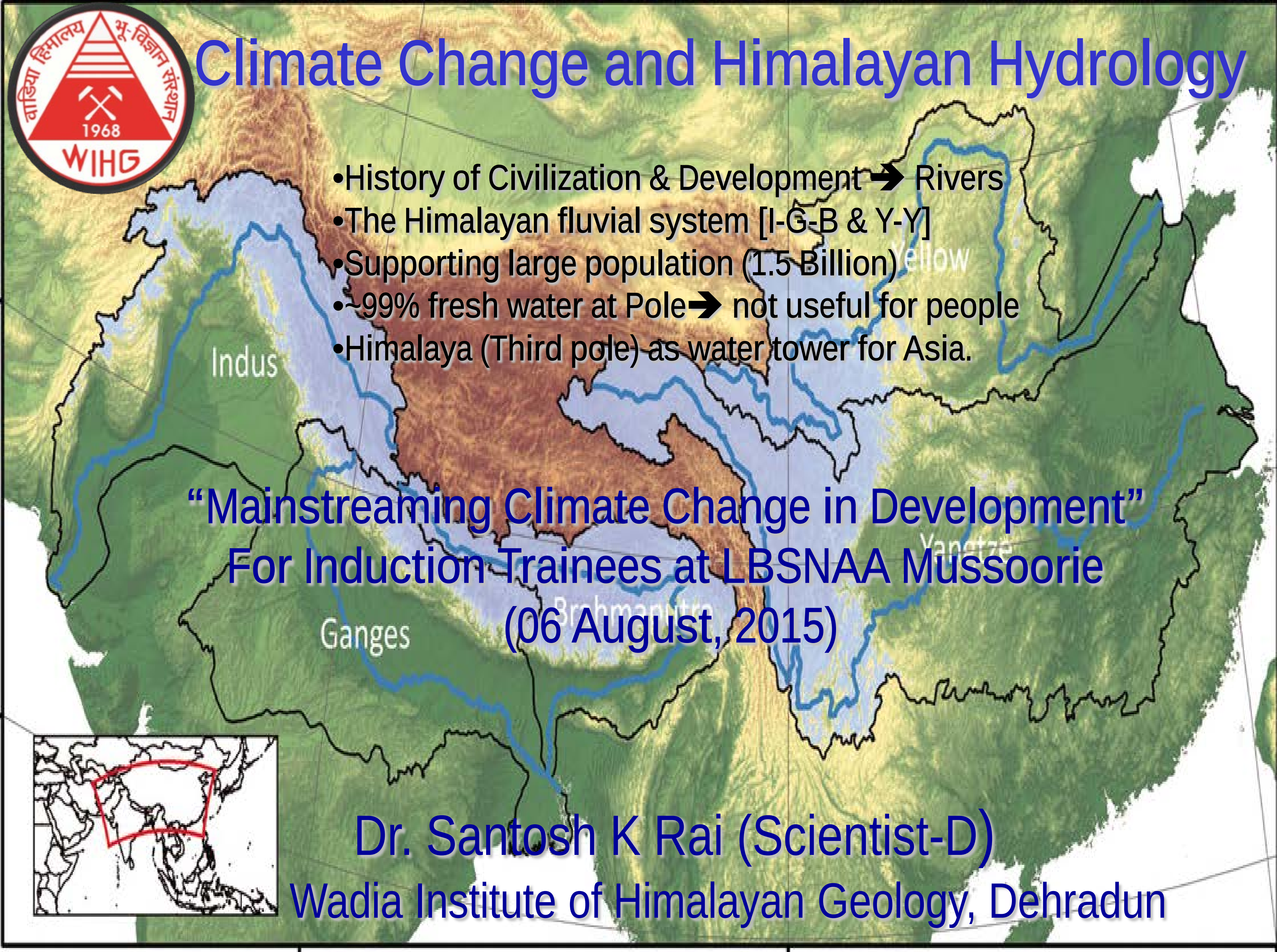


Climate Change and Himalayan Hydrology

- History of Civilization & Development ➔ Rivers
- The Himalayan fluvial system [I-G-B & Y-Y]
- Supporting large population (1.5 Billion)
- ~99% fresh water at Pole➔ not useful for people
- Himalaya (Third pole) as water tower for Asia.

"Mainstreaming Climate Change in Development"

For Induction Trainees at LBSNAA Mussoorie
(06 August, 2015)

Dr. Santosh K Rai (Scientist-D)
Wadia Institute of Himalayan Geology, Dehradun

Ten major river basins of the Himalayan region

Rivers	River Basin Area (sq.km)	Countries of Flow	Population (X 1000)	Population density (per sq.km)
Amu Darya	534,739	Afghanistan, Tajikistan, Turkmenistan, Uzbekistan	20,855	39
Brahmaputra	651,335	China, India, Bhutan, Bangladesh	118,543	182
Ganges	1,016,124	India, Nepal, China, Bangladesh	407,466	401
Indus	1,081,718	China, India, Pakistan	178,483	165
Irrawaddy	413,710	Myanmar	32,683	79
Mekong	805,604	China, Myanmar, Laos, Thailand, Cambodia, Vietnam	57,198	71
Salween	271,914	China, Myanmar, Thailand	5,982	22
Tarim	1,152,448	Kyrgyzstan, China	8,067	7
Yangtze	1,722,193	China	368,549	214
Yellow	944,970	China	147,415	156
Total	8,594,755		1,345,241	

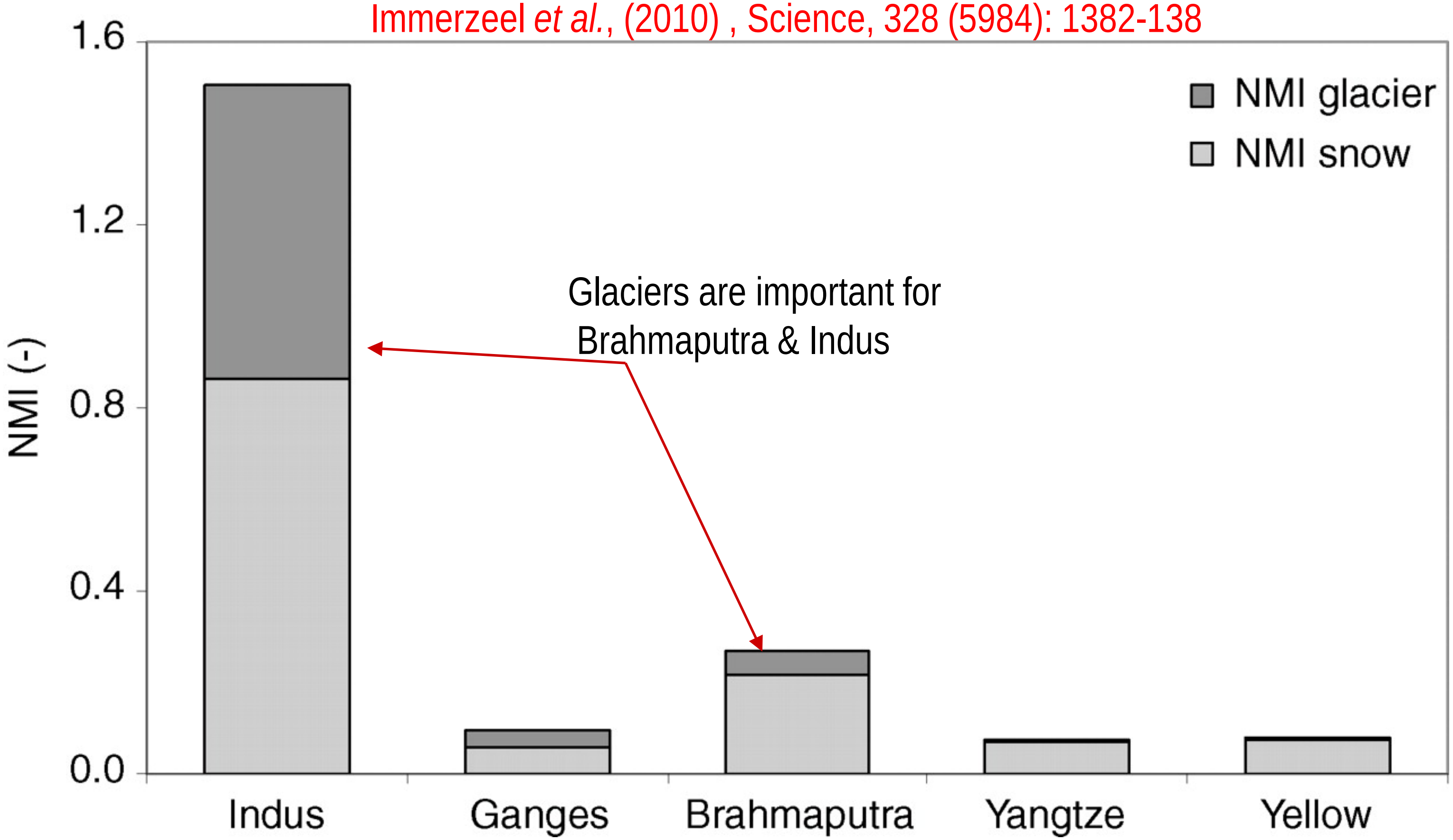
Characteristics of Major South East Asian Rivers

Parameter	INDUS	GANGA	BRAHMAPUTRA	YANGTZE	YELLOW
Area (Km^2)	1,005,786	990,316	525,797	2,055,529	1,014,721
Population (10^3)	209,619	477,937	62,421	586,006	152,718
Annual Rainfall (mm)	423	1,035	1,071	1,002	413
Upstream of the river (%)	40	14	68	29	31
Snow Cover (%)	2.2	1.0	3.1	0.1	0.0
Annual Rainfall (Upstream) (%)	36	11	40	18	32
Annual Rainfall (Down stream) (%)	64	89	60	82	68
Irrigated Area (Km^2)	144,900	156,300	5,989	168,400	54,190

Immerzeel *et al*., (2010) , Science, 328 (5984): 1382-138

Major River systems of Himalaya

Immerzeel *et al.*, (2010) , Science, 328 (5984): 1382-138



Glaciers are important for Brahmaputra & Indus

Contribution of Snow and Ice melt normalized to the downstream rainfall

Formation [Glacier] = Accumulation – (Melting+ Sublimation)

Glacier Dynamics = f (Precipitation, Rain/Snow ratio, Melting Sublimation)

→Retreat of Glacier may not imply melting always!!

Precipitation is important in formation of glaciers

Northwestern Himalaya (India) in a Climate change era: Major Issues

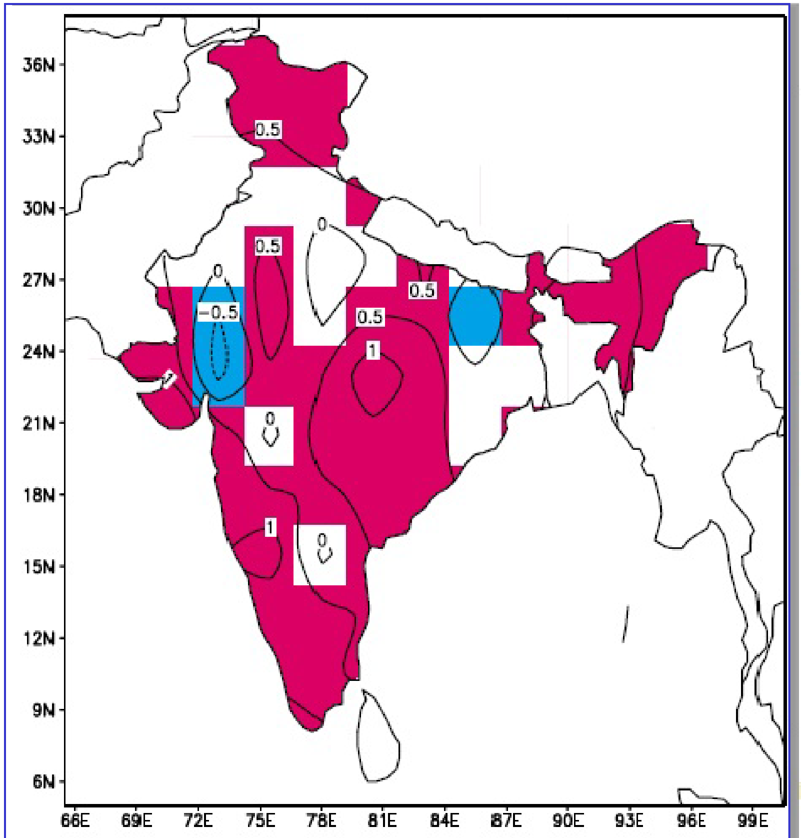


Fig 7: Spatial Pattern of Trend (^{0}c/ 100 years) in Mean Annual Temperature Anomalies (1901-2009). Areas where trends are significant are shaded (red : warming, blue : cooling)

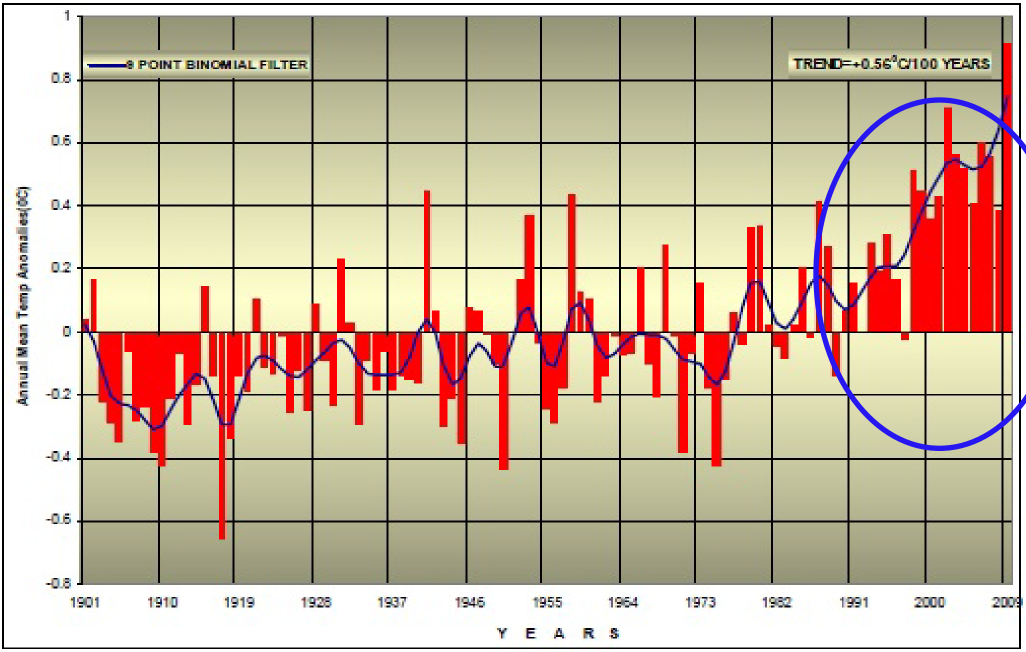
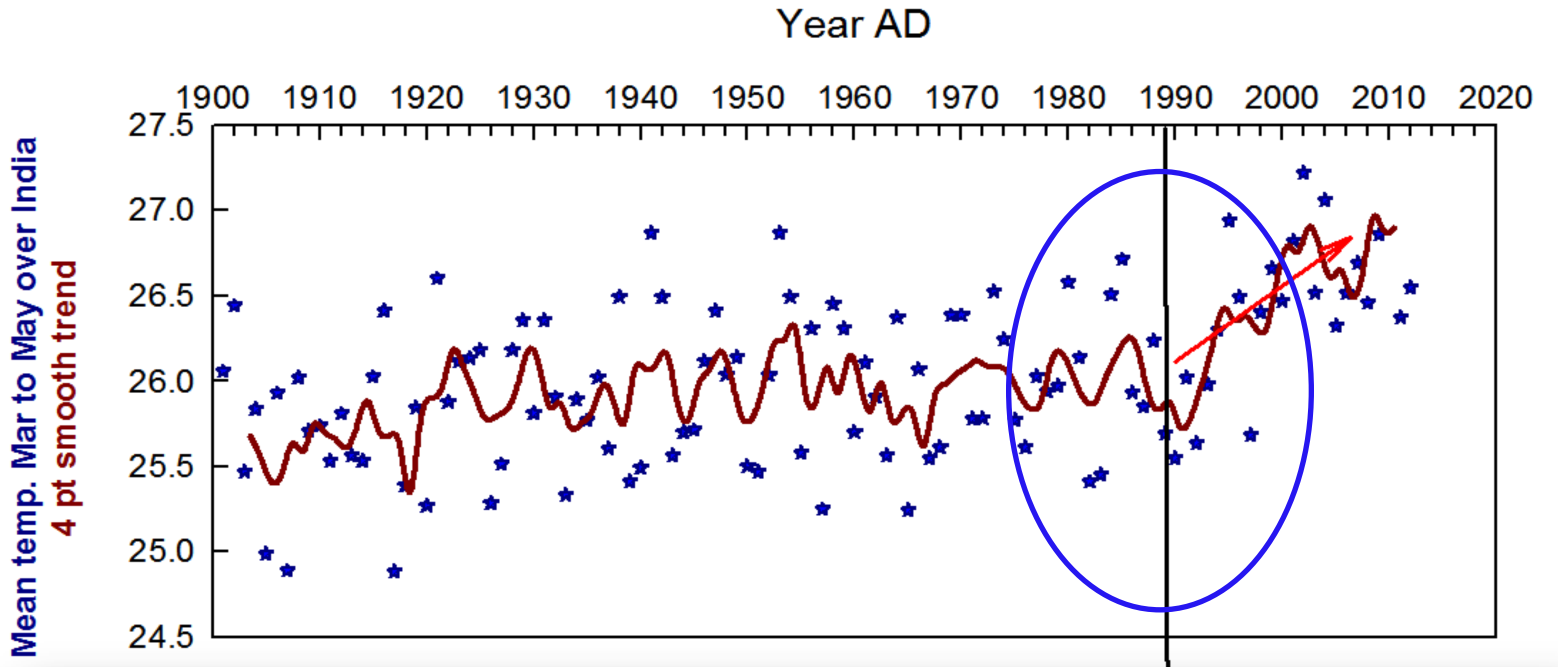


Fig 4: All India annual mean temperature anomalies for the period 1901-2009 (based on 1961-1990 average) shown as vertical bars

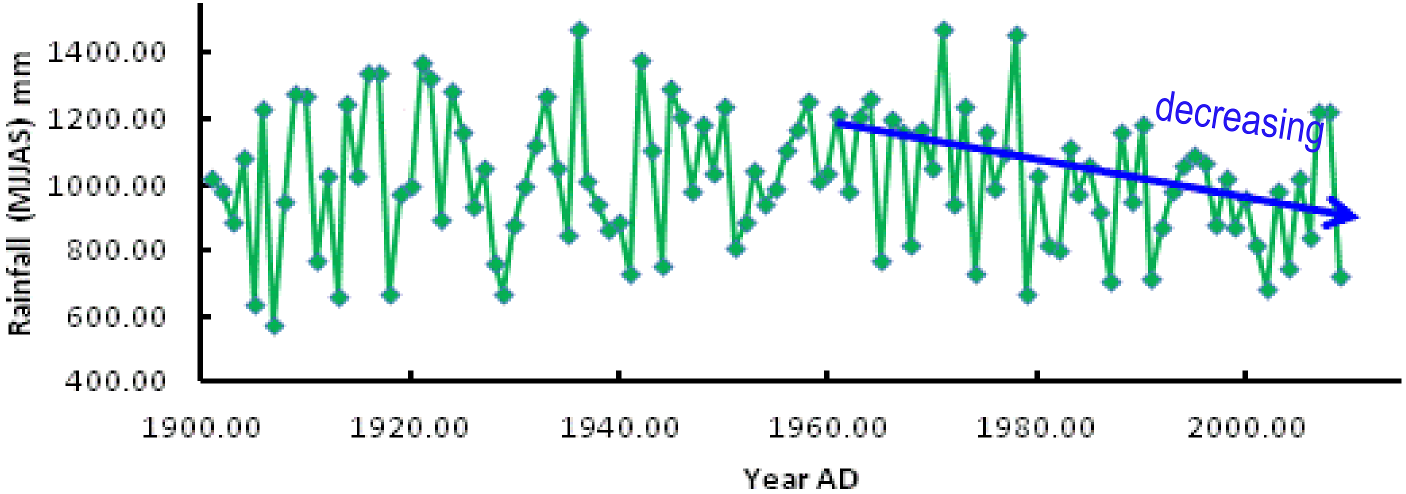
(The solid blue curve show sub-decadal time scale variations smoothed with a binomial filter)

Q: Is temperature over Northwestern Himalayas of India also increasing? Answer is yes!!



UK rainfall from 1901 to 2009

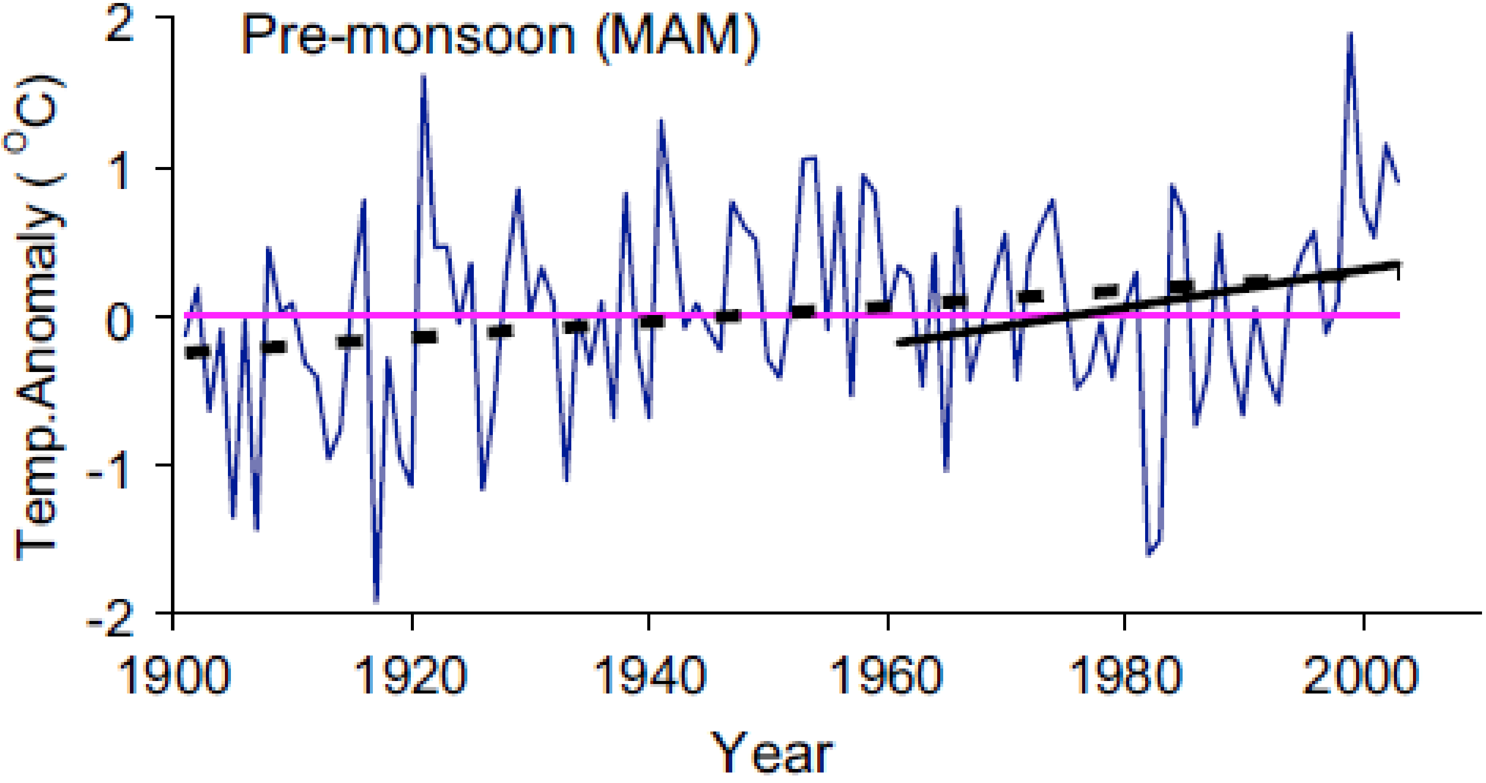
[GPCC Network data analyzed & calibrated for Uttarakhand Region



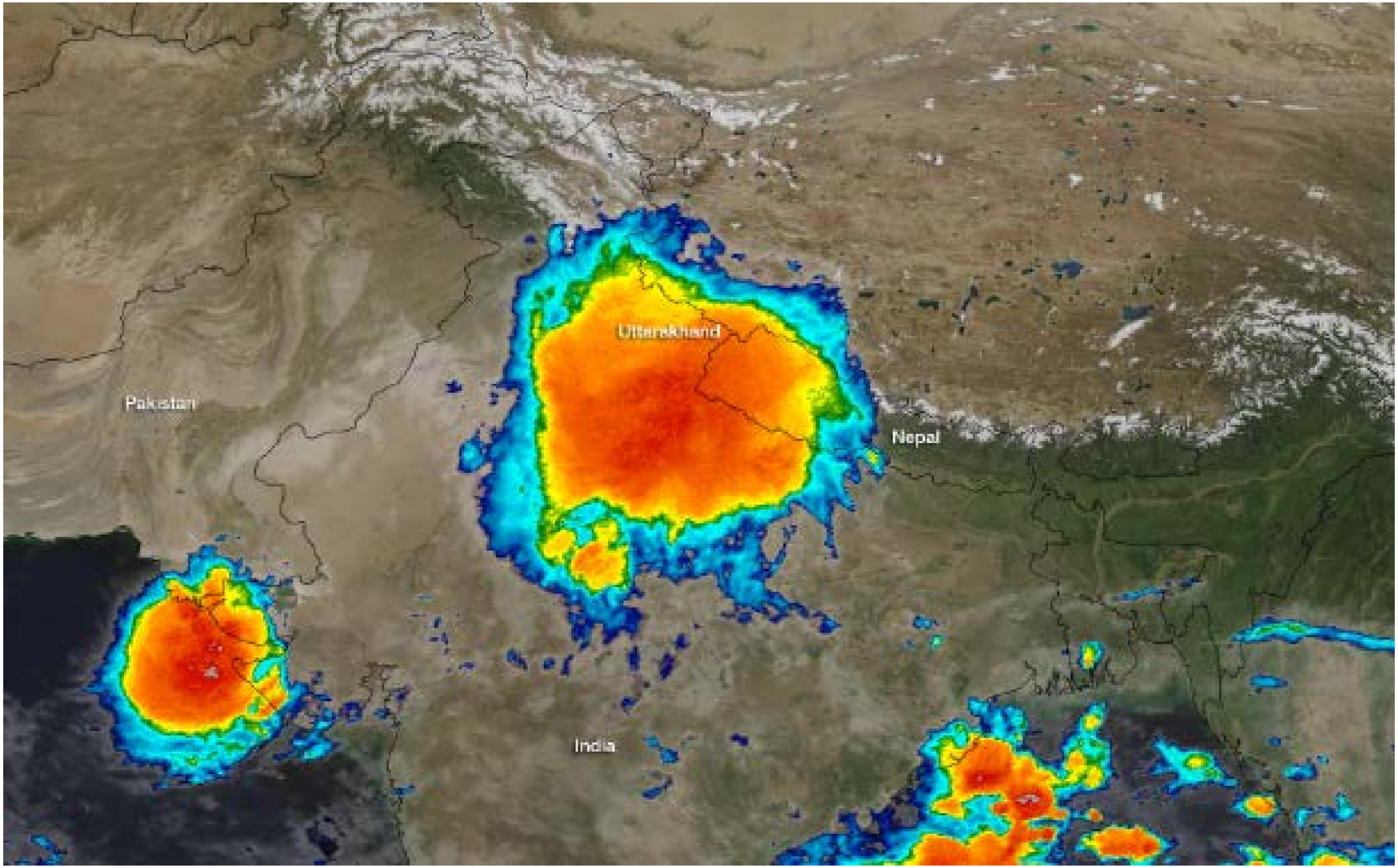
Rajesh Agnihotri, NPL New Delhi [personal communication]

Pre- monsoonal rainfall over Uttarakhand is increasing

(Tree ring records)!



Amidst this scenario, abrupt rainfall events over UK such as 15-17 June 2013 (shown in next slide) are causing immediate concerns demanding knowledge of origin of this kind of devastating events.



METEOSAT-7 satellite Image (June 11, 2013) shows a monsoon storm that formed over Uttarakhand State, that along with subsequent rains led to thousands of people being trapped by raging water courses that have destroyed infrastructure.

Rain led devastation as captured in images

Plausible factors for the observed scenario?

High resolution past climate records spanning to ~1000 years to estimate whether such type of climate / monsoon anomalies have been witnessed in the recent past?

Natural variability of climate or Anthropogenic activity such as enhanced aerosol loading paying a role?

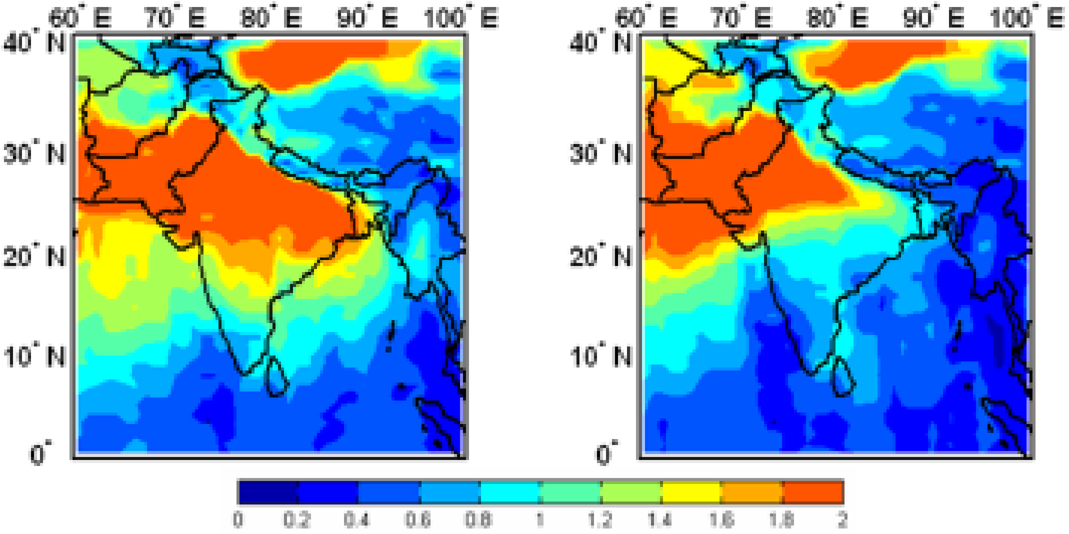
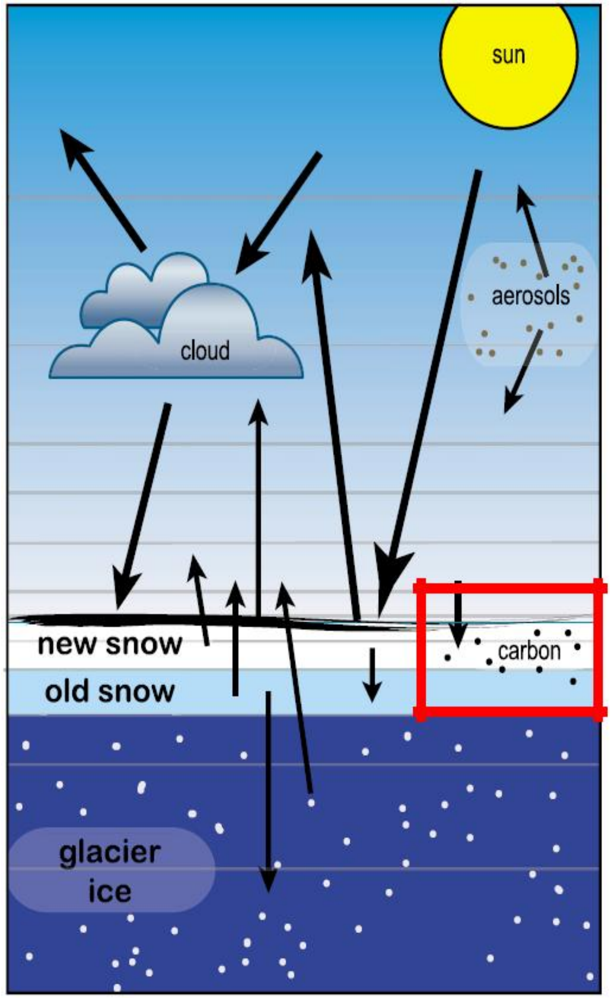


Fig. 3. TOMS Aerosol Index Climatology for May (left) and June (right).

Black Carbon induced melting of Ice over Himalaya?

- “It causes warming in two ways.
- First; Black Carbon in the atmosphere absorbs solar radiation, which heats the surrounding air;[Global mean of 0.9 W m^{-2}]
- Second; surface deposition of airborne Black Carbon ➔ darken snow and ice ➔accelerate melting;[0.03-0.11 W m^{-2}]
- Model simulations ➔ ~0.6°C of the 1°C warming in the Tibetan Himalayas since the 1950s may be due to atmospheric Black Carbon.

Ramanathan V, Carmichael G (2008) “Global and regional climate changes due to black carbon”, Nature Geosciences



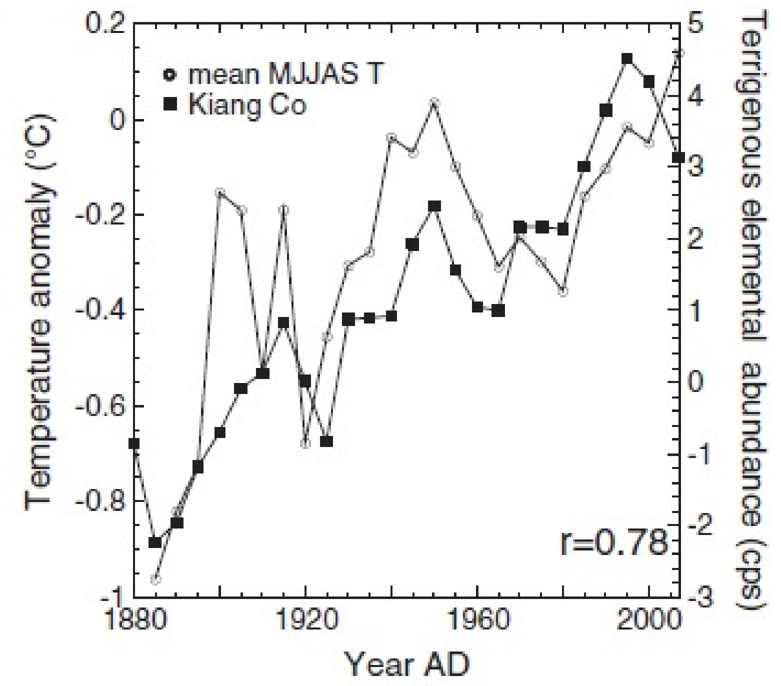
Regional dustiness

- •Regional dustiness influences glacial stream flow and sediment transport in higher Himalayas and southern Tibetan Plateau region.

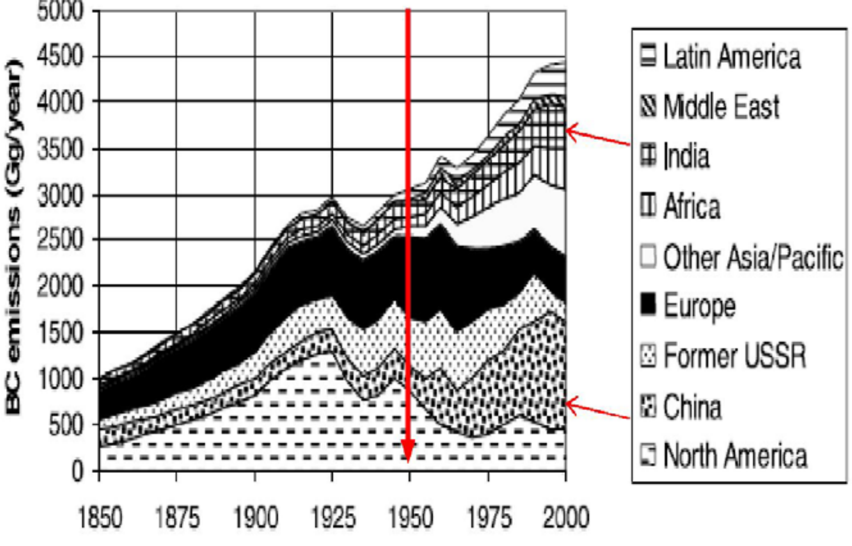
- •Relationship between temperature of melting & stream flow in this region during the period of 1870 to 2007 AD.

- •Highlighting a likely scenario of future dustiness with continued warming➔ increases in melting and high-elevation stream flow in coming decades.

Conroy et al. (2013; GPC)



BC emissions from India and China



Major issues for Himalayan Glaciology

1. How the rainfall over the region is responding to Natural as well as the anthropogenic activities. (1) Carbon emissions, (2) Aerosol loadings (3) increasing dustiness of the sky (4) increasing land temperatures in summer.

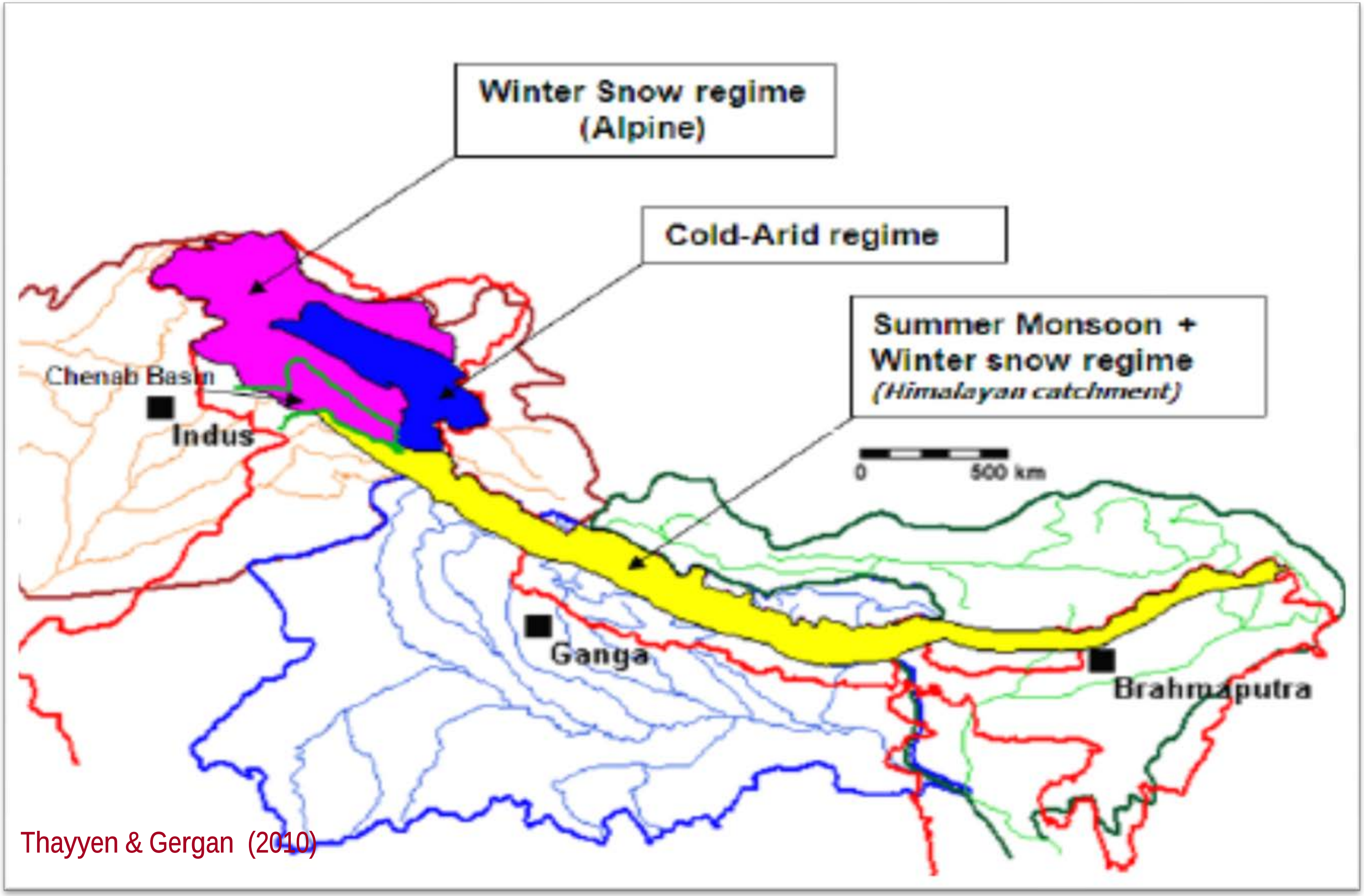
2. Moisture source and apportionment of snow melt contribution to the Himalayan Rivers (I-G-B) ➔Input to the policies for engineering structures [dam, etc.].

3. Meteorological monitoring of natural extreme events in the Glacier-fed streams to check the risks of flash floods ➔ Loss mitigation.

4. Time series analyses of water samples from Glacier fed stream near the Indo-China boundary ➔ STRATEGIC IMPORTANCE!! ➔Data sharing mechanism between both country to minimize the risk on any natural/engineered flash flood *[June 2000 flash flood, Brahmaputra].*

5. Generating baseline data in the Glaciers of Himalayan region to address these points.

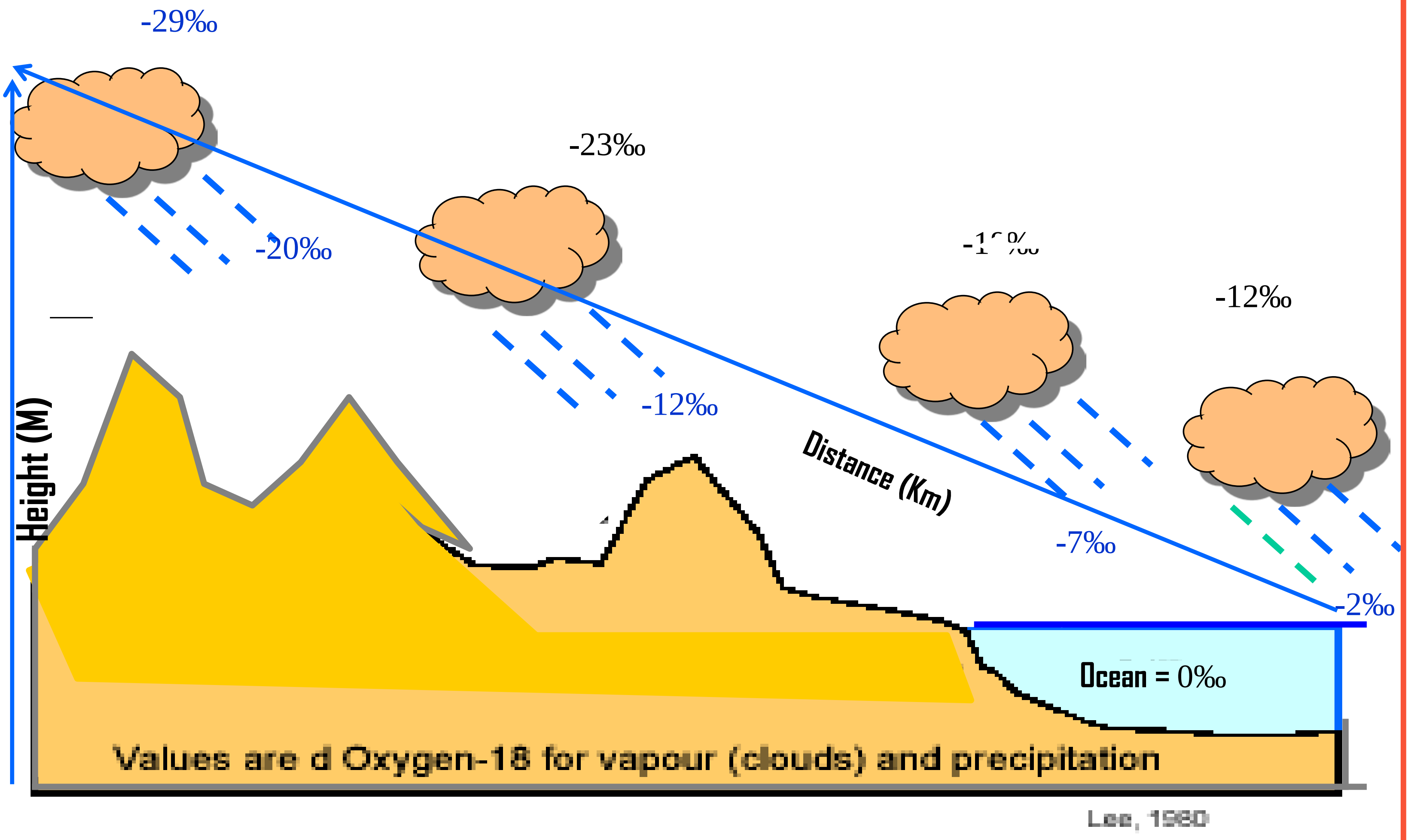
Moisture Source & snow melt contribution to Rivers



Thayyen & Gergan (2010)

Glacio-hydrological regimes of the (IGB System) Himalayas

Altitude Effect in Precipitation



GLOBAL METEORIC WATER LINE(GMWL)

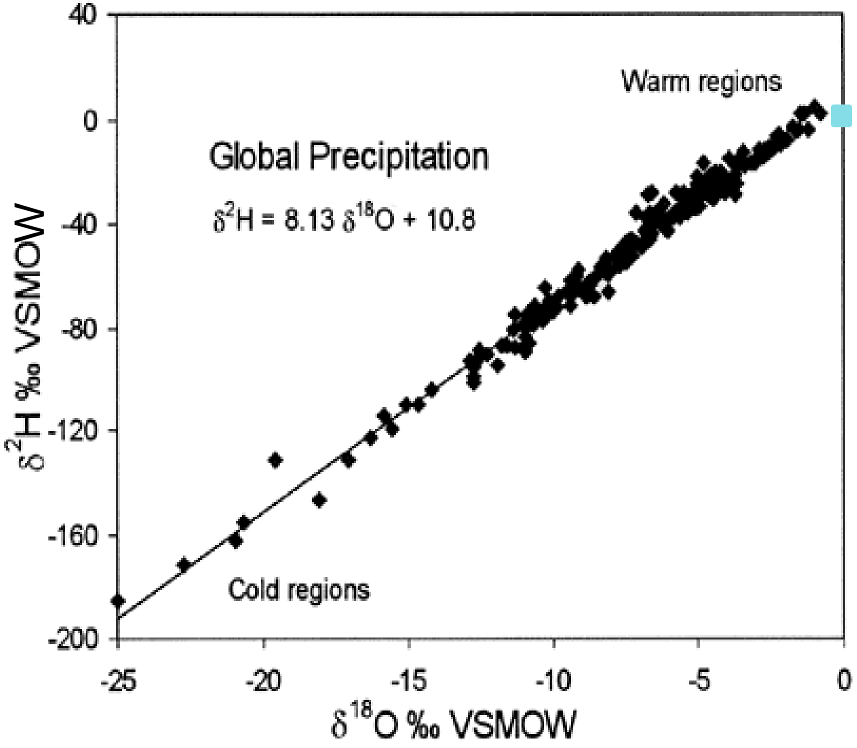
- **Craig(1961) for the first time Observed:**
- In spite of the great complexity in different compounds of the hydrological cycle➔$\delta^{18}O$ and δD in fresh surface waters (representing precipitation) correlate on a global scale. The regression line between $\delta^{18}O$ and δD is referred to as GMWL and defined as:

$\delta D = 8 * \delta^{18}O + 10(‰)$------------------ (I)

- Improving the precision of the Craig's GMWL, Rozanski et al.(1993) compiled the isotopic data of actual precipitation from 219 stations of IAEA, operated from global network for isotopes in precipitation.

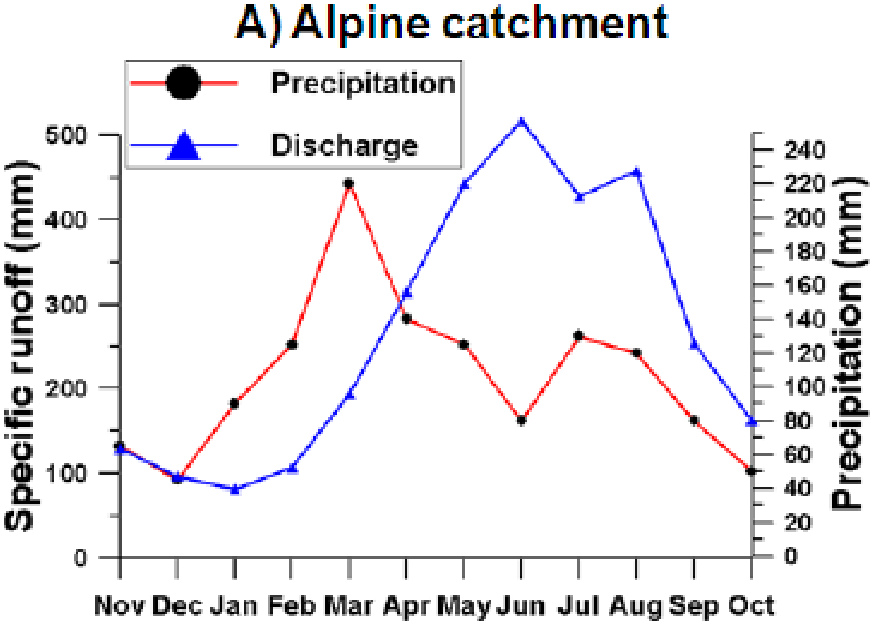
This refined relationship between $\delta^{18}O$ and δD as

$\delta D = 8.17(\pm 0.07) * \delta^{18}O + 11.27(\pm 0.65)$---------(II)

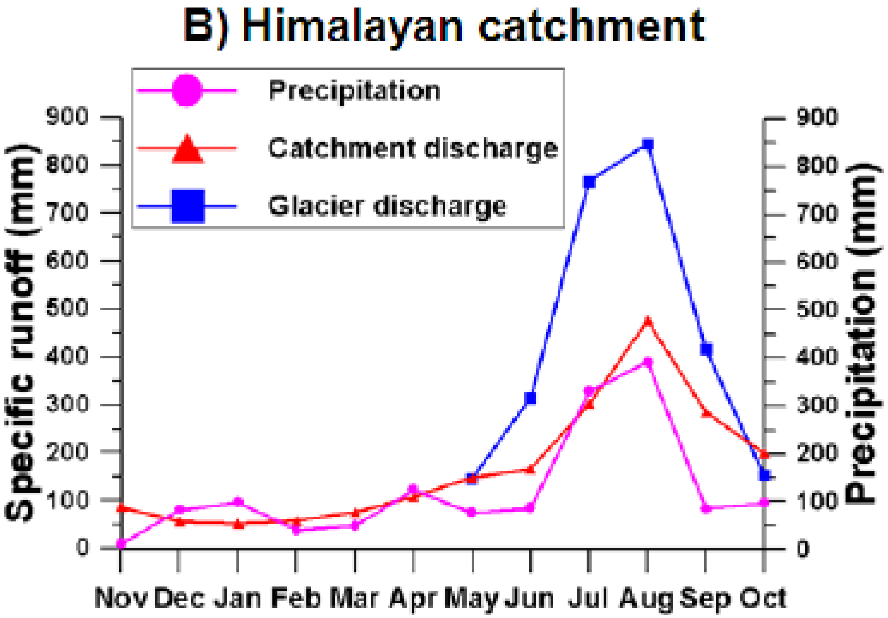


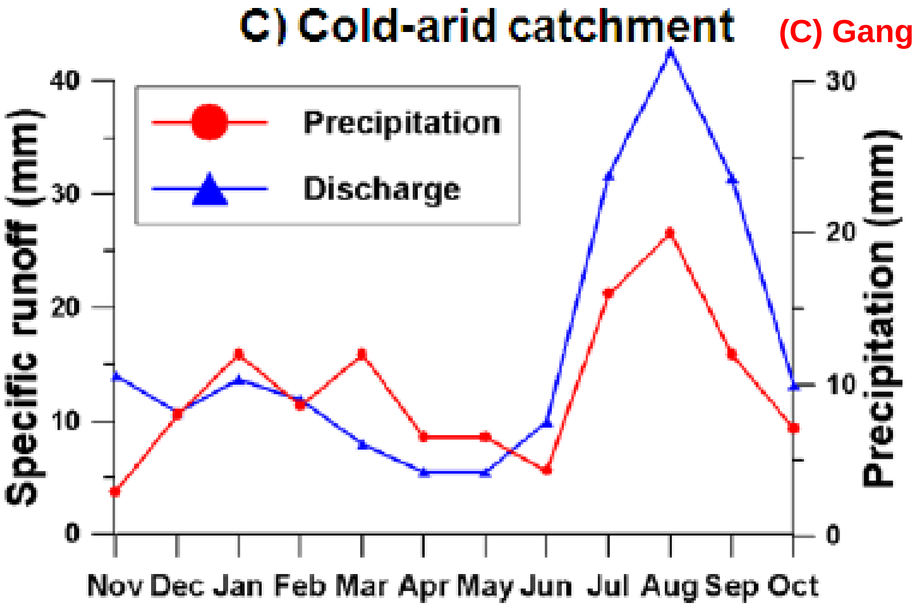
(Clark and Fritz 1997, p. 37, as compiled in Rozanski et al. 1993, modified by permission of American Geophysical Union).

(A) Snow dominant, Lidder valley, Kashmir



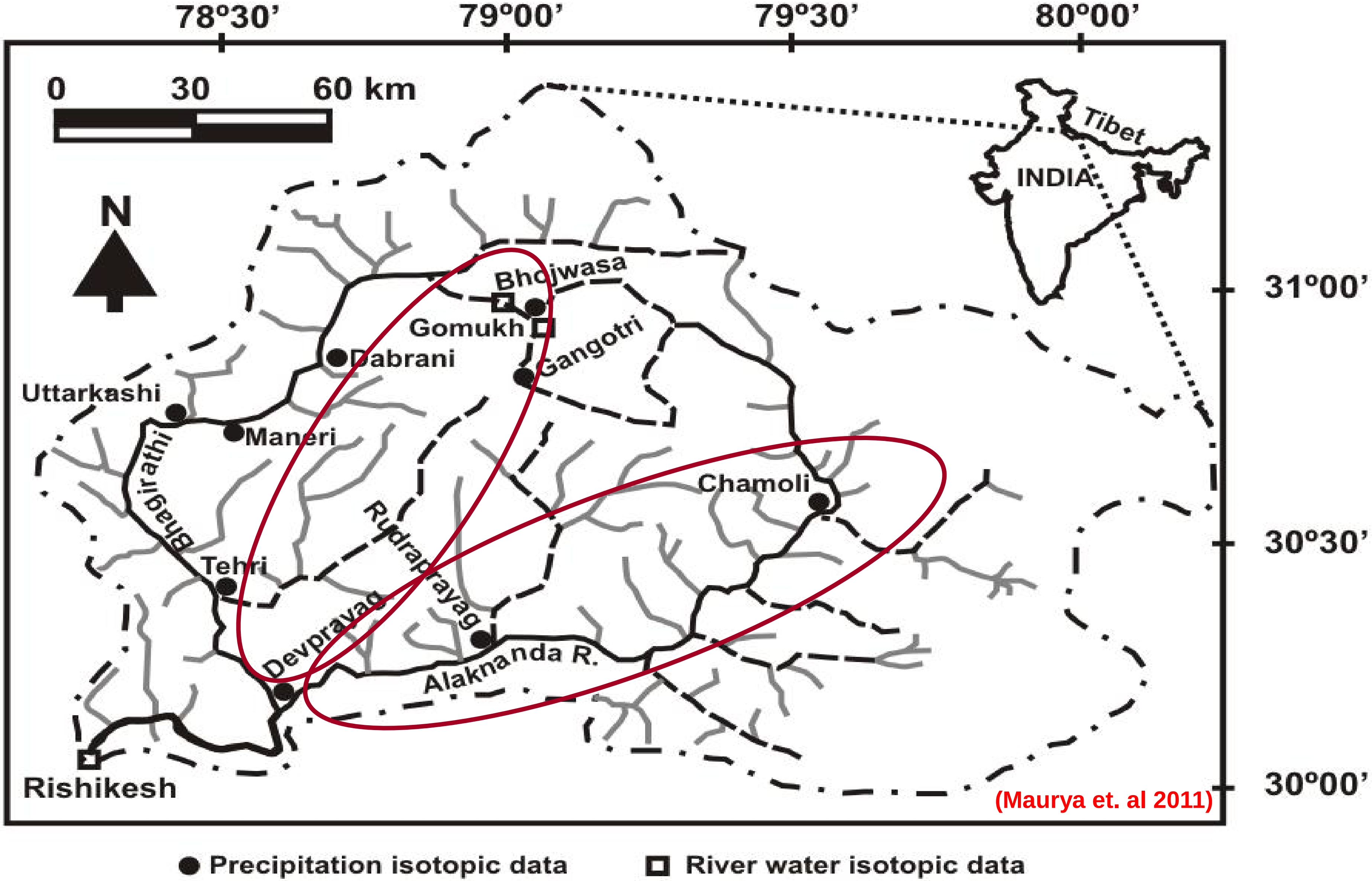
(B) Monsoon dominant ,Din Gad (Ganga)



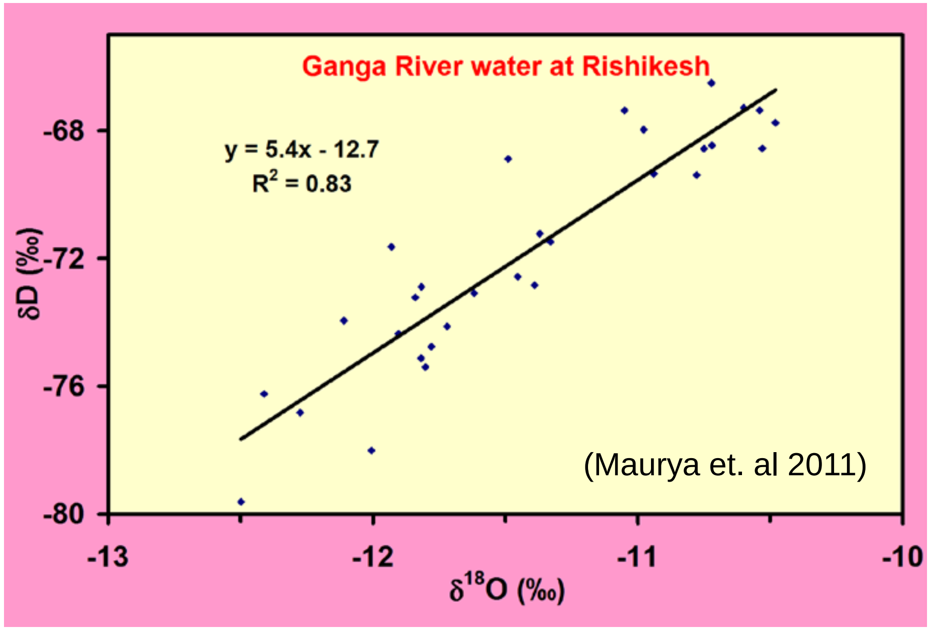


(C) Ganglass Ladakh

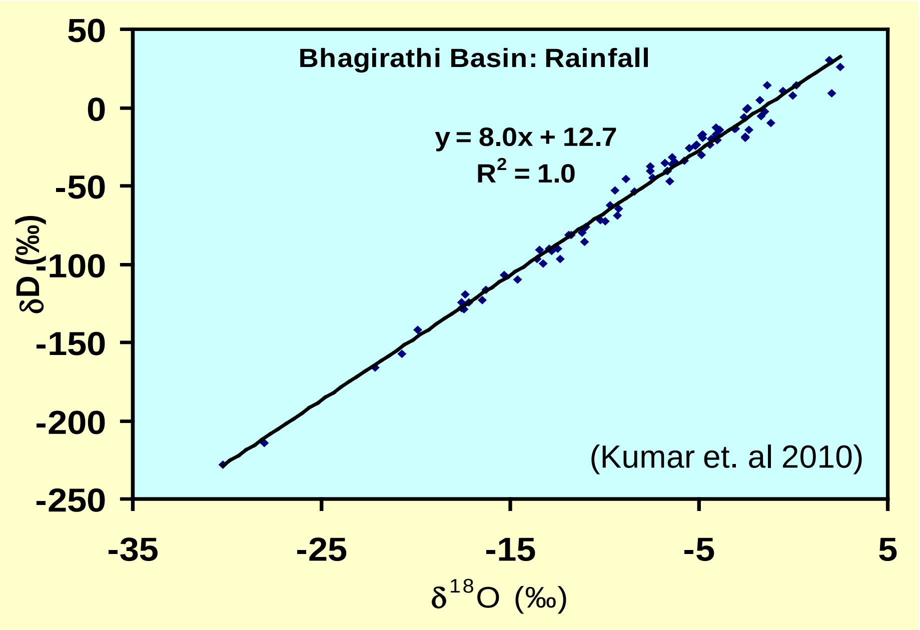
Thayyen & Gergan (2010)



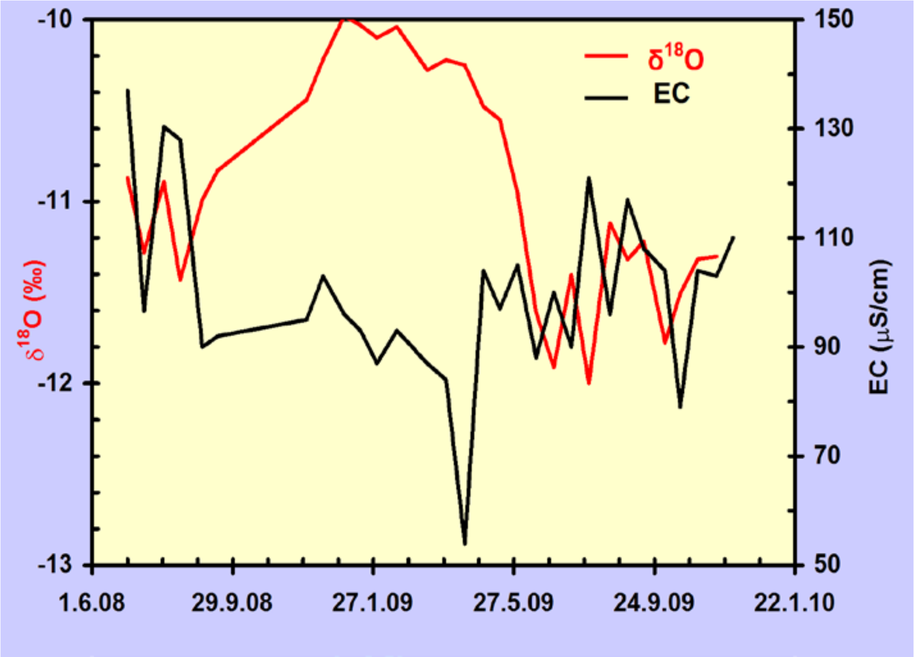
Fortnightly Water samples (Rishikesh) with EC, pH, Temp. & dissolved oxygen
[δ^{18}O and δD by standard equilibration method (IRMS)]

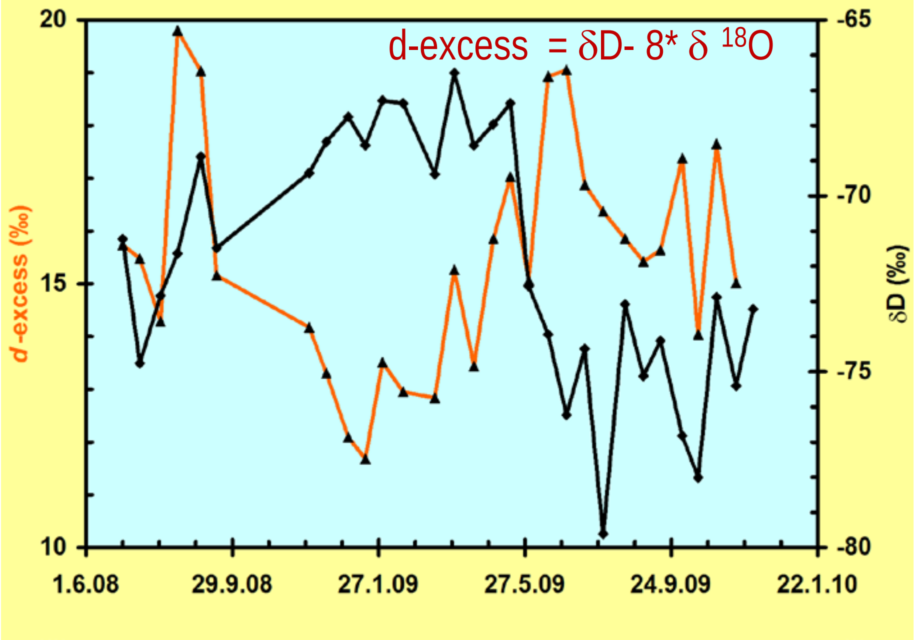

Ganga River water at Rishikesh

(Maurya et. al 2011)

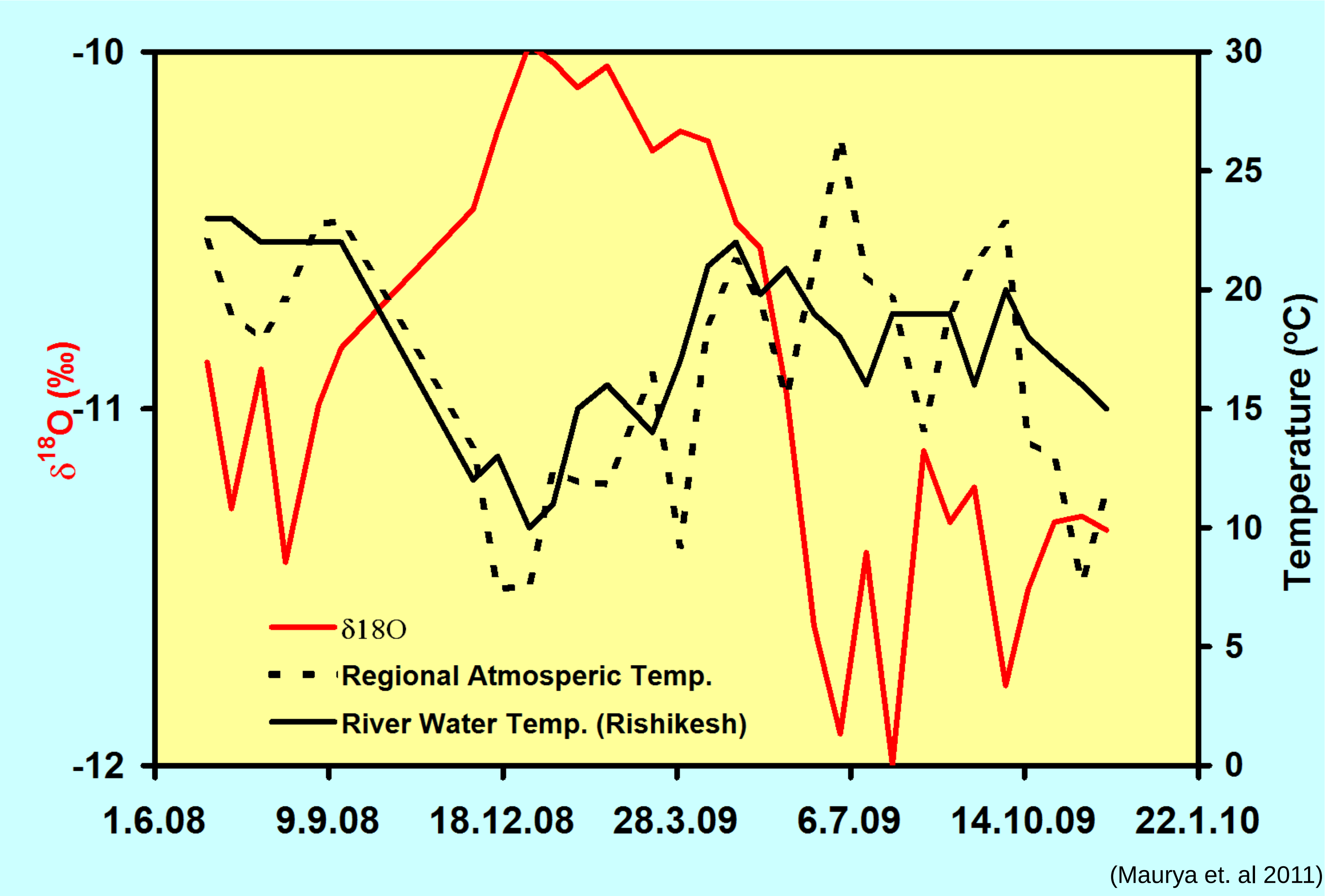

Bhagirathi Basin: Rainfall

(Kumar et. al 2010)




d-excess = δD- 8* δ 18O

Temporal variation in the Regional atmospheric temperature, measured river water temperature with δ¹⁸O at Rishikesh



(Maurya et. al 2011)

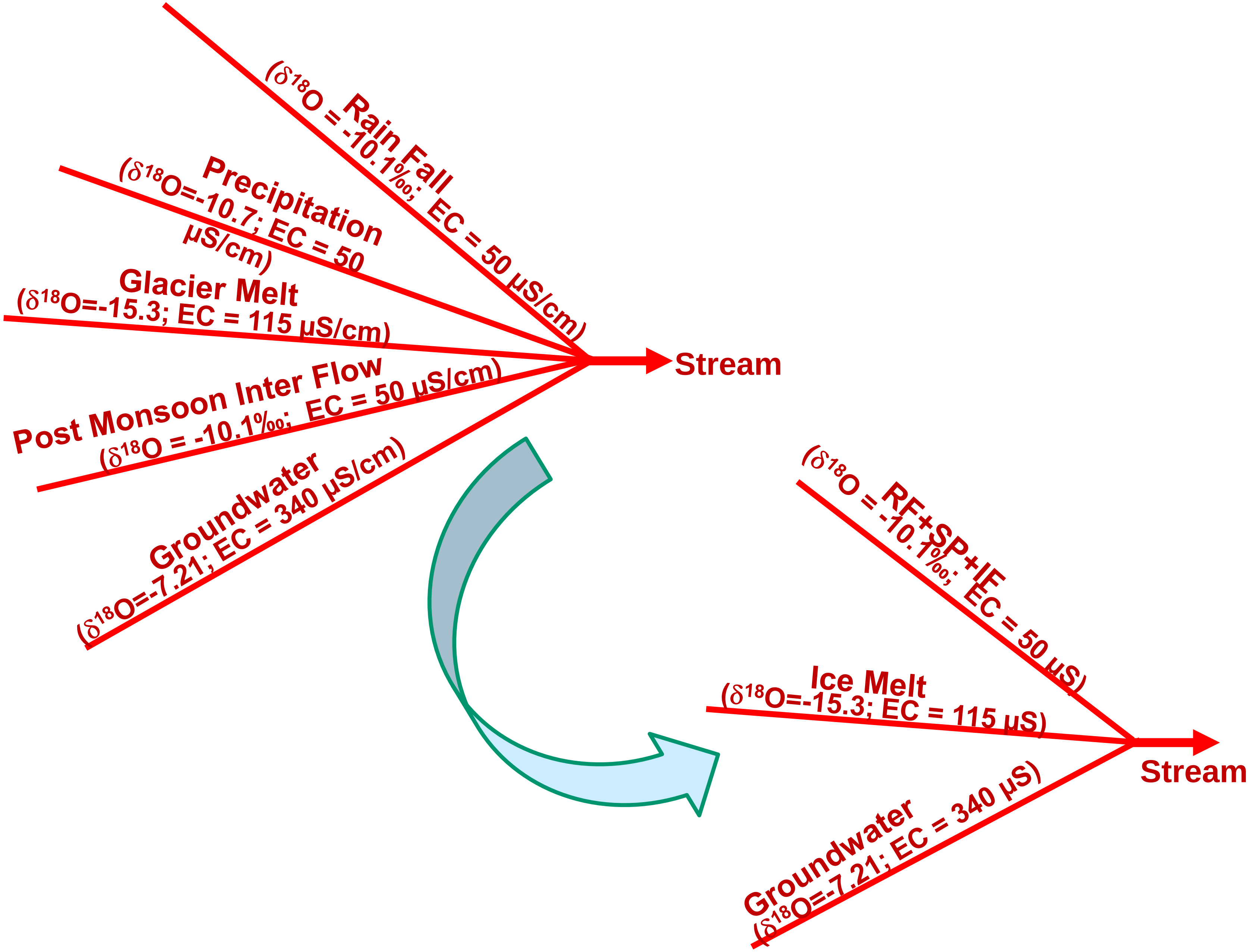
Hydrograph Separation

To estimate the temporal variation in proportions of the various components, contributing to the total discharge of the River

Assumptions :

- Specific water sources (end members) contributing to river runoff at a particular location are known
- Various sources can be distinguished by statistically different values of specific properties
- Stream water is a mix of individual water sources

Possible Sources (End Members)?



Rain Fall
(δ^{18}O = -10.1‰; EC = 50 µS/cm)

Precipitation
(δ^{18}O=-10.7; EC = 50 µS/cm)

Glacier Melt
(δ^{18}O=-15.3; EC = 115 µS/cm)

Post Monsoon Inter Flow
(δ^{18}O = -10.1‰; EC = 50 µS/cm)

Groundwater
(δ^{18}O=-7.21; EC = 340 µS/cm)

Stream

RF+SP+IF
(δ^{18}O = -10.1‰; EC = 50 µS)

Ice Melt
(δ^{18}O=-15.3; EC = 115 µS)

Groundwater
(δ^{18}O=-7.21; EC = 340 µS)

Stream

Assumptions for Hydrograph Separation

(1) Total river discharge is comprised of three components, namely:

- Surface runoff due to summer rainfall, post monsoon interflow and winter snowmelt: (r)
- Glacial ice-melt from higher reaches: (i)
- Groundwater discharge: (g)

(2)The d^{18}O and EC values of the above three components (end members) do not vary throughout the year.

(3)The observed variations in the values of these parameters in the river water is a reflection of the temporal variation in relative contributions of the constituent members.

Values different members for the discharge of Ganga at Rishikesh.

No.	Discharge Component	Altitude(m)	$\delta^{18}O$ (‰)	δD (‰)	EC (µS/cm)
1	Ice-melt (i)	3500-6000	-15.3	-107	115
2	Rainfall/Winter Snow Fall / Inter Flow (r)	830-4000	-10.1	-69	50
3	Groundwater (g)	600-1700	-7.2	-49	340

Sources:

1. **Pande *et al.*, 2000; Nijampurkar *et al.*, 2002; Nijampurkar and Rao, 1993; Lambs, 2000; Rai *et al.*, 2009; Chakrapani *et al.*, 2009.**
2. **Rai *et al.*, 2009; Kumar *et al.*, 2010.**
3. **Maurya et al 2010**

$$I + G + R = T \qquad (1)$$

$$i + g + r = 1 \qquad (2)$$

Where i, g, r denote discharge fractions due to ice-melt, groundwater and runoff respectively, obtained such that i = I/T, g = G/T and r = R/T.

$$i.\delta_I + g.\delta_G + r.\delta_R = \delta_T \qquad (3)$$

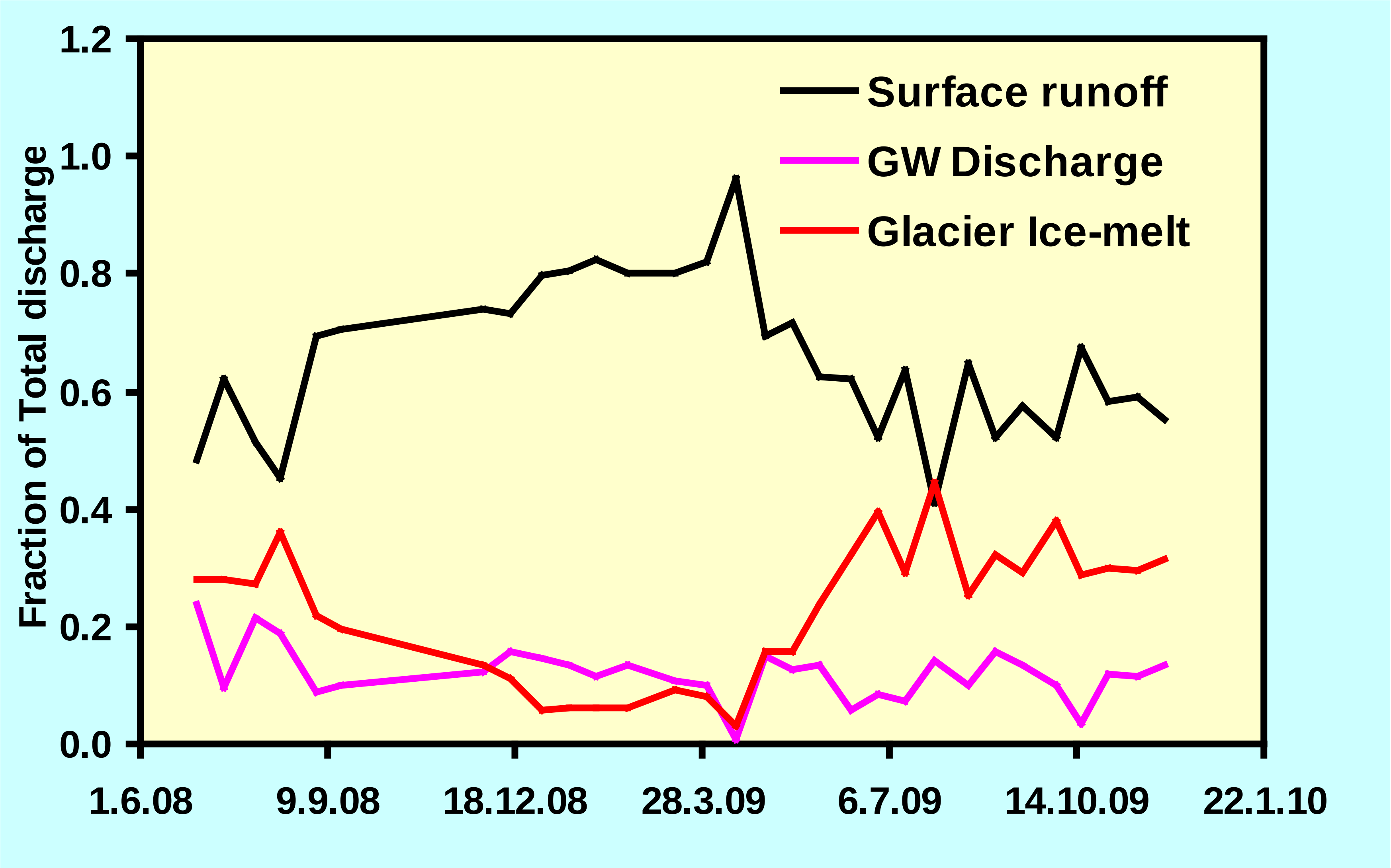
$$i.E_I + g.E_G + r.E_R = E_T \qquad (4)$$

The **δ** and E denote the d^{18}O and EC values of different components and the total discharge, qualified by respective subscripts. Solving equations, and for the three unknowns i, g and r:

$$r = \frac{(\delta_T - \delta_I)(E_G - E_I) - (\delta_G - \delta_I)(E_T - E_I)}{(\delta_R - \delta_I)(E_G - E_I) - (\delta_G - \delta_I)(E_R - E_I)} \qquad (5)$$

$$g = \frac{(\delta_T - \delta_I)(E_R - E_I) - (\delta_R - \delta_I)(E_T - E_I)}{(\delta_G - \delta_I)(E_R - E_I) - (\delta_R - \delta_I)(E_G - E_I)} \qquad (6)$$

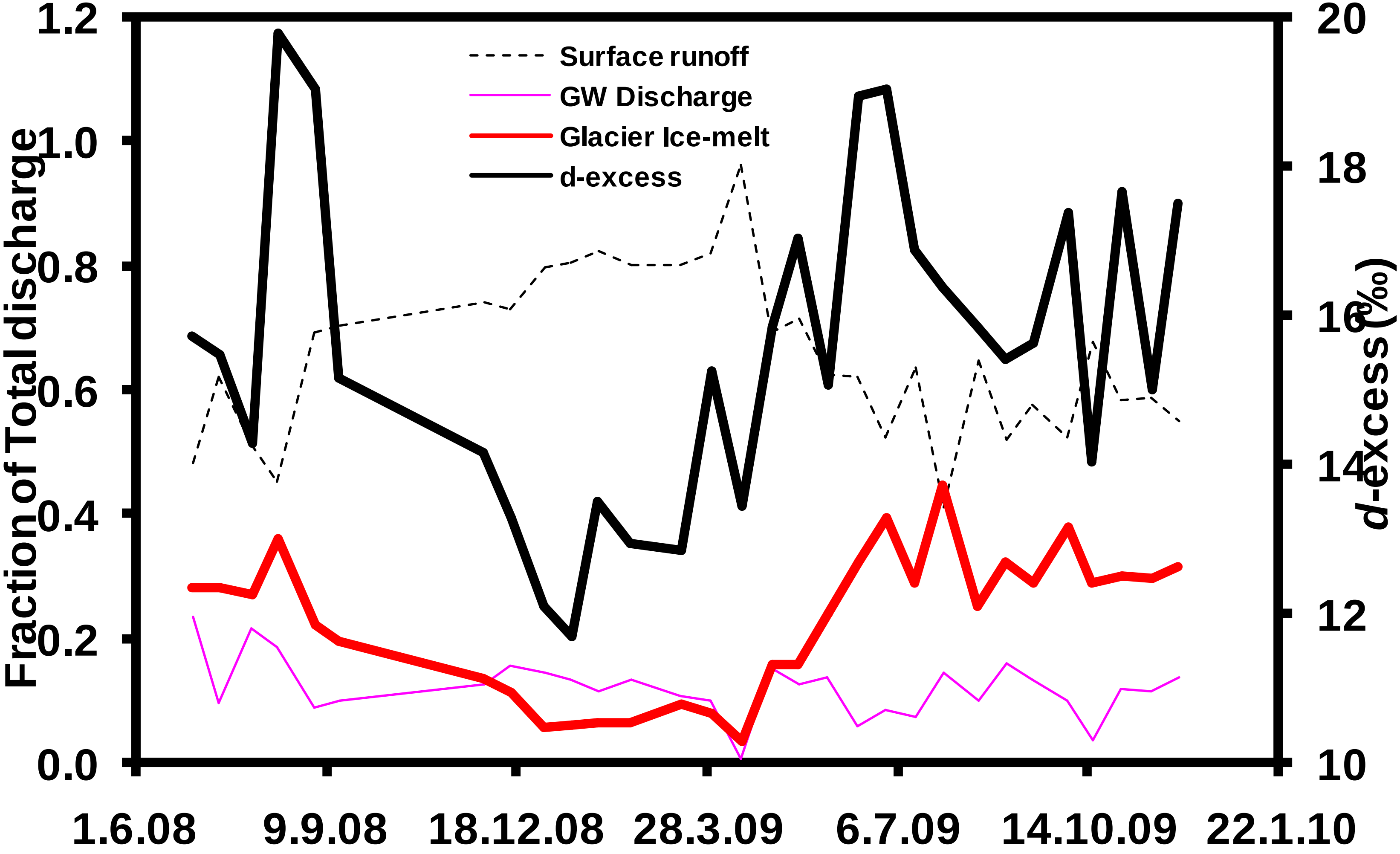
Estimated fractions of the Ganga River at Rishikesh



Maurya et al, 2011

Precipitation Source Identification

Temporal variation of *d-excess* with discharge fraction in Ganga at Rishikesh



d-excess = dD- 8*d^{18}O

The isotopic imprints of evaporation under non-equilibrium (kinetic) conditions and also the rapid recycling of the vapour.

During evaporation in dry climatic conditions, the kinetic fractionation becomes stronger and the residual water has low *d*-excess, whereas the resultant vapour will have high *d*-excess values and the precipitation from such a vapour also has high *d*-excess

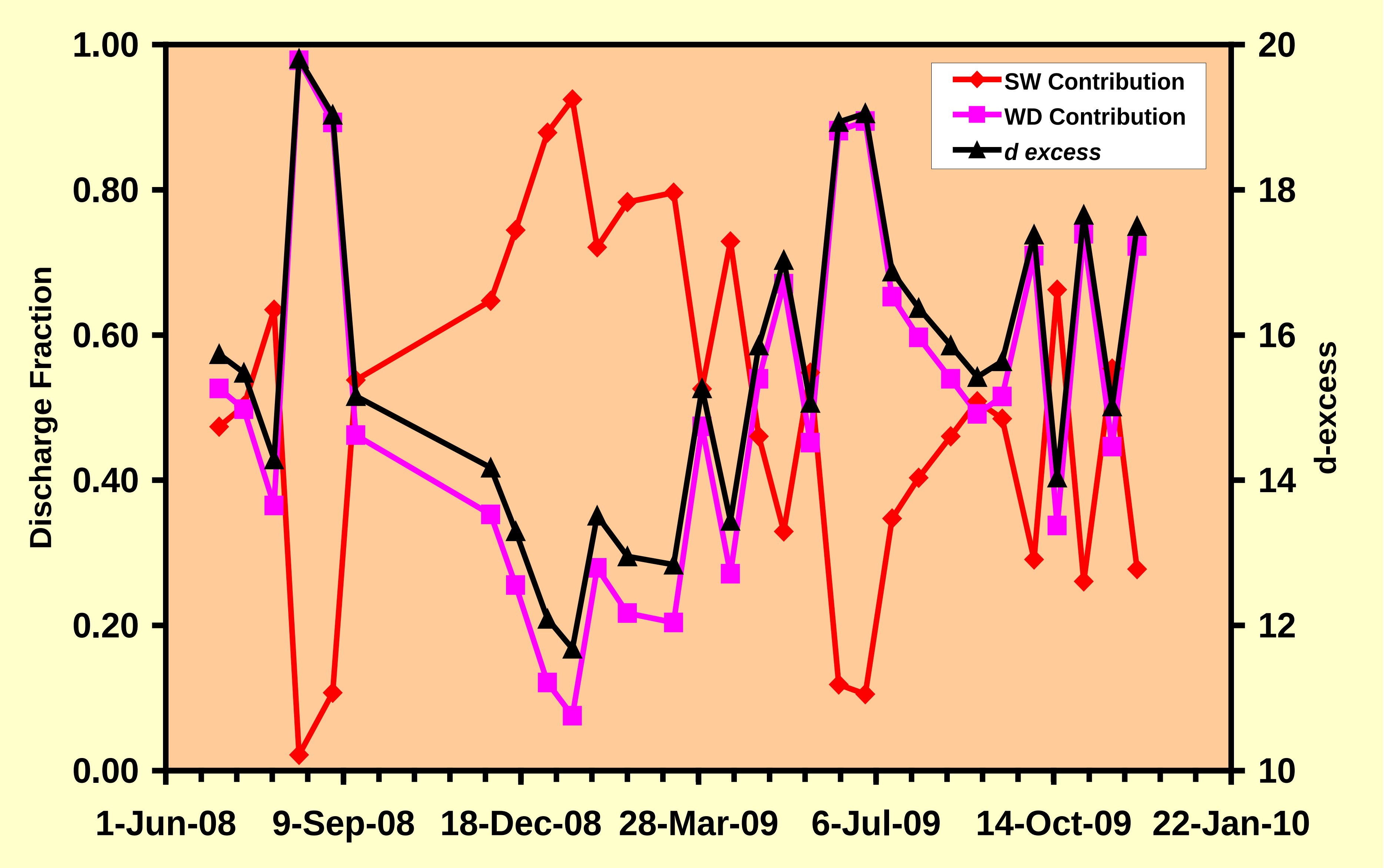
Avg. *d-excess* of S-W Monsoon= 11 ‰

Avg. *d-excess* of River water= 15.5 ‰

Avg. *d excess* of Groundwater= 13 ‰

Avg. *d*-excess of Western Disturbance (WD) = 20 ‰

Fractional Contribution of WD and SW Monsoon in Ice-melt water



New Tool- ^{17}Oexcess: Why and what is it?

General focus on two most common isotope in water: δ ^{18}O and δD
➔ applications to paleoclimate, hydrology, and biogeochemistry etc..

Studies focus on ^{18}O, relative to the more^{16}O but ^{17}O (~0.04% of stable oxygen) often goes overlooked. It can be used to understand:

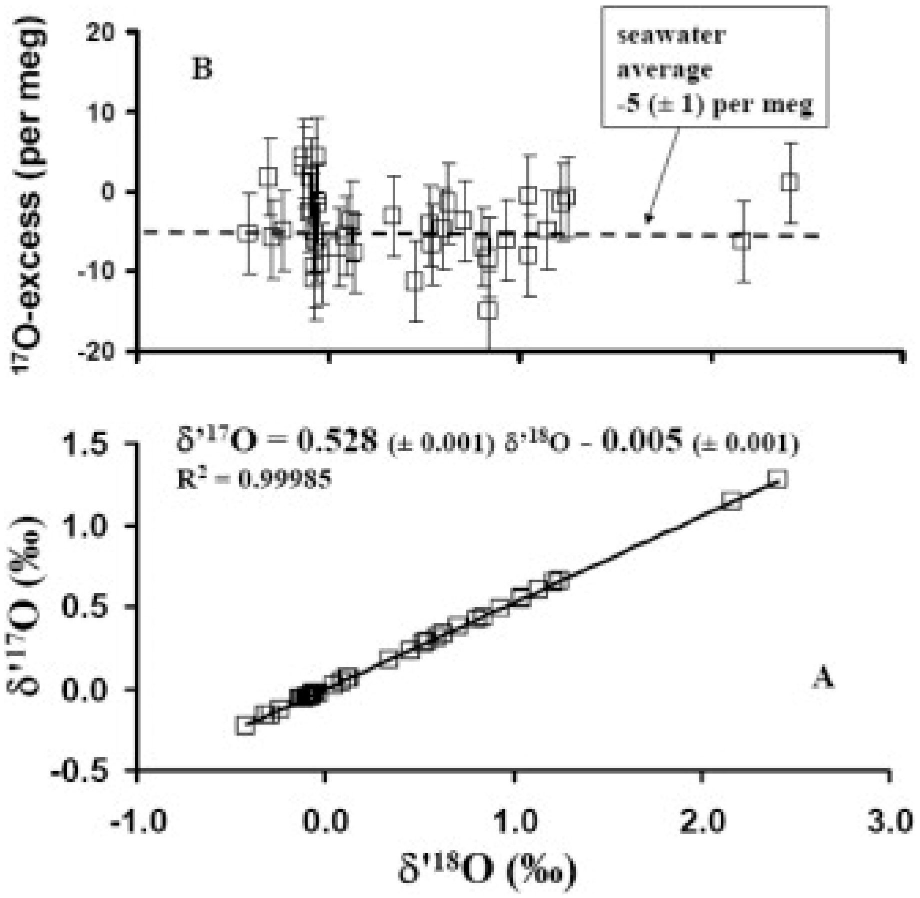
1) Past Humidity (from ice cores),
2) Evapo-transpiration(from leaf and stem water),
3) General evaporative regime (from liquid water),

•Due to its small signal variability, measuring ^{17}O requires instrumentation capable of extremely high precision (better than 0.01 ‰, or 10 per meg).

•Traditional techniques used to measure ^{17}O require conversion to O_2 – a complicated and time-consuming methodology, which can only be done in a lab.

Source of Vapour [Meteoric waters vs. Seawater]

$$^{17}\text{O-excess} = \ln(\delta^{17}\text{O}+1) - 0.528(\delta^{18}\text{O}+1)$$

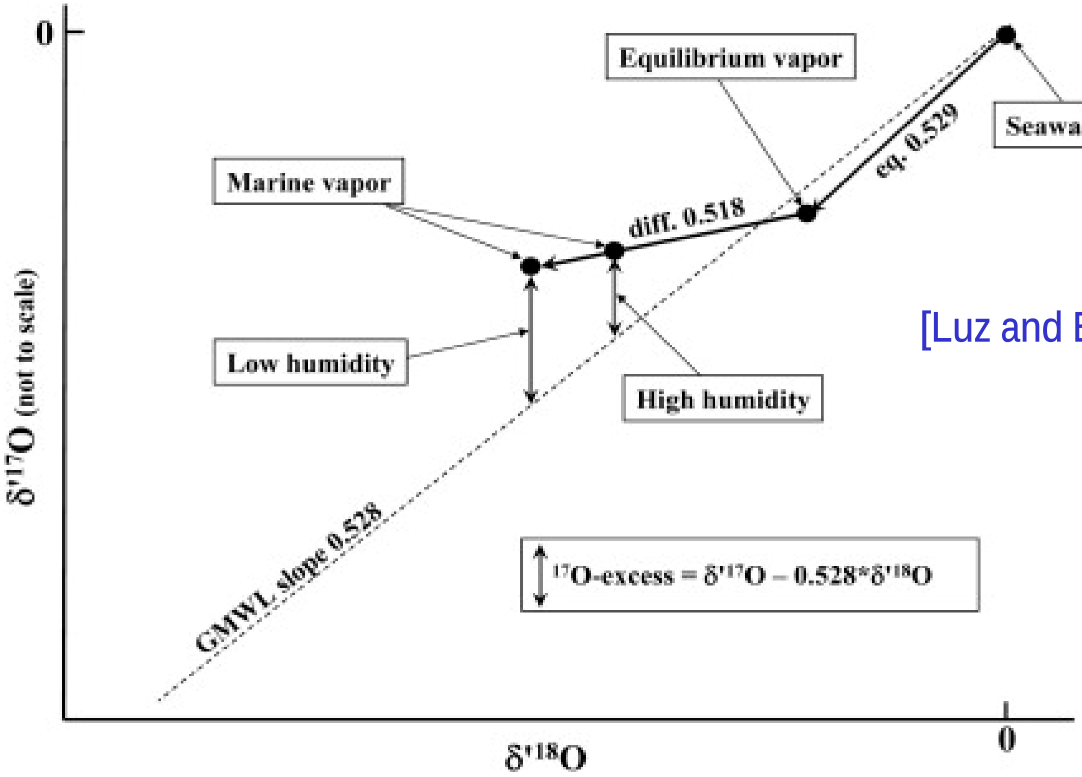


^{17}O-excess quantifies the deviation from the "GMWL(0.528).

This excess in ^{17}O can be used to probe the hydrological system, adding additional information over the more traditional "deuterium-excess" (d-excess = dD – 8δ^{18}O) because ^{17}O-excess is much less sensitive to changes in temperature.
[Luz and Barkan, 2010; GCA].

Meteoric water has an excess of ^{17}O isotopes relative to that of oceanic water.
➔ Identification of vapour source in the Himalayan Glaciers.

Evolution of Vapour [^{17}Oexcess as tracer of process]

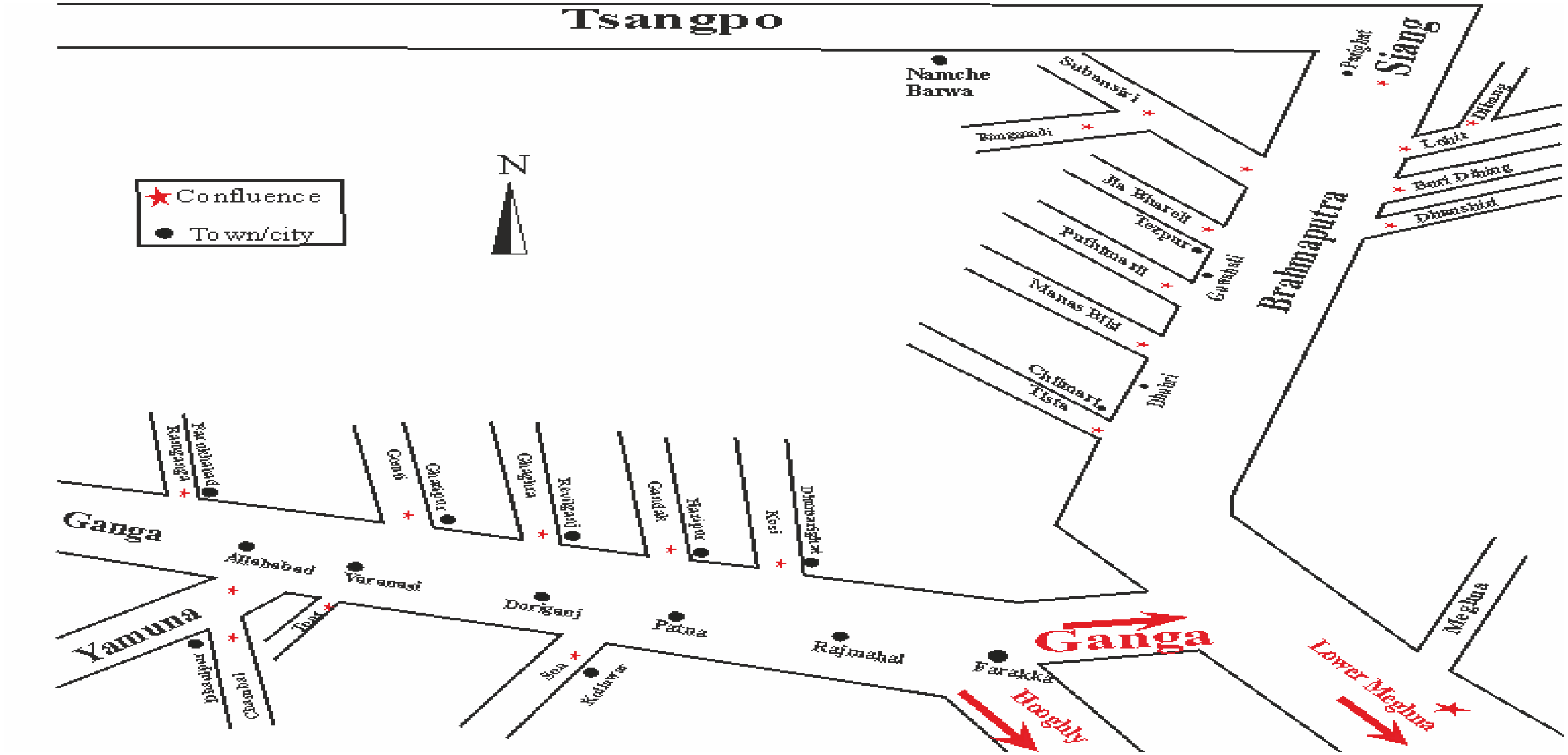


[Luz and Barkan, 2010; GCA]

Vector diagrams with different slopes ➔ Origin of ^{17}O-excess for marine water & its evolution
Water vapour at the vicinity above the ocean (100% humidity) will follow a slope of 0.529, resulting in a slight depletion in ^{17}O relative to the GMWL (0.529).
Upon diffusing into dry air, the slope decreases to ~ 0.518. This results in a ^{17}O-excess in the water vapour, which will evolve dependent on the relative humidity of the air parcel.
Deviation of slope, relative humidity can be estimated

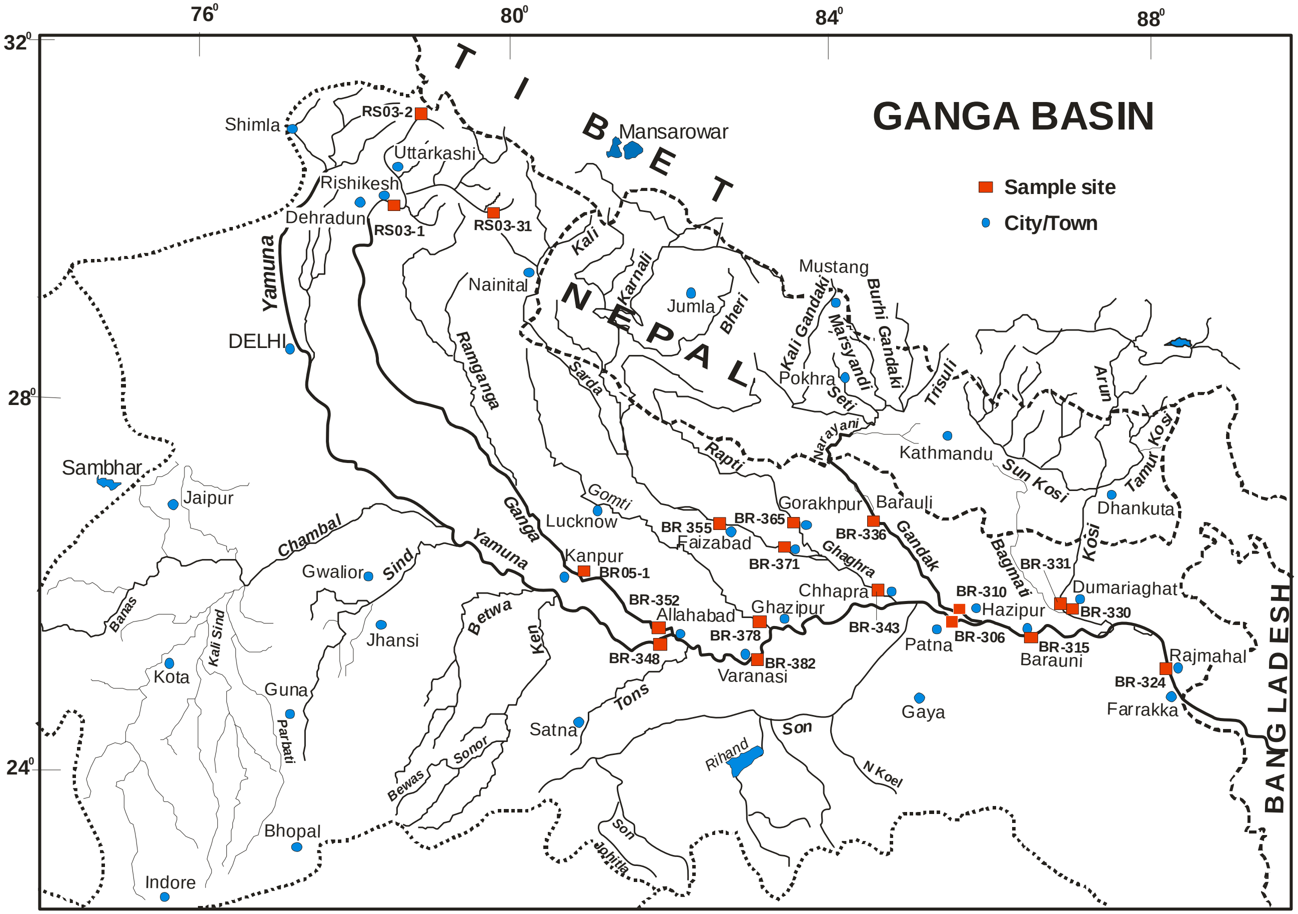
The Ganga – Brahmaputra (GB) River System

- The Ganga and Brahmaputra are the major River systems of the Himalaya [Area ~1.7 million km^2 ; Dis. ~(8-10)x10^9 m^{3}y^{-1}]
- G-B ranks first in the sediment supply to the ocean (~12%) and fourth in water discharge
- Ganga drains ~10^6 km^2 in the Himalaya and the plains and support a large part of population it its catchment.
- Ganga transports ~1000×10^6 tons of sediment per year supporting agriculture.
- Physical Erosion in its Himalayan drainage is among the highest in the world
- *Weathering-Erosion-Uplift-Climate coupling in the Himalaya ➔ Susceptible to extreme events.*



1. Erosion and the Himalaya-Ganga-BOB System

- Sources of sediments to the Ganga plain.
- Relative contributions from the sub basins to the sediment and water budget
- Spatial variability of physical erosion and its implications to regional tectonics.
- Identify major controls on erosion and weathering.
- How physical erosion controls weathering ➔ River chemistry ➔ Evolution of water



Weathering studies: Aquatic chemistry

Major ions (Na^+,K^+,Ca^{++},Mg^{++}), Trace elements (Sr, Ba etc.) and Si

Isotopes ($^{87}Sr/^{86}Sr$, $^{142}Nd/^{144}Nd$, $\delta^{13}C$, $\delta^{18}O$, $\delta^{7}Li$ etc.).

(1) Chemical weathering rates ➔ in dissolved load

=TDS*x(Discharge/ Area); (g/l).(l/year)/Km^2 = g/Km^2/year TDS* ➔ (TDS – Sea input)

(2) Physical erosion rates: (particulate material)

=(particulate matter)x(Discharge/ Area) ; (g/l).(l/year)/Km^2 = g/Km^2/year

(3) Sources identification:

Sr and Nd isotopic composition and concentrations.

(4) Nature of Weathering (Silicate weathering; CO_2/H_2SO_4)

Li, Hf, Os, C_{DIC} isotopes

SILICATE WEATHERING

Silicate weathering rates (1): River water

$R_{sil} = (Q/A)*[(Na^*+Mg_{sil}+ Ca_{sil} + K_{sil}) + SiO_2]$

Q is water discharge and A is the drainage area.

$Na^* = (Na_r - Cl_r)$ and assigned (Ca/Na =0.7 ± 0.3), (Mg/Na= =0.3 ± 0.2) in silicate end members (Krishnaswami et al 1999)

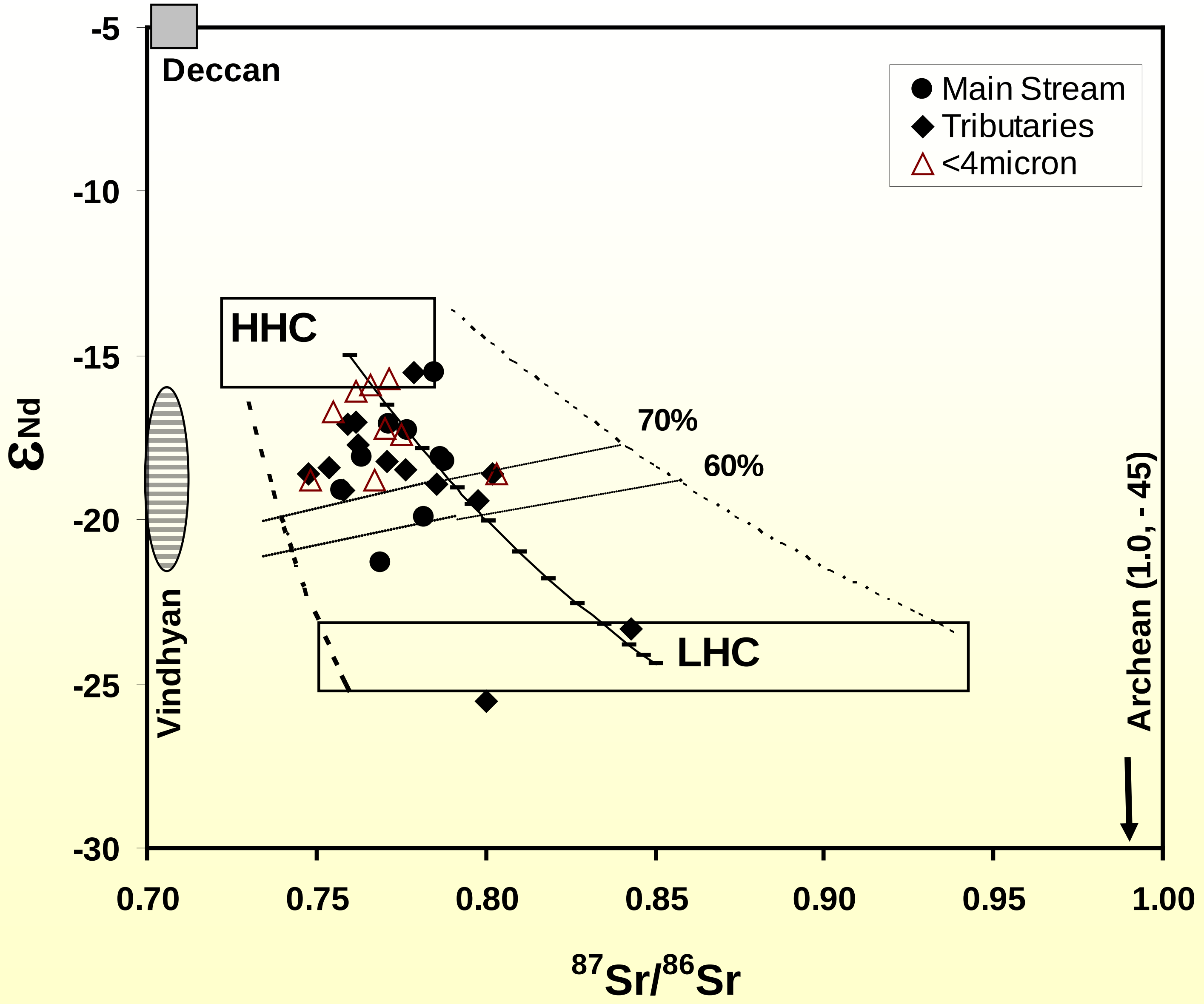
Silicate weathering rates (2): River Sediments

The amount of rock eroded per unit time in a river basin : flux of dissolved and particulate phases

(Martin and Meybeck 1979; Stallard et al 1995; Roy et al 1999).

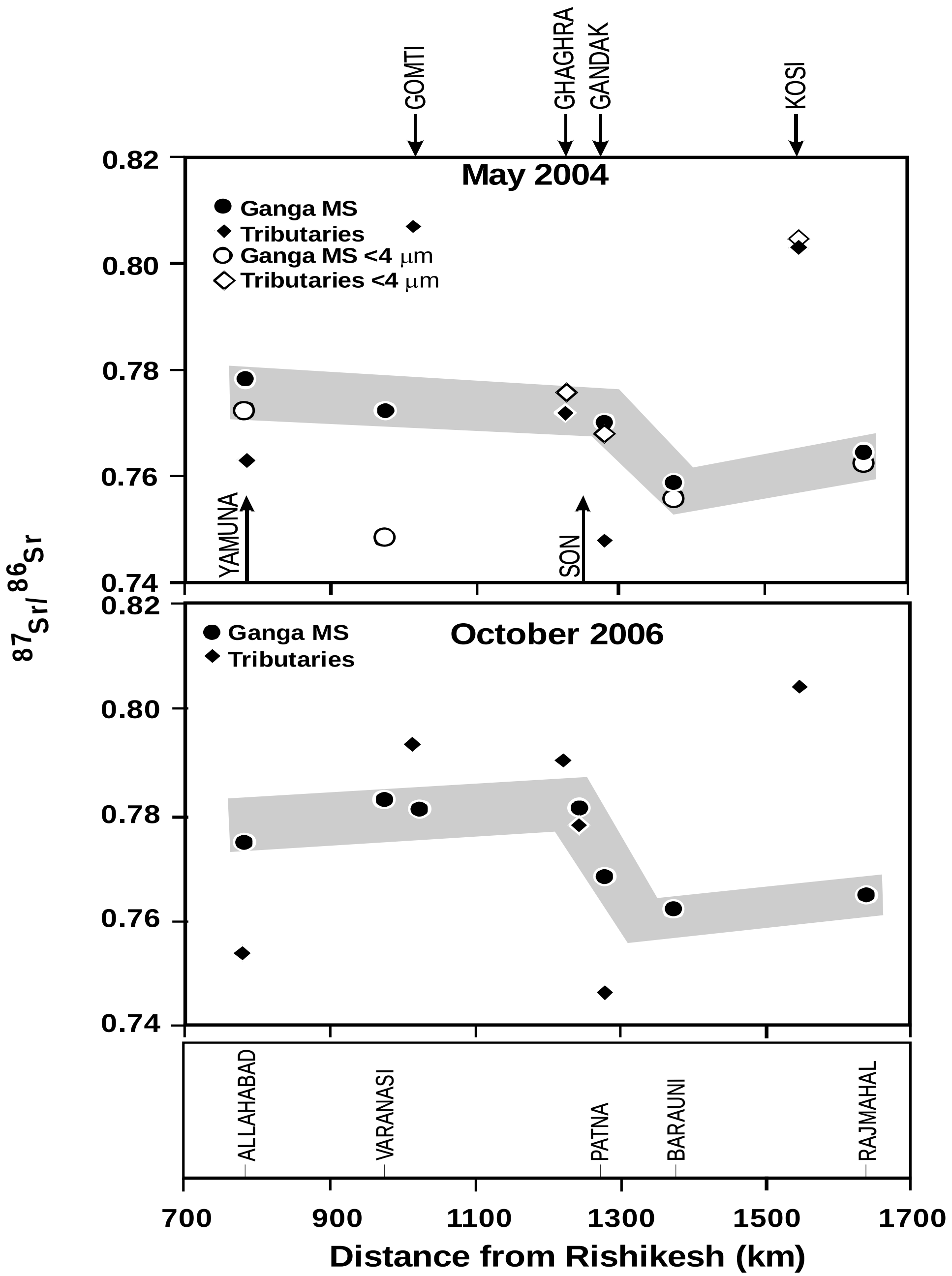
Long Residence time of the particle in the Basin. Average chemical weathering over these time scales.

Erosion: Sources of sediments in the Ganga River



Singh S.K. , Rai S.K. and Krishnaswami S. (2008-JGR)

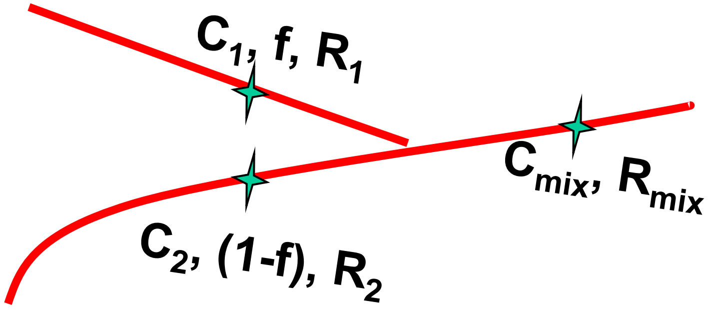
Contribution of sediments tributaries to the Ganga River



Major change after the confluence of the Gandak

The Gandak has major impact on sedimentary budget of the Ganga river

Mass Balance : Mixing Model



$R_{mix}*C_{mix} = R_1*C_1*f + R_2*C_2*(1\text{-}f)$
$R_{mix} = (^{87}Sr/^{86}Sr)$ of mixture

C_{mix} , C_1 and C_2 are the conc. of Sr in mixture and components 1 & 2 respectively.
f is the fraction of first component in the mixture

$$R_{Erosion} = \left(\frac{F_{flux} \cdot f_{trib}}{A_{trib}} \right) \quad M_t.Km^{-2}$$

$$R_{Erosion} = \left(\frac{(1000.10^{12}\, gy^{-1}).(f_{trib})}{(2.5g/cm^{-3}).(10^{10}.A_{trib}km^2)} \right) cm/y$$

= ~6 mm/y (Gandak Basin)

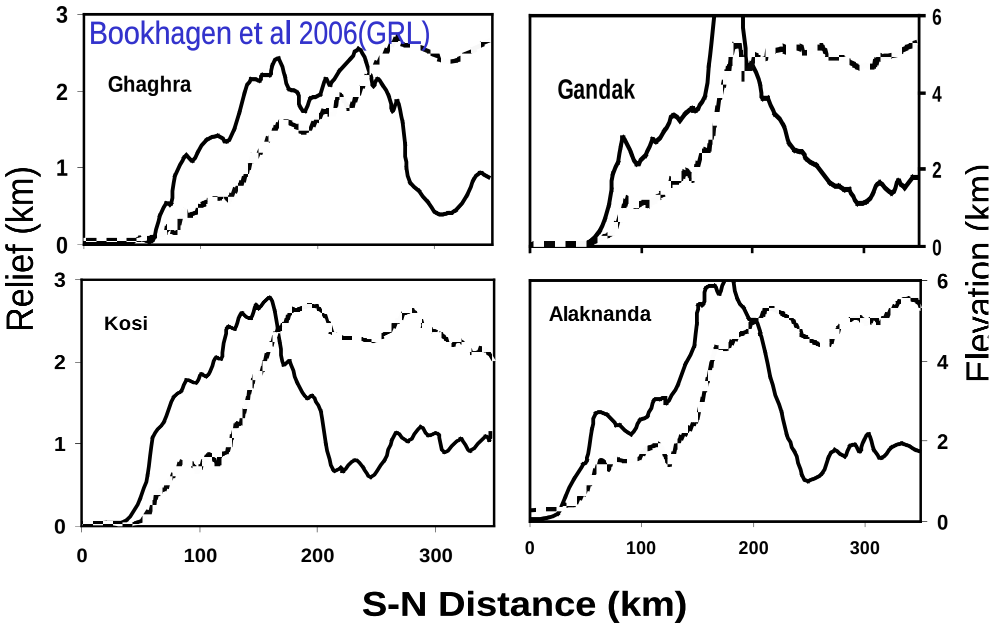
Estimates of Physical erosion rates in Ganga sub-basins*

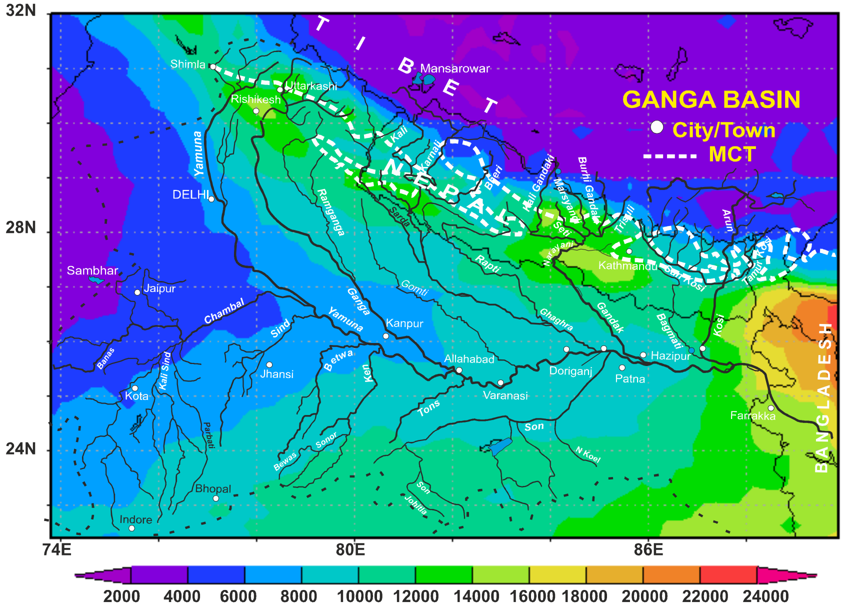
Basin	Discharge[a] 10^6 m^3 y^{-1}	Run off m y^{-1}	Sediment[+] Fraction (%)	Sediment Yield[+] 10^3 km^{-2} y^{-1}	Physical erosion rate (mm y^{-1})[+]	
					Total Area	Him. Area
Gandak	49	1.6	45 (51)	14.1 (16)	3.9(4.4)	5.7(6.4)
Kosi	48	0.9	13 (6)	2.5 (1.2)	0.7(0.3)	1.0(0.5)
Ganga upstream Patna (GA+ RG+ YAM+GH)	108	1.2	42 (43)	4.6 (4.7)	0.2(0.2)	1.8(1.9)

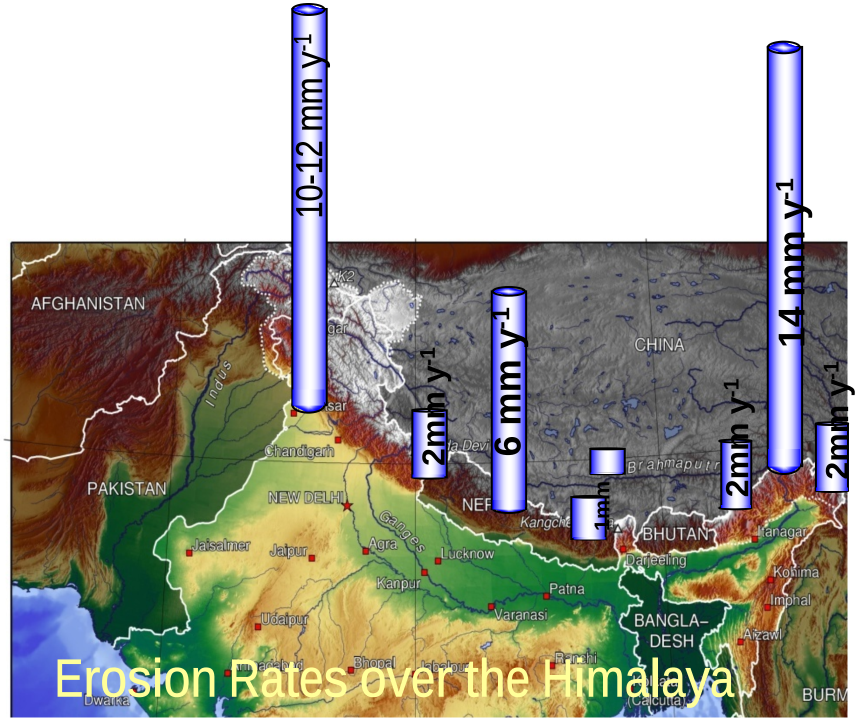
GA: Ganga; Rg: Ramganga; YAM: Yamuna; GH: Ghaghra

+ two numbers are given 2004 and 2006, the latter in parenthesis

Errors 30% - 40%







1. High relief & Precipitation (mm) in the headwaters of the Ganga (TRMM data Jan 1998 to May 2007)
2. High Physical Erosion generation of sediments
3. Physical erosion accelerates weathering
4. Weathering fluxes alters elemental composition of the Ganga River.

Possible Implications:

These hotspots are associated with high peaks and regional tectonics and isostatic rebound, caused by high erosion rate of the Gandak basin, is probably responsible for the high peaks of the Dhaulagiri (~8200 m) and the Annapurna (~8100 m).

➔Faulting of the Himalaya (Erosionally induced tectonics).

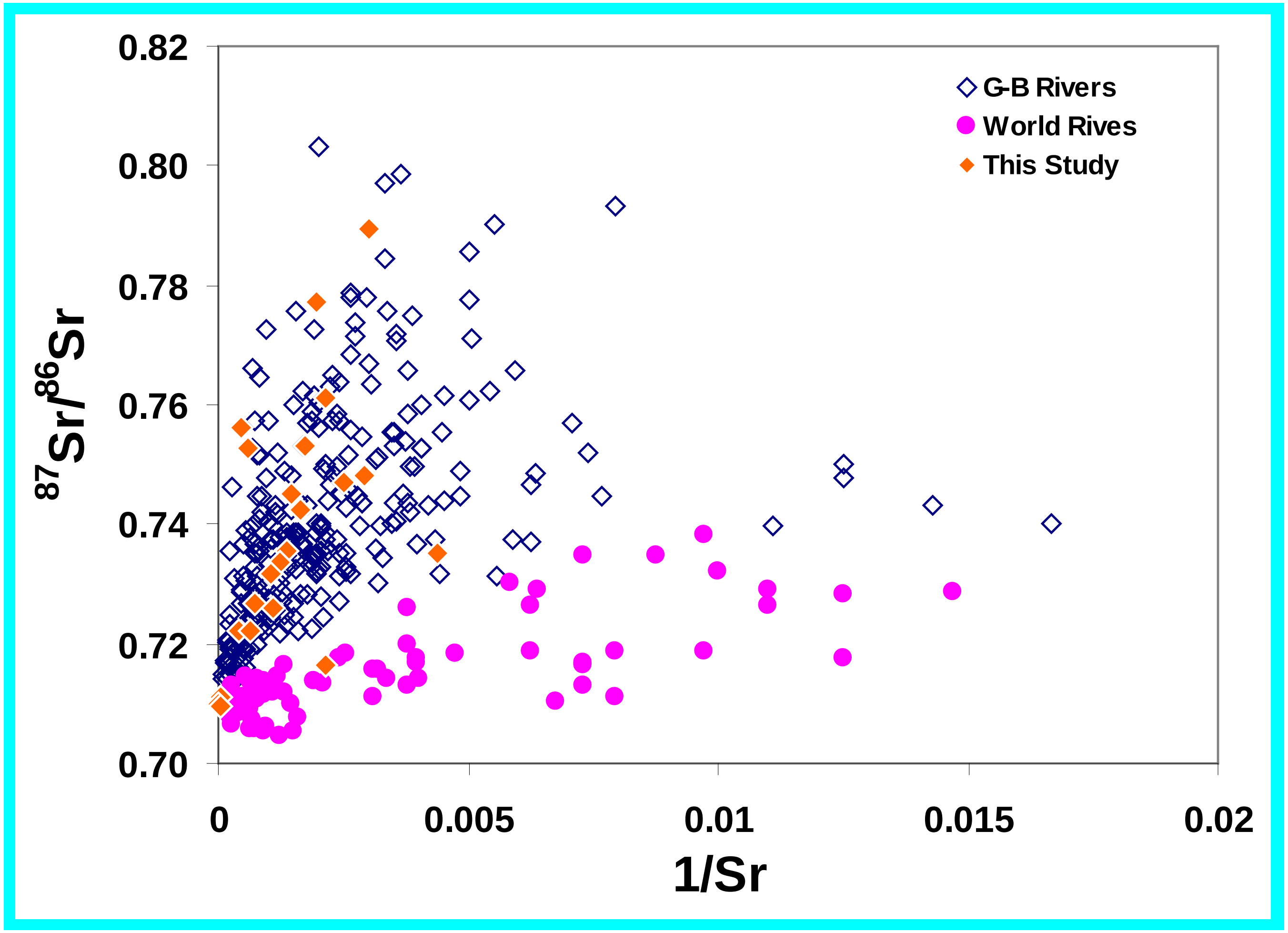
Table: Hotspot contribution in world sediment budget

Hot spots of the Himalaya	Sediment flux (million tons yr^{-1})	Area (km^2)	Reference
Eastern Syntaxis	900	26000	Singh, 2006
Gandak (Himalayan drainage)	480	31800	Singh et al., 2008 ; Rai, PhD Thesis, 2008
Western Syntaxis	137	12600	Garzanti et al., 2005
Total	**1517**	**70400**	
World Riverine Sediment flux	20000	100x10^6	Hay et al., 1998; Holland (1978, 1981).

Contribution of Hotspots in sediment Generation = ~7-8 (%)

Area of Hotspots in world surface area = 0.07 (%)

2. Elemental removal in the Ganga Basin: Evolution of Water chemistry



Ganga Brahmaputra rivers have highly radiogenic Sr isotopic composition ($^{87}Sr/^{86}Sr \geq 0.720$) with moderately high Sr concentration

Silicates: (0.73-1.0) Edmond et al 1992; Krishnaswami et. al 1992; Singh et al.1998: Bickle et al 2003)

Carbonates (Vein calcites, Metamorphosed carbonates) (Palmer et al 1992: Blum et al 1998; Jacobson and Blum, 2000)

- Third end member Evaporite , phosphate

- $^{87}Sr/^{86}Sr$ of Evaporites (Gypsum) from Lesser Himalaya range (0.715 – 0.717) with their Ca/Sr ~$5x10^3$, similar to that of Pc. Carbonates

- Most of the waters (particularly in plains) are super saturated w.r.t. calcite and they precipitate to form calcite (Kankar carbonates).

- Can calcite precipitation explain anomalies in Ca and Sr budget in the Ganga waters?

In calcite precipitation, the $^{87}Sr/^{86}Sr$ of water does not change, but Ca/Sr decreases.
(Sr partition coefficient <<1)

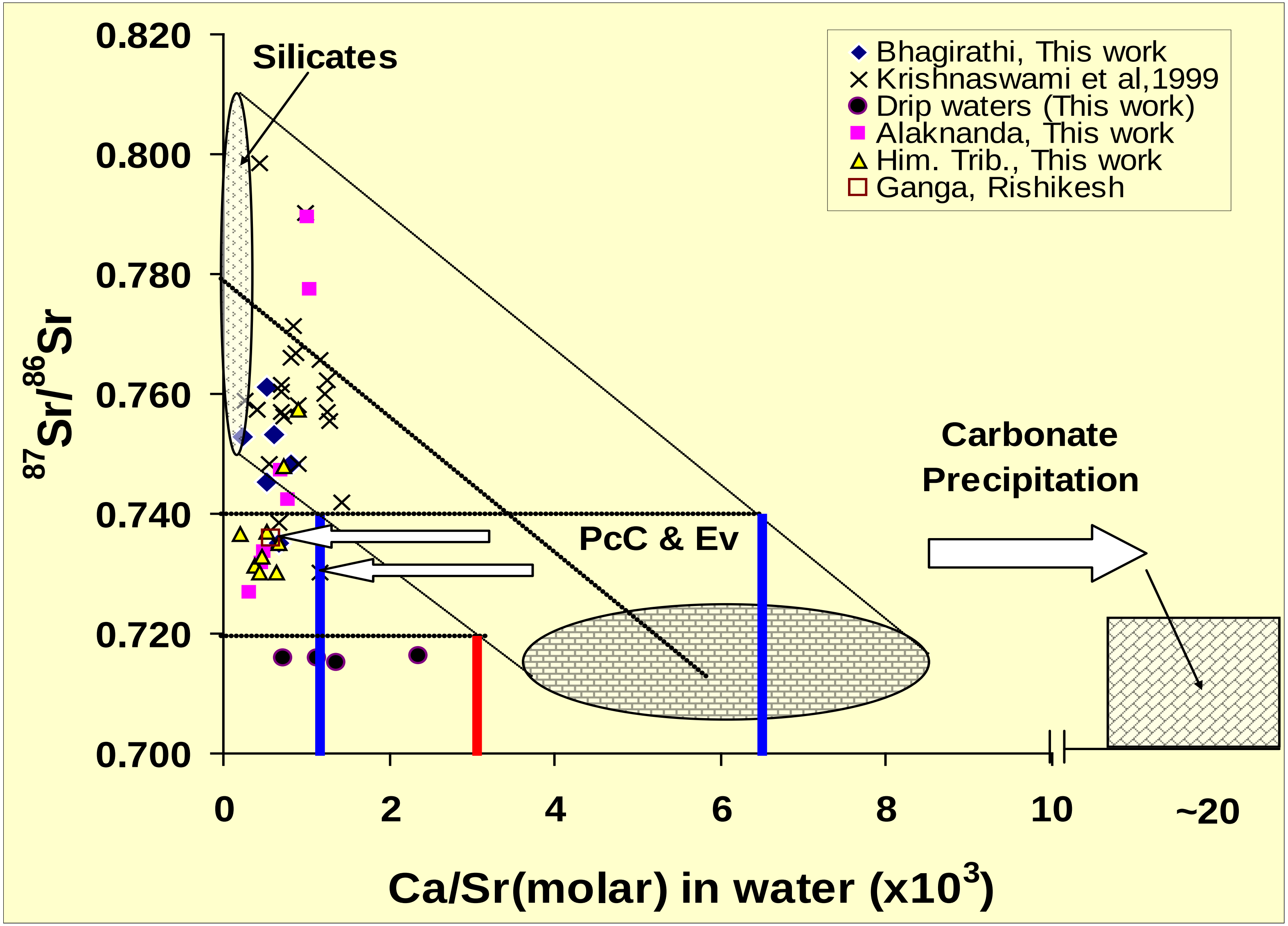


Fig: River waters of the Ganga system from the Himalayan sub-basin. The values for the two end members are also shown. The arrows show the direction of movement of Ca/Sr in water following precipitation of $CaCO_3$. Precipitation decreases the Ca/Sr ratio in water without affecting the $^{87}Sr/^{86}Sr$.

Precipitation of Calcite in the Plains:

Using a linear relationship: Initial Ca/Sr of waters

$(Ca/Sr)_0 = [0.81 - (^{87}Sr/^{86}Sr)_w]/0.02$

Fraction of Ca left after precipitation:

$$f_p = \left(\frac{Ca_w}{Ca_0}\right) = \left(\frac{\left(\frac{Ca}{Sr}\right)_0}{\left(\frac{Ca}{Sr}\right)_w}\right)^{\left(\frac{1}{(K_d - 1)}\right)}$$

(Albarede, 1995)

K_d <<1 (0.06) ; for Sr relative to Ca in Calcite
(Banner 1995 ; Rimstidt and Balog 1998)
[Sr(1.13A^0) and Ca(0.99A^0)]

➔ Lost Ca = $(1-f_p)*100$
≈ 50% (For Himalayan Tributaries in plain)

Studies of Ca, Sr and $^{87}Sr/^{86}Sr$ in the Ganga river water shows:

River waters (in plains) are supersaturated w.r.t calcite.

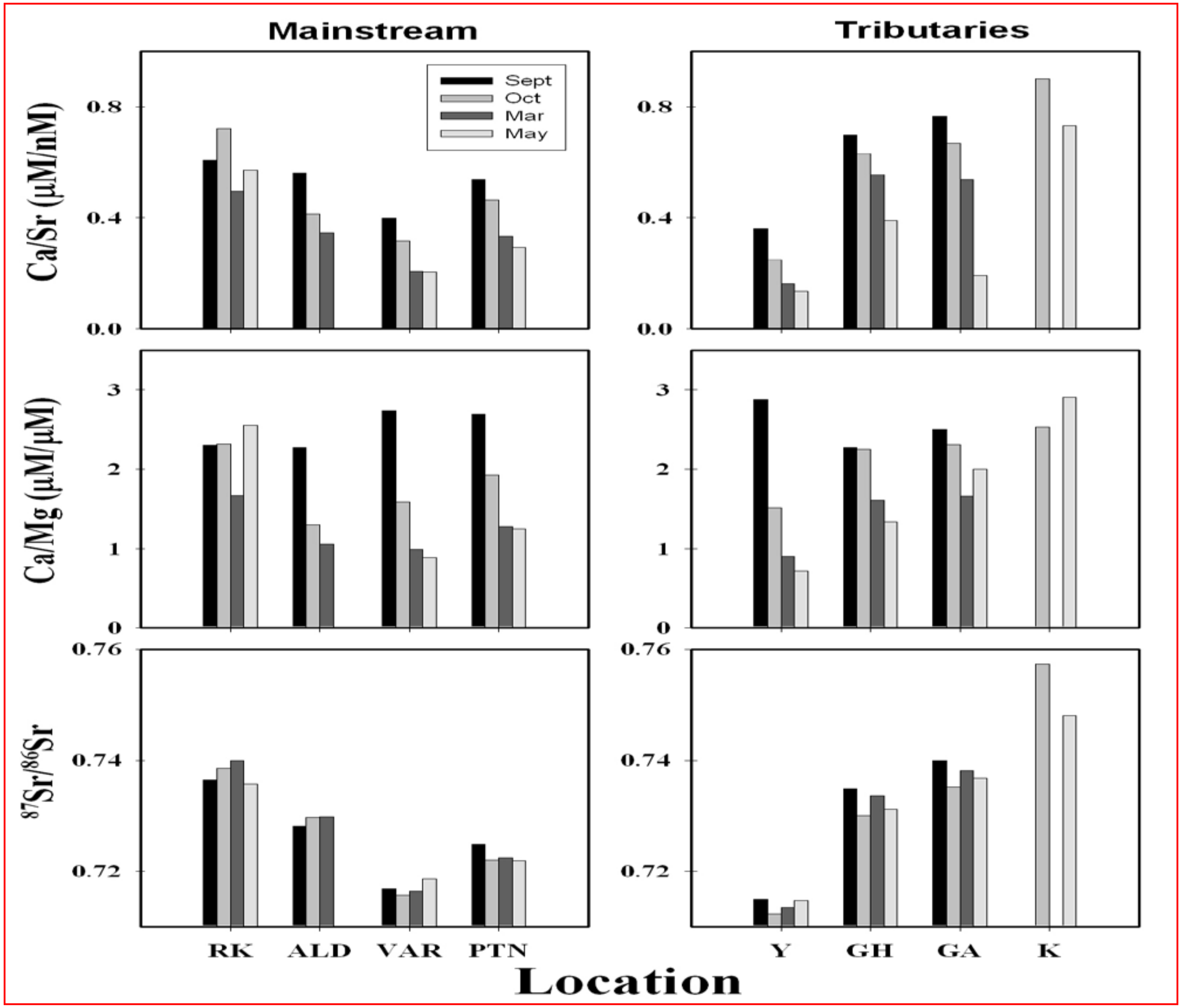
Results on precipitated carbonates show that ~ 50% of Ca in Ganga river can be removed as calcite.

This number is consistent with $^{87}Sr/^{86}Sr$ data of water and silicates.

If such a mechanism is operational in these waters, the distribution pattern of different water sample in Ca/Sr - $^{87}Sr/^{86}Sr$ plot can be explained

Precipitation: A pseudo end member

Seasonal variation in Ca/Mg, Ca/Sr and $^{87}Sr/^{86}Sr$ in the Ganga and its tributaries in the plain

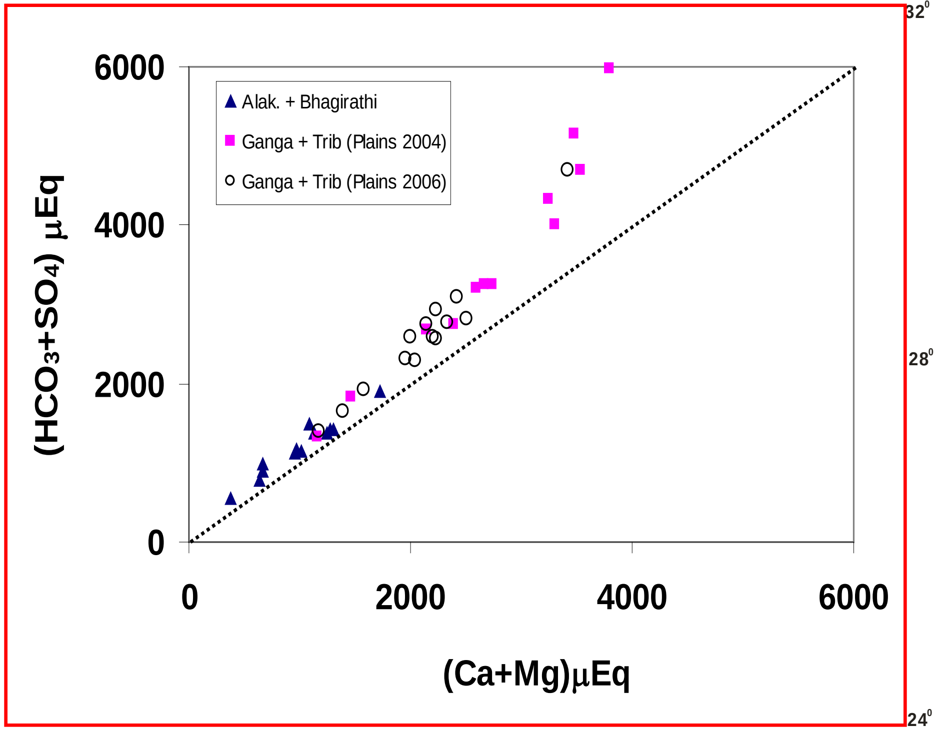


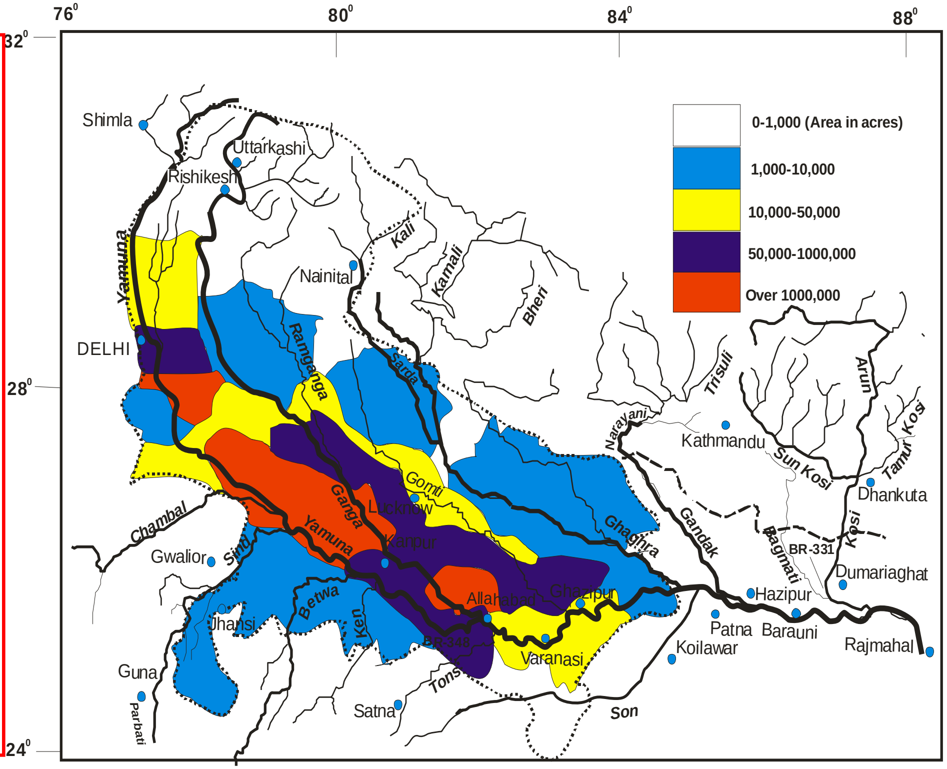
Elemental ratios decrease from higher values during peak flow (Sept, Oct) to low values during lean flow (March, May) ➔ Precipitation of Calcite

3. Impact of of salt affected (Saline/Alkaline) soils in Ganga Basin

(A) Arial distribution of salt affected (usar) soils in Ganga Basin (after Agarwal and Gupta, 1968)

(B) The dashed line represents 1:1 ratio (the equiline). Deviation from the equiline, particularly in samples collected during May 2004 indicates the contribution of (HCO_3+SO_4) as Na salts from alkaline/saline soils in the Ganga plain.





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Chemical weathering in the plain and peninsular sub-basins of the Ganga: Impact on major ion chemistry and elemental fluxes

Santosh K. Rai[1], Sunil K. Singh*, S. Krishnaswami

1. High concentrations of Na in the plains (Gomti, the Yamuna and the Ganga at Varanasi) with much of the Na in excess of Cl.

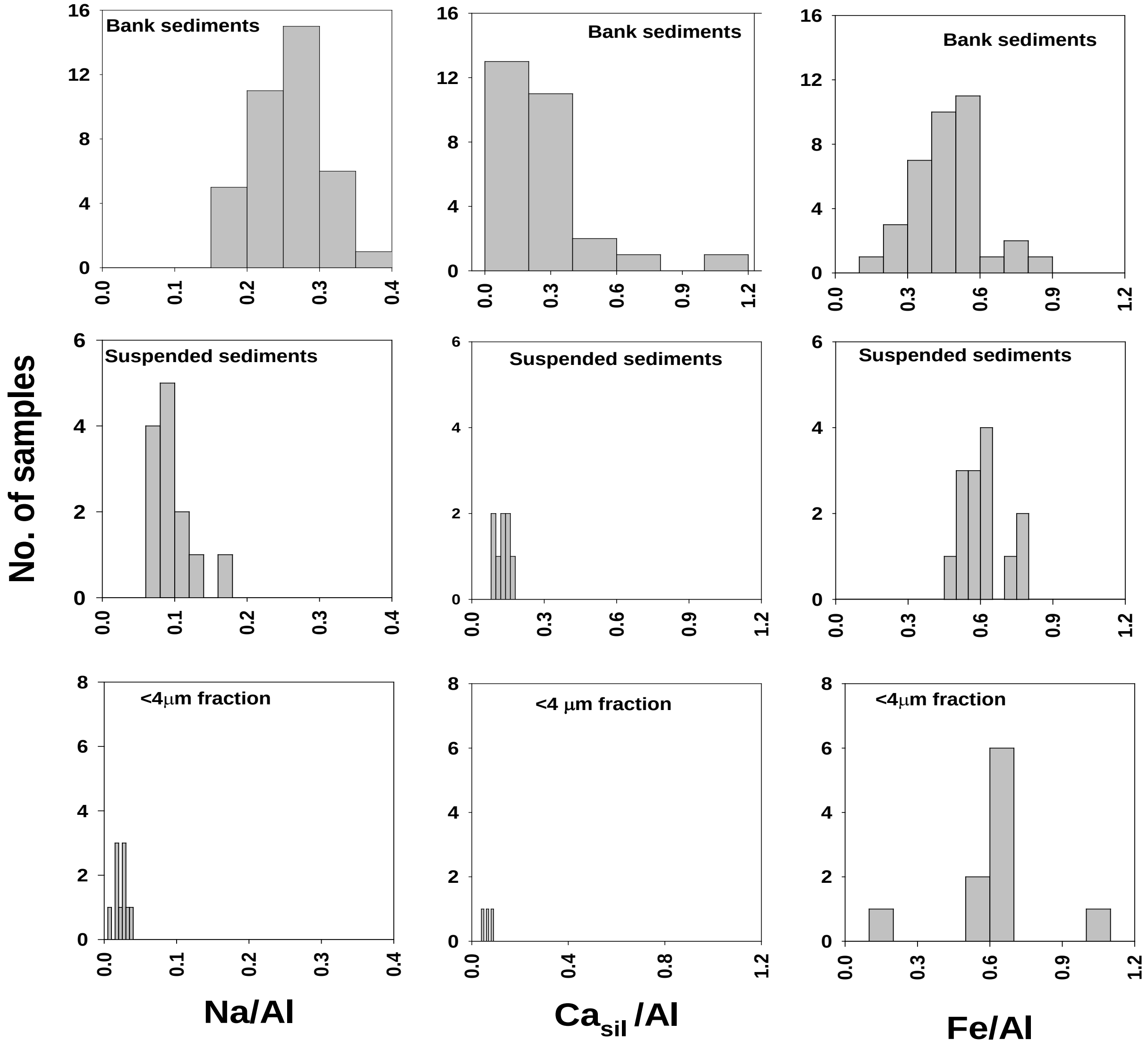
1. The use of this ‘excess Na’ ($Na^* = Na_{riv} - Cl_{riv}$) a common index of silicate weathering yield values of 18 tons km^{-2} yr^{-1} for silicate erosion rate (SER) in the Gomti and the Yamuna basins.

2. There are however, indications that part of this Na* can be from saline/alkaline soils abundant in their basins, raising questions about its use as a proxy to determine SER of the Ganga plain.

3. Independent estimation of SER based on dissolved Si as a proxy give an average value of 5 tons km^{-2} yr^{-1} for the peninsular and the plain drainages, several times lower than that derived using Na*. ➔Impact of saline/Alkaline Soils are important.

4. The major source of uncertainty in this estimate is the potential removal of Si from rivers by biological and chemical processes.

SEDIMENT COMPOSITION: SILICATE WEATHERING



Chemical Index of Alteration (CIA)

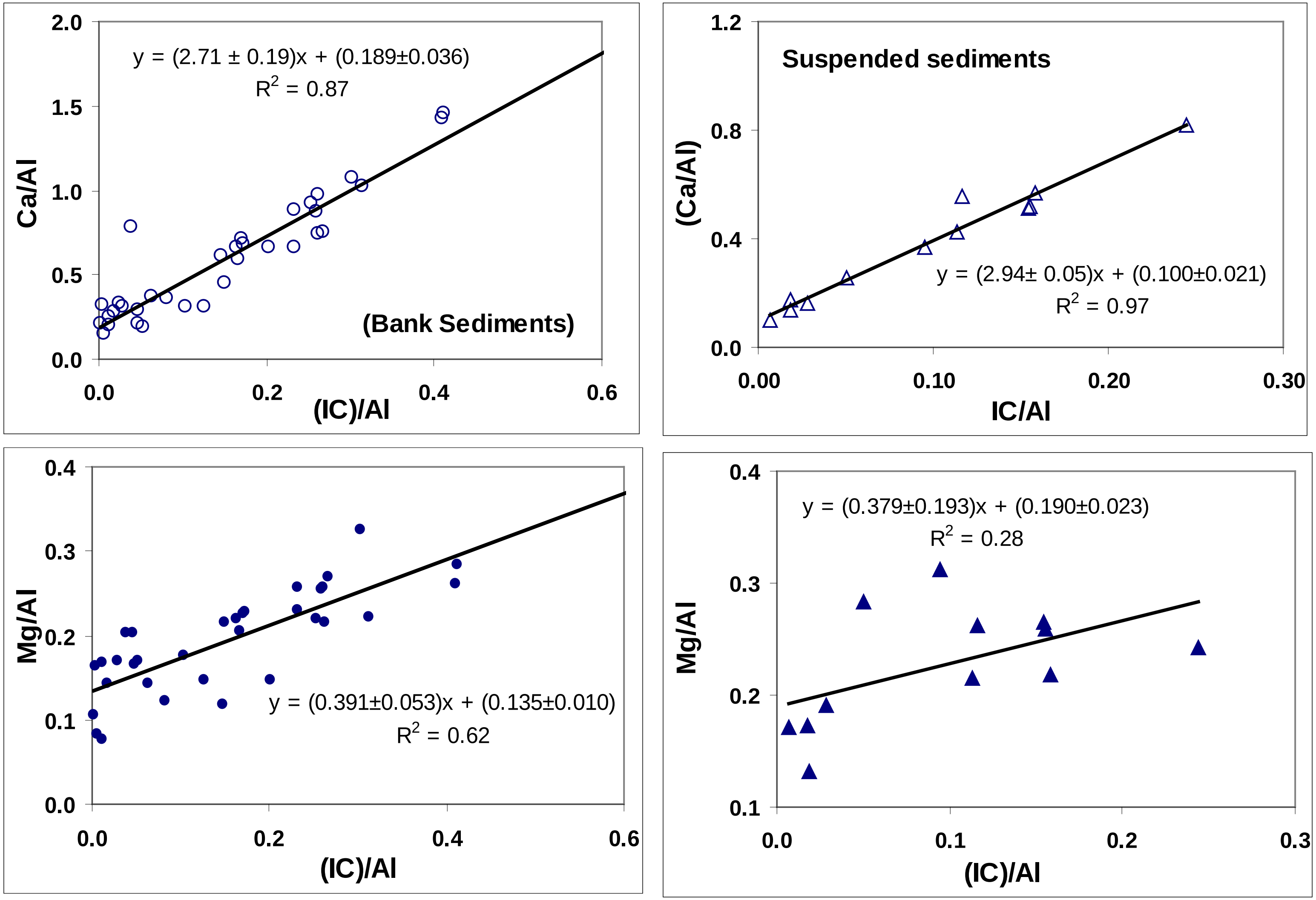
$$CIA = 100x\left(\frac{Al_2O_3}{Al_2O_3 + CaO^* + K_2O + Na_2O}\right)$$

Ganga bed sediments ~54 ; Suspended Load ~70; The HHC and LHC (~50-55) Fresh Granitic rocks ~50 (Fedo et al 1995).

Suspended sediments are weathered. Composition of bed sediments ➔ representative of the source rock.

Dissolved Material = [Fresh Rocks - Weathered Sediments]
Analyses of Particulate phase➔ Water evolution (present & Past)

A systematic decrease in Na/Al and Ca/Al from bank sediments to suspended sediments to <4μm (bank sediments) is clearly evident. The Fe/Al ratio does not seem to show any significant trend [Rai et al, 2013, under prep].



Scatter plots of Ca/Al and Mg/Al with (IC/Al) in the Ganga bank and suspended sediments (all in wt%). The intercept represents the elemental ratios in the silicate component. (Ca/Al) data show a much better fit with (IC/Al).

Silicate weathering flux and associated CO_2 consumption in the Ganga Basin			
Silicate Flux	From sediments	From dissolved major ions in river water	
Element	This study	This study	Sarin et al -1989
	moles yr^{-1}	moles yr^{-1}	moles yr^{-1}
Ca	$(9.1 \pm 4.3)E+10$	$(6.4 \pm 2.7)E+10$	$(7.9 \pm 3.4)E+10$
Na	$(2.9 \pm 0.5)E+11$	9.1E+10	1.1E+11
K	$(5.9 \pm 5.6)E+10$	2.4E+10	2.2E+10
CO_2 Consumption			
(moles km^{-2} yr^{-1})	$(5.3 \pm 1.1)E+05$	$(2.4 \pm 0.5)E+05$	$(2.9 \pm 0.7)E+05$

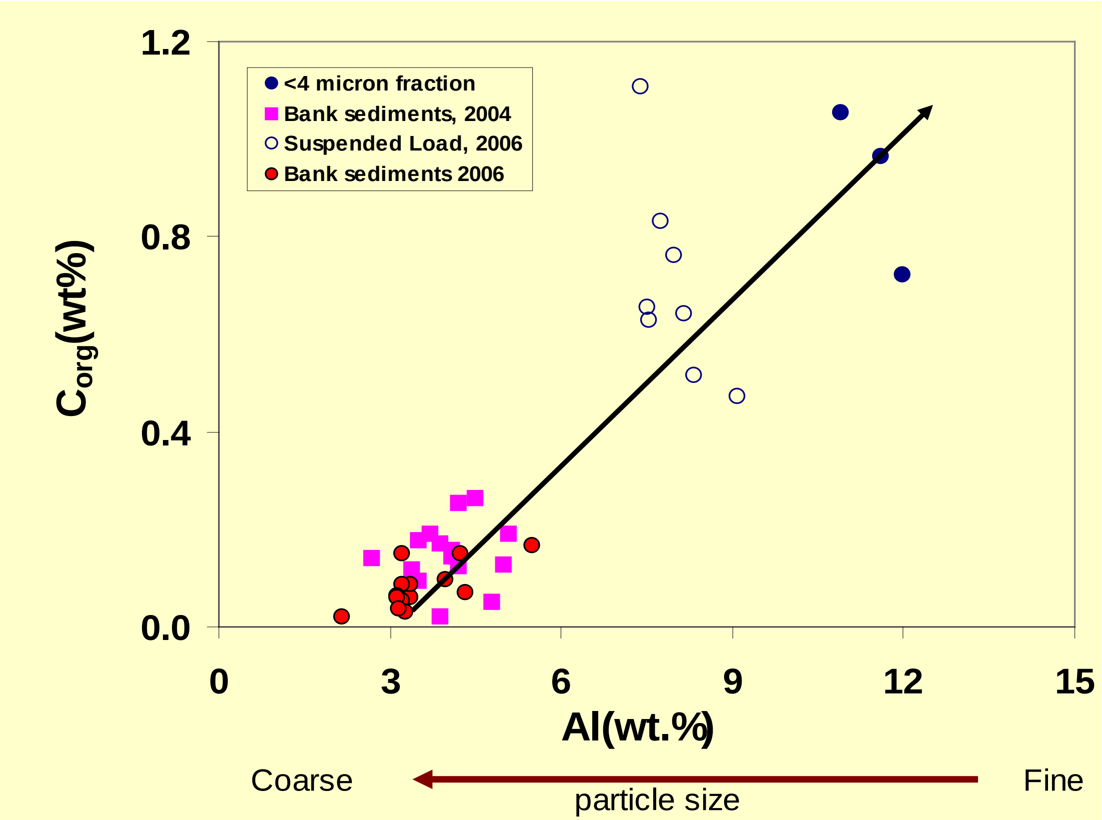
Dissolved fluxes of silicate erosion fluxes estimated from sediment data overlaps with the river water data for K and Ca within errors and are a factor of ~2 higher for Na.

(i) Sample heterogeneity: The current estimate rely on a single sample of suspended sediments collected at Rajmahal
(ii) uncertainties in end member elemental ratios used in calculations in the waterdata based estimates
(iii) Temporal variations in silicate erosion.
(iv) errors associated with suspended sediment flux estimates.

Fluxes and transport of C_{org} in the Ganga River System : Burrial

C_{org} in the Ganga particulate Load (wt%)

Sample	N	range	average
Bed Load (BL)	39	0.001-0.26	0.12±0.07
Susp. Load (SL)	12	0.47-2.20	1.02±0.57
$SL_{<4\mu m\ (clay)}$	3	0.72-1.06	0.91±0.17



- Variation of C_{org} with Al in different components of the Ganga River.
- Organic carbon content increases with Al, (i.e. decreasing particle size)
- SL as expected, falls between the bed load and its < 4µm fraction, as it is a mixture of these two endmembers
- SL is the principal mode (80%) of transport C_{org} in the Ganga system.

Ongoing work (With PhD Student/Collaborations)

1. Sulphuric acid mediated chemical weathering in the Indus basin and their implication in estimating the CO_2 consumption based on major ions of the River (With Dr. S.K. Bartarya).

2. Using Stable isotope as proxies for characterizing the relative intensities of CO_2 degassing from MCT zone of the Himalaya (Sameer Tiwari, PhD Student) .

3. Bulk (Organic) and Component specific stable isotope studies in the Ganga basin for the paleo-climatic interpretation (Dr. Shailesh Agarwal, Postdoc).

4. Use of non traditional isotopes (Li, Ca, Mg, Fe, Si, Ge etc) for the studies in weathering and erosion (Dr. Sunil K. Singh, PRL Ahmedabad)

5. Isotopic studies to trace the provenance of the Himalayan Quartzites (Dr. H.K. Sachan & Dr. S.K. Ghosh).

Future work (2015-2017):
Spatial and temporal evolution of water in the Ganga Basin:

1. The Himalaya-Ganga-Bay of Bengal System- Sediment budgeting
2. Water in the precipitation (Rain/Snow and their moisture sources)
3. Compositional changes during water-rock interaction:
    - ➢ Weathering – Erosion; Silicate, Carbonate & weathering
    - ➢ Suspended load-water interface (surface adsorption on clay)
    - ➢ Deposition-Scavenging process:
        - i. Kankar carbonate/impure calcites (core/cliff)
        - ii. Mollusks/Diatoms (Fluvial biogeochemistry)
        - iii. Saline/Alkaline Soils in the plain (Sources & recycling of salt)
        - iv. Speleothems (Fluid inclusion: Palaeo-composition)
        - v. Aeolian transport (Aerosol particles)
4. Mixing of Water masses: River water time series, Ground water
5. **Residence Time of water & sediments in the Ganga System**
6. Water budgeting (Snow Melt contribution) of the Ganga River System
7. Anthropogenic contribution: (Fertilizers, land use change and Industrial waste/ Sewage/Nala etc. mixing to Ganga River system)
8. **Geochemical proxies as a tool for approaching these targets!**

Residence Time and recycling of Ganga sediments

- River sediments are used to characterize source-sink relationship and climatic changes employing different geochemical & Geophysical techniques.

- The climate of the Ganga basin (& hence its discharge) is dominated by monsoon and its morphology, especially in upper reaches by tectonics.

- This basin serves as an archives of the Himalayan denudation under varying climatic conditions.→ Sediment Coring

- The importance of *residence time* (hence *sedimentation rates*) in the Ganga basin and their role in inferring the climate using sediment cores from the Foreland.

Estimation of the Residence time in different River Basins

River Basin	Residence times T (Kyr)	References
Amazon River	6 ± 1	Dosseto et al. (2006a)
Amazon lowland rivers	100–500	Dosseto et al. (2006a)
Amazon highland rivers	4±1	Dosseto et al. (2006a,b)
Deccan traps Rivers	54–84	Vigier et al. (2005)
Mackenzie River	25 ± 8	Vigier et al. (2001)
Icelandic rivers	1-6	Vigier et al. (2006)
Ganges tributaries	30–350	Granet et al. (2007)
Amazon River*	7	Wittmann & Blankenburg (2009)

*** Measured by cosmogenic nuclides (^{10}Be, ^{26}Al & ^{14}C) whereas others are done with U-Series.**

Challenges & Issues of Residence time for Core studies

Source-Sink relationship studies have assumed ➔ no significant time lag between sediment generation and their subsequent transfer to the different basins.

Estimated a range of residence time (~5 -100 Ka) of particles in different fluvial systems (The Ganga and the Amazon etc.) in the plain.

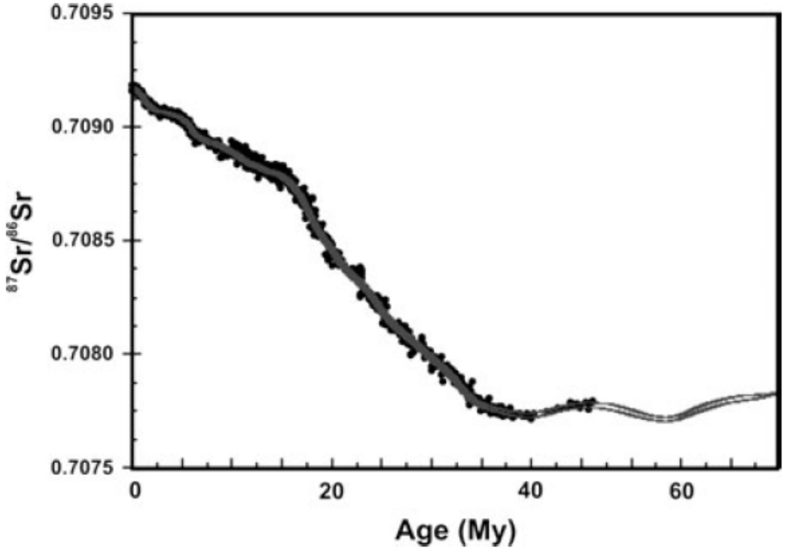
It is very crucial to check whether the response of changing monsoon intensities to sediment transfer on smaller time scales (less than residence time of sediments in the catchment) could be resolved during the Holocene.

If there is a significant time lag (~5 -100 Ka), it will have (~5 -100 Ka) implications for estimating the timing of monsoon intensities in the Himalaya.

Recycling of sediments in the Ganga plains which pose a difficulty in correlating sediment transport to climatic signals. The third constraint on the such interpretation on source to sink relationship in time is the varying sedimentation rates in the fluvial system as compared to marine set up.

Mass Spectrometric techniques (U-Series & Cosmogenic isotopes) can be used as a potential tool to study Lanscape evolution, timescales for soil evolution and sediment transport to address the issue.

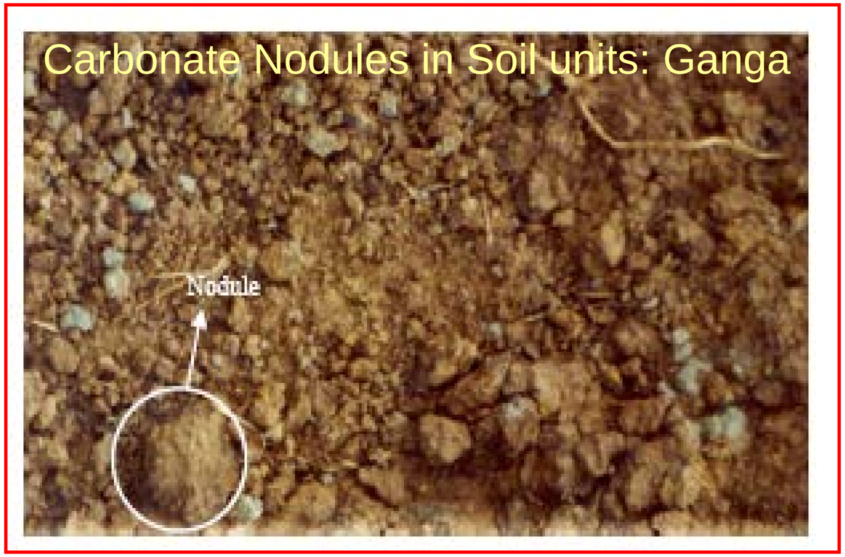
Long-term evolution of River Water and its impact on Sea Water

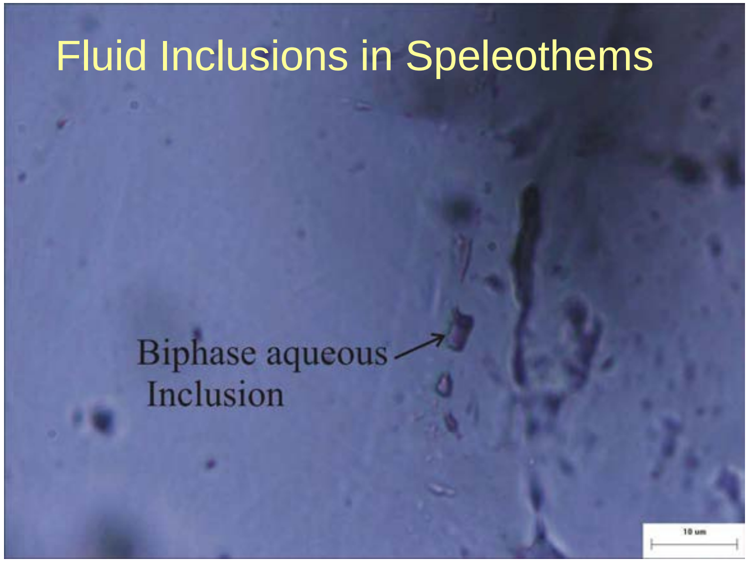


Intense chemical weathering in the Himalaya is suggested as a potential cause for the steady increase in $^{87}Sr/^{86}Sr$ of Sea water since 40 My (Raymo and Ruddiman 1992).

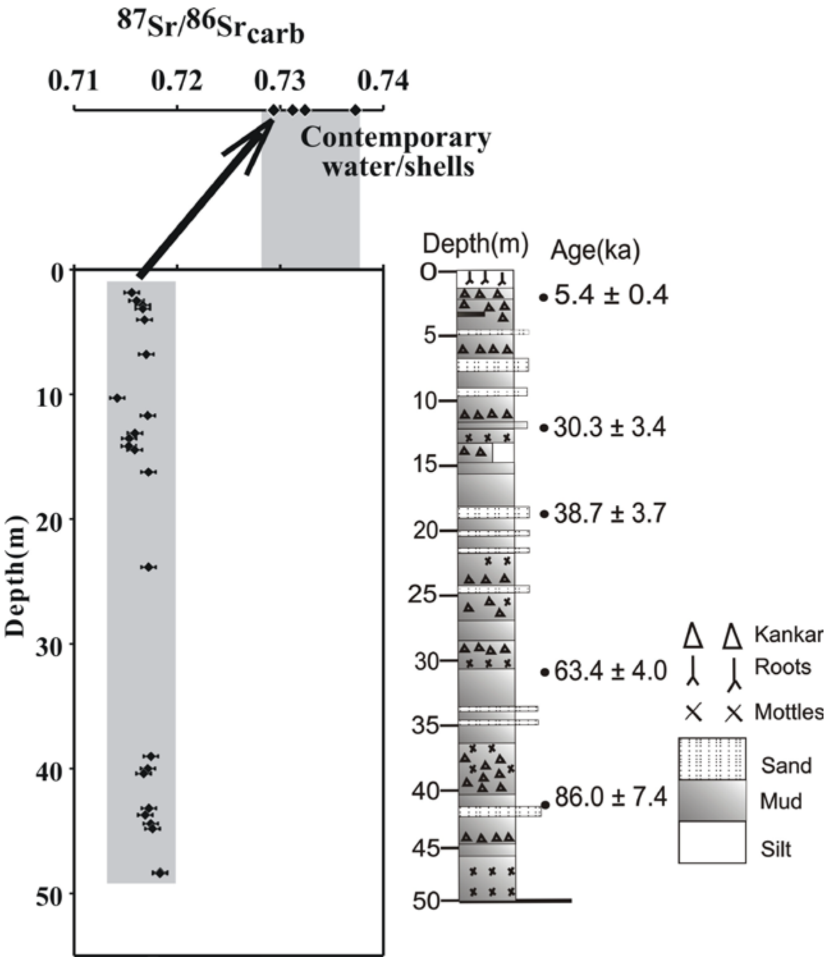
Assumption:

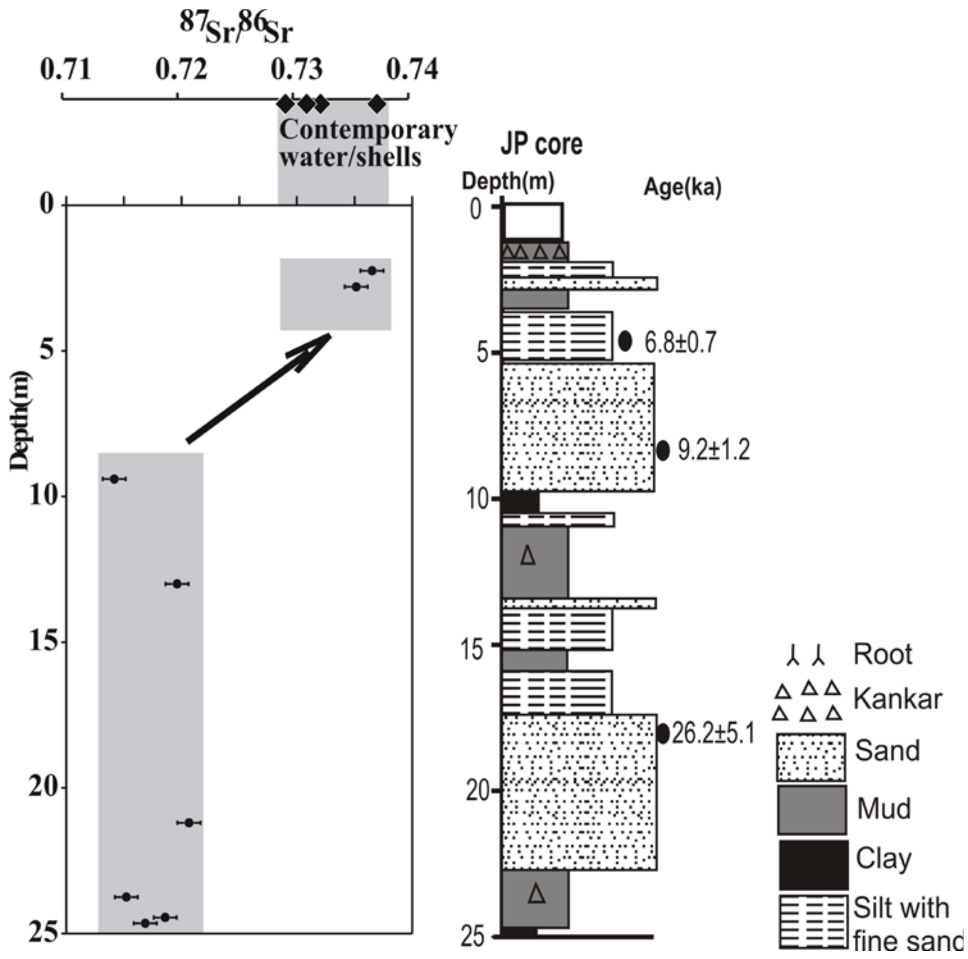
- Himalayan are more radiogenic in Sr than other global rivers.
- $^{87}Sr/^{86}Sr$ (~0.725) of the Himalayan rivers was invariant during past


Carbonate Nodules in Soil units: Ganga


Fluid Inclusions in Speleothems

How Ganga water has evolved over the past ~100 ka and what are its implications to global sea water budget?





Rahaman et al. 2011, Chemical Geology

Flash Floods in the Himalayan Fluvial Systems

- The Himalayan region with youngest mountain ranges represent a high energy environment ➔ prone to natural disasters.

- High relief, steep slopes, complex geological structures with active tectonic processes and continued seismic activities.

- Climate characterized by great seasonality in rainfall ➔Combining all together make natural disasters, especially water-induced hazards, common phenomena.

- *Chemical composition of the materials from these events ➔ Tracer?*

The flash flood event-**June 2000**

1. One of the world's largest recorded landslides occurred on April 9, 2000, when more than 100 million cubic meters (3.5 billion cubic feet) of loose rock, ice, and other debris tumbled down a steep, narrow gorge in eastern Tibet.

2. The dam occupied 2.5 square kilometers (1 square mile) and was 90 meters (295 feet) high at its tallest edge. River water began to back up immediately, creating a large lake behind the dam

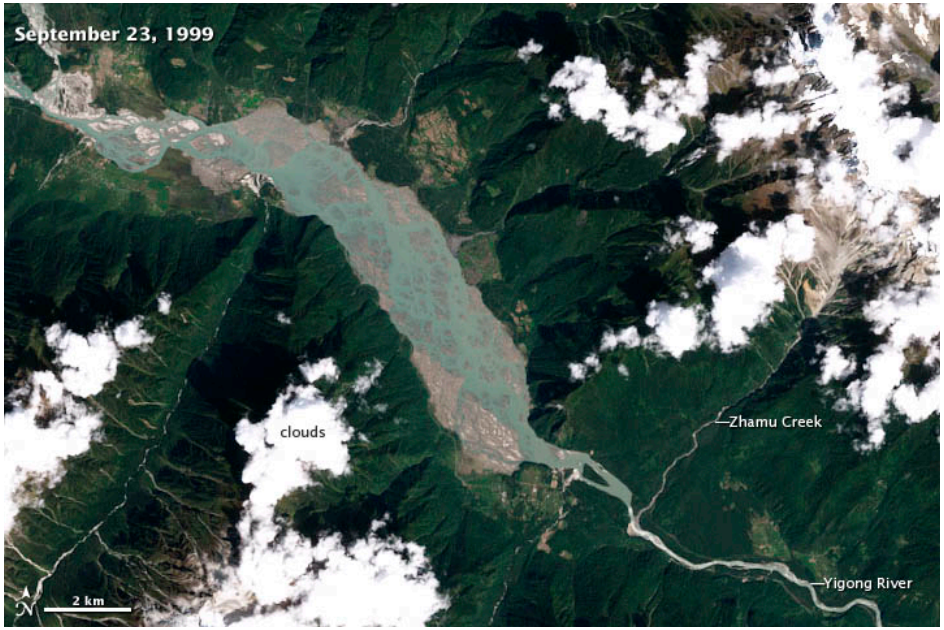
3. Catastrophic flood in Brahmaputra River, which struck in early June 2000 and inundated five districts of the state of Arunachal Pradesh and parts of Assam.

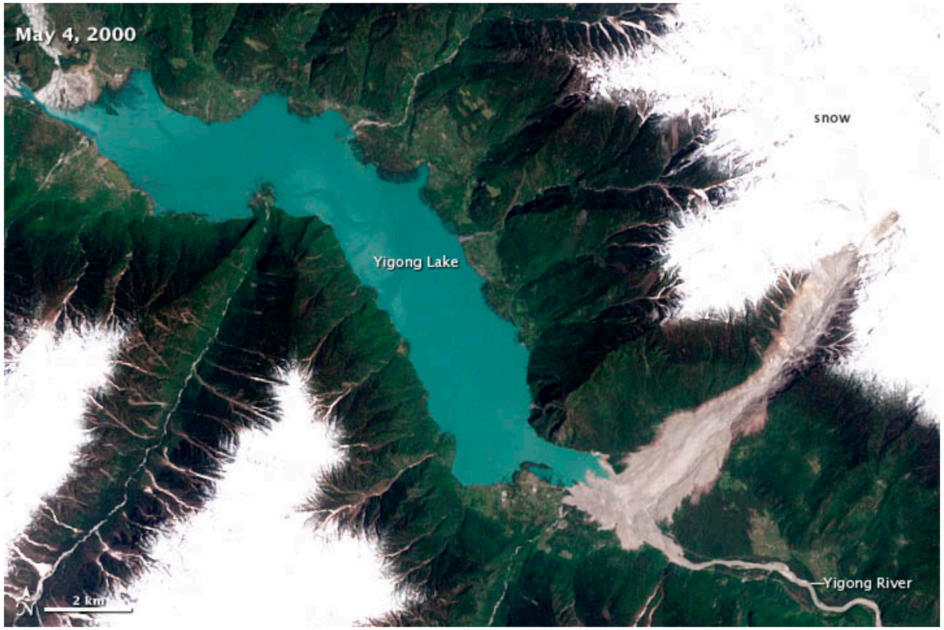
4. killed at least 30, leaving over 100 missing and rendering 50,000 homeless.

5. The flood was triggered by the overflowing of a lake in the upper reaches of the Brahmaputra River, or Yarlung Tsangpo as it is called in China's Tibetan region, which had formed after a landslide.

6. No sharing of information by China to India despite it was proposed by Chinese Scientists!!

http://www.newschinamag.com/magazine/the-river-wild/





How to trace extreme events:

Weathering➔ Loss of Cohesion Land Slide/ Erosion

Flash Floods ➔ Sudden discharge of water

Cloud bursts ➔ Excessive rain fall

Chemical composition of Riverine material can help tracking their causes.

Geochemistry
Geophysics
Geosystems
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Temporal variation in Sr and ^{87}Sr/^{86}Sr of the Brahmaputra: Implications for annual fluxes and tracking flash floods through chemical and isotope composition

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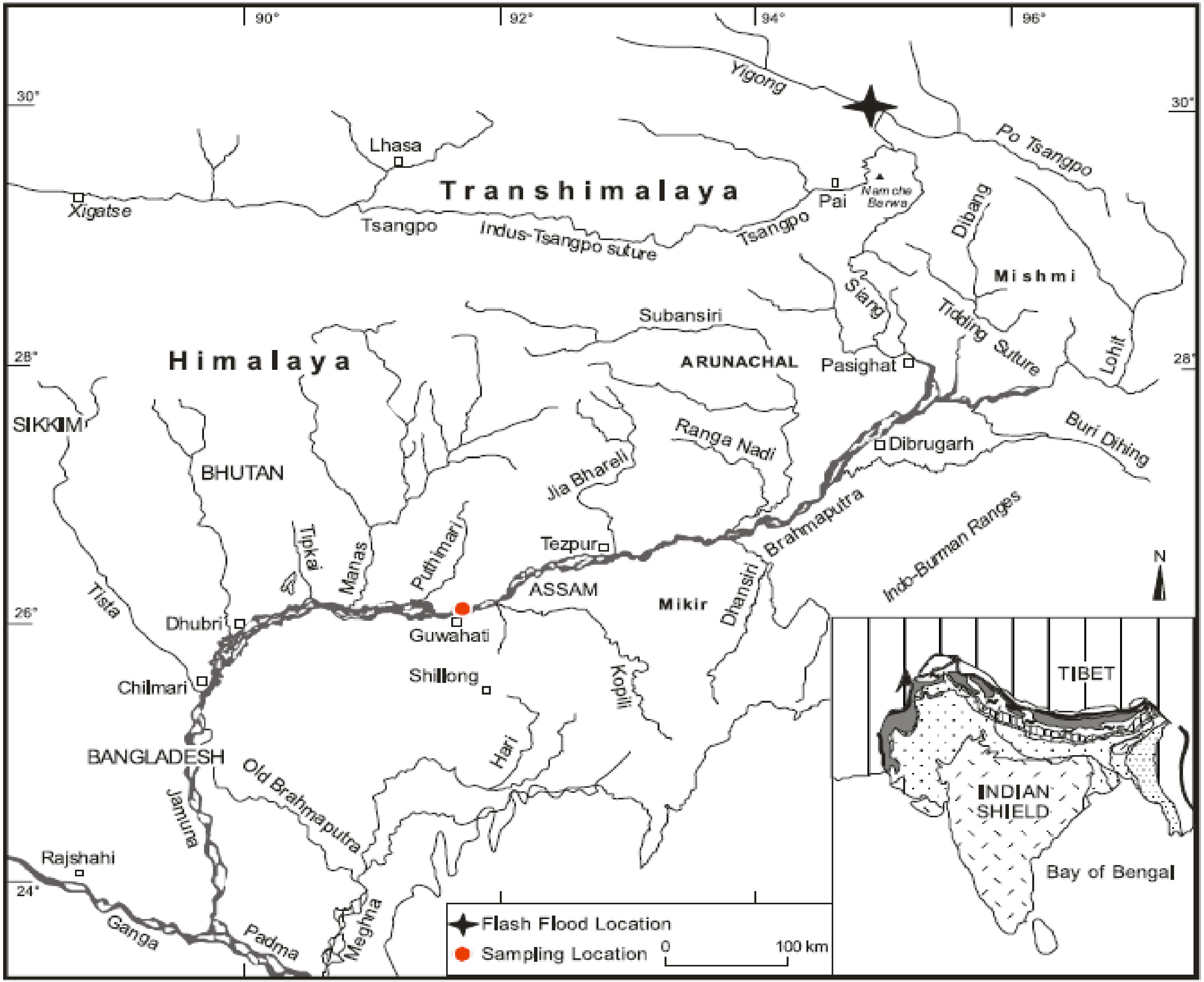
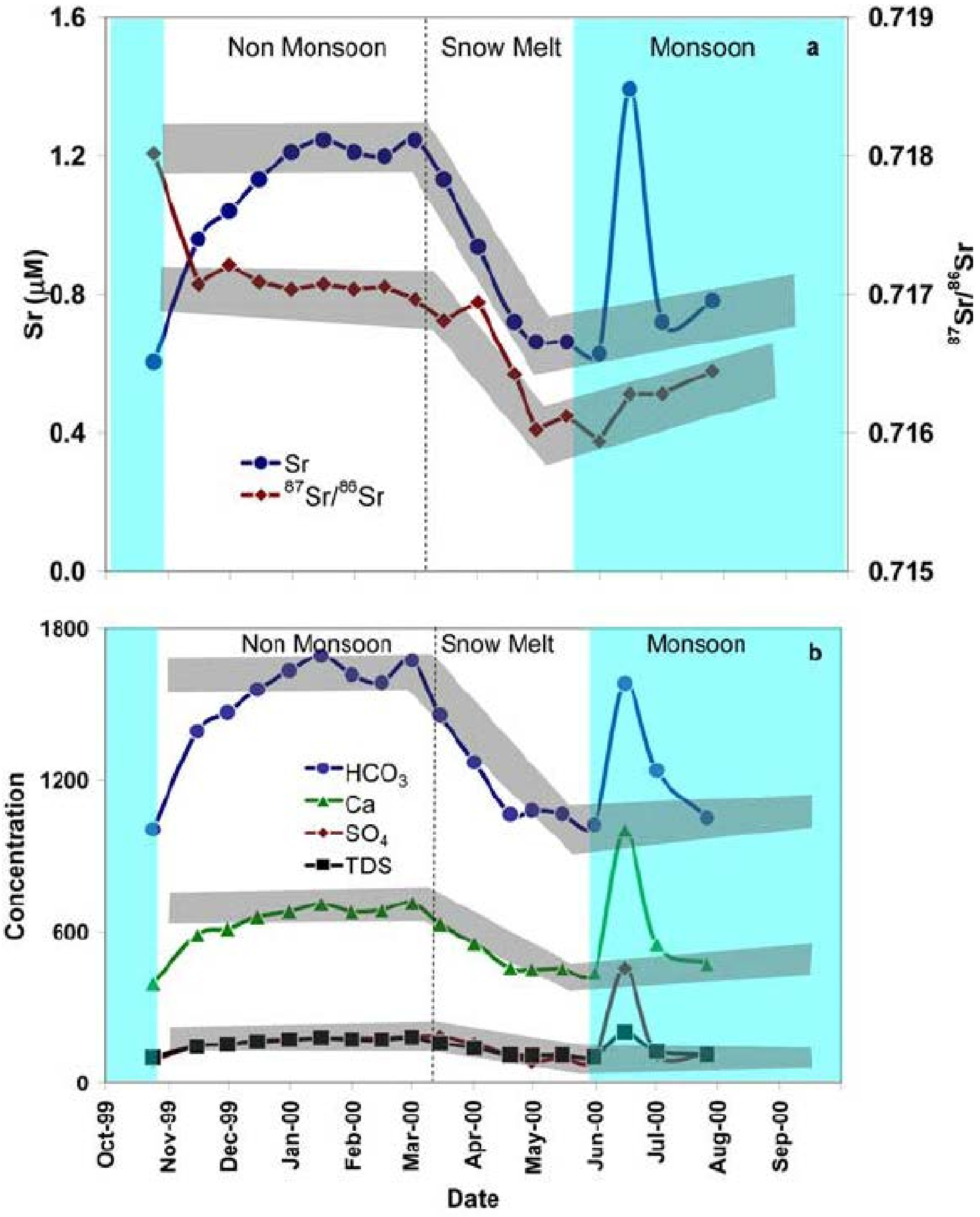
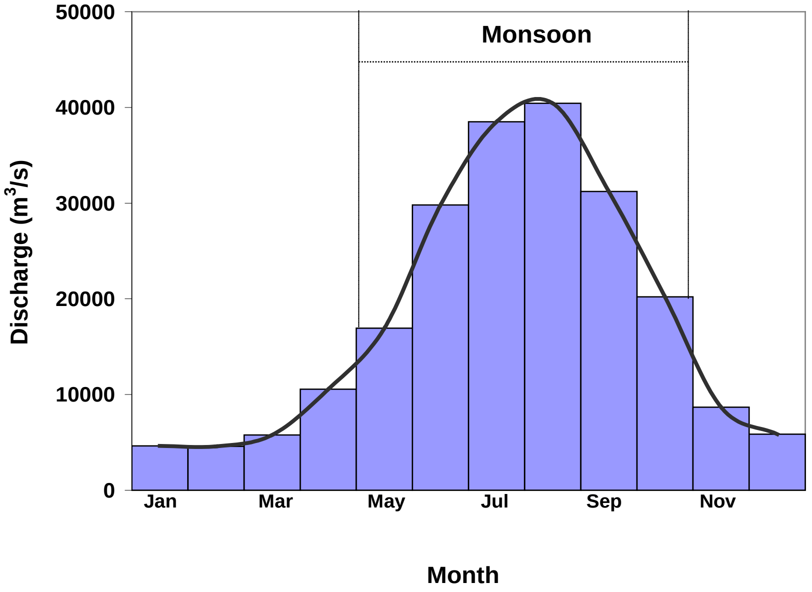


Fig: The Brahmaputra River System. The locations of the biweekly samples, Guwahati, and that of the flash flood are marked by orange circles and crosses, respectively.



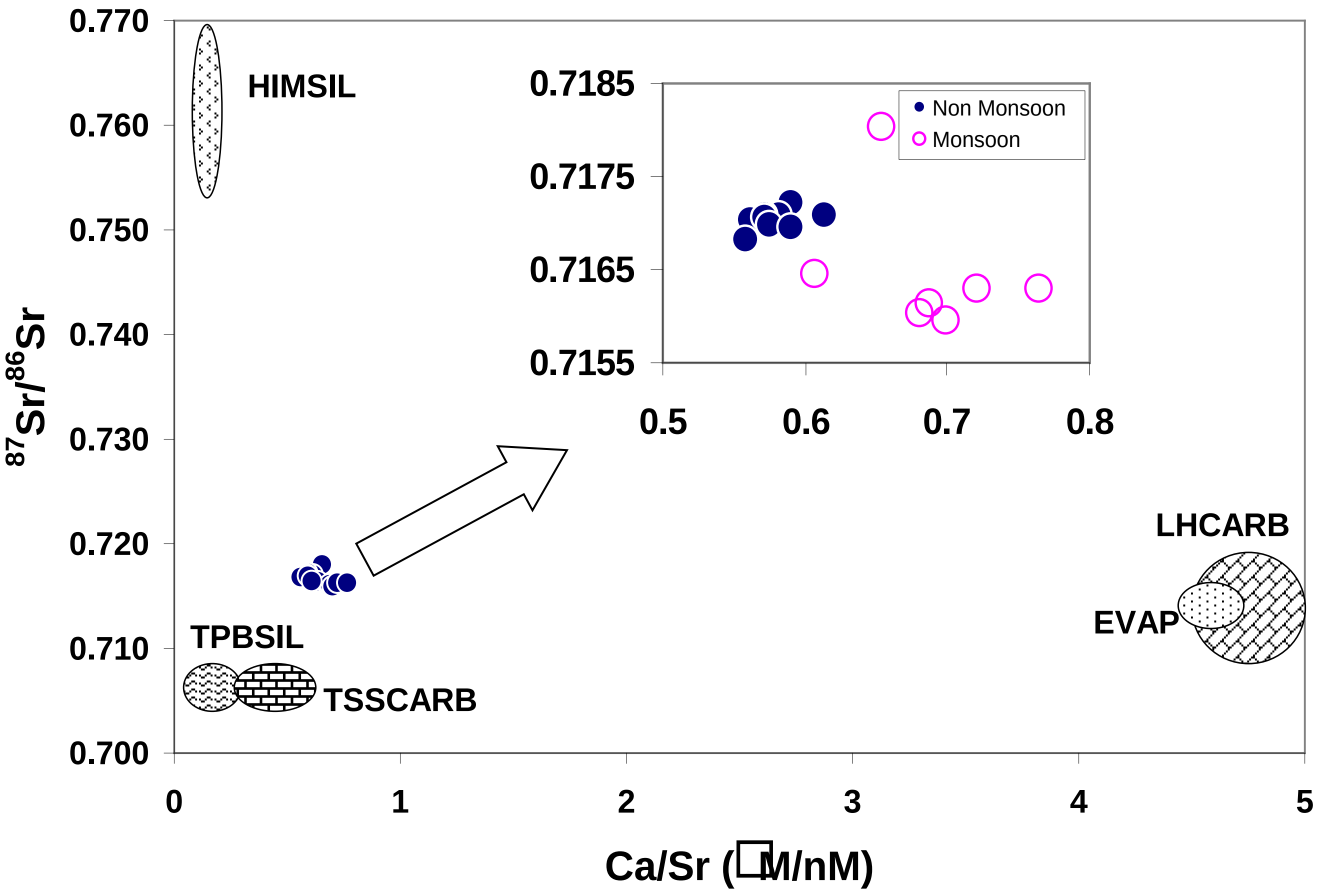


The major ion concentrations vary by a factor of about two over the sampling period despite one order magnitude variation in the discharge.

Barring the sample of 15 June, monsoon samples are diluted in all major ions.

87Sr/86Sr of the monsoon samples are also lower, indicative of a higher contribution of Sr from less radiogenic lithologies, carbonate /evaporites.

The 15 June sample has elevated conc. of most of the ions and Sr ➔ has its origin from a flash flood in Tibet



The $^{87}Sr/^{86}Sr$ data cluster around the two end-members, one the nonsilicates (carbonates /evaporites) and the other the TPBSIL, suggesting that Sr in these waters is derived primarily from carbonates and evaporites and from silicates of the Transhimalayan Plutonic Belt (TPB) & TSS

The inset shows that $^{87}Sr/^{86}Sr$ in the monsoon samples are lower than that of drier months and the $^{87}Sr/^{86}Sr$ is negatively correlated with Ca/Sr. The results are consistent with the hypothesis that carbonates'/evaporites' Sr contribution during monsoon is higher.

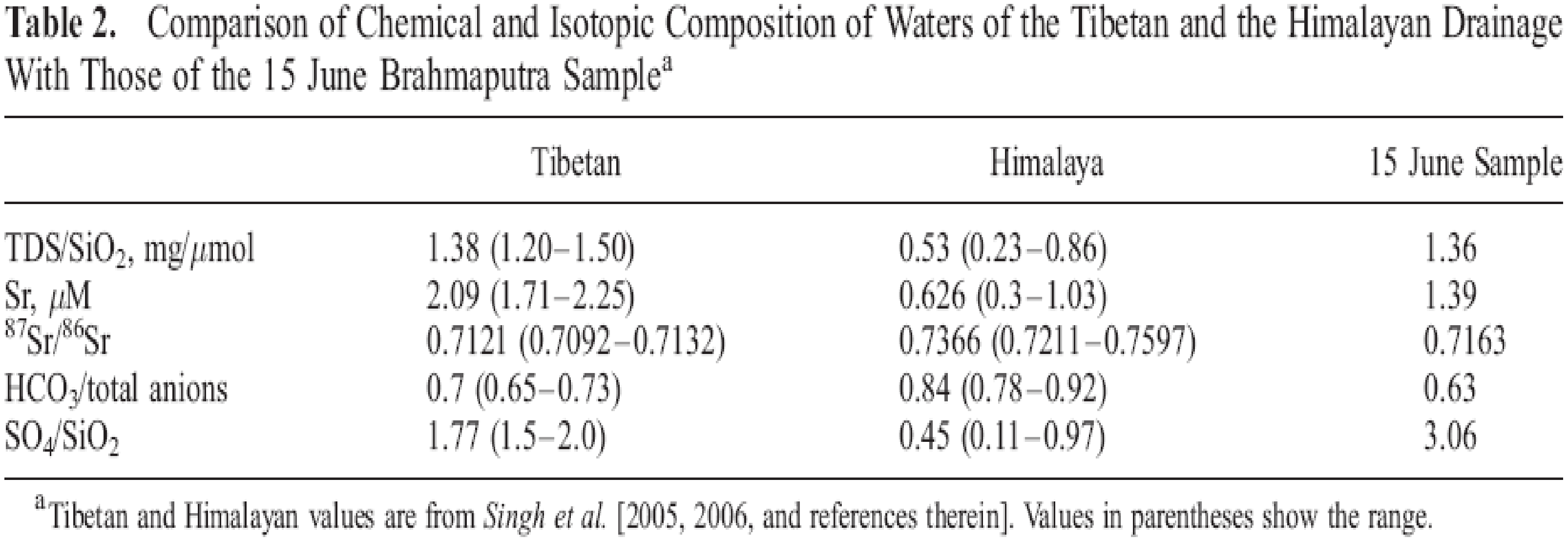


Table 2. Comparison of Chemical and Isotopic Composition of Waters of the Tibetan and the Himalayan Drainage With Those of the 15 June Brahmaputra Sample[a]

	Tibetan	Himalaya	15 June Sample
TDS/SiO_2, mg/μmol	1.38 (1.20–1.50)	0.53 (0.23–0.86)	1.36
Sr, μM	2.09 (1.71–2.25)	0.626 (0.3–1.03)	1.39
$^{87}Sr/^{86}Sr$	0.7121 (0.7092–0.7132)	0.7366 (0.7211–0.7597)	0.7163
HCO_3/total anions	0.7 (0.65–0.73)	0.84 (0.78–0.92)	0.63
SO_4/SiO_2	1.77 (1.5–2.0)	0.45 (0.11–0.97)	3.06

[a] Tibetan and Himalayan values are from *Singh et al.* [2005, 2006, and references therein]. Values in parentheses show the range.

Comparison of the concentrations of Ca, Sr and HCO_3 and TDS/SiO_2, HCO_3/total anions, SO_4/SiO_2 ratios (Table 2) in the 15 June sample with very sparse data the Tibetan waters [Singh et al., 2006, Harris et al., 1998] show that they are similar.

The overall similarity in the concentration of major ions in the two waters and their $_{87}Sr/_{86}Sr$ indicate that ➔ Source of flood waters in the Brahmaputra at Guwahati on 15 June 2000 was dominated by contribution from the Tibetan drainage.

Natural flash flood vs China's water hegemony?

http://www.globaldefence.net/portals/security/21949-chinas-growing-assertiveness-shaping-the-indian-response.html?start=2

by Lt Gen Kamal Davar, PVSM

China virtually exercises control over the waters of rivers like the Tsangpo (Brahmaputra), Indus and Satluj flowing into India owing to is superior upper riparian position in the Tibet plateau.

China plans to **unilaterally divert the waters of the Brahmaputra** to its vast arid areas in the north and west. It also has commenced work to dam some other rivers flowing into India. India's hydel project on the Brahmaputra, upstream of Pasighat, has been hanging fire for a very long time.

Chinese callous attitude in its areas in water management upstream of the Indian rivers has resulted in two devastating flash floods for India. In June 2000 parts of Arunachal Pradesh were suddenly flooded due to the bursting of Yiong River Dam or release of water from the dam.

[In 2005 again, the Satluj river was flooded in Himachal Pradesh from the Pare Chu Lake]

In addition, its proposed construction of the 116 metres high Zangmu Dam on the Tsangpo in eastern Tibet in a high seismic zone can cause havoc to Assam in the event of a major earthquake in the region.

A trans-border early warning system (Data sharing mechanism) is must between China and India➔ people in Assam , Himachal and Arunachal ➔ Save their property, livestock and life.

Attention to NDMA & Govt of India to act in Time!!

Summary (Flash Flood)

- This work demonstrates that the tracing of source of a flash flood based on geochemical signatures is possible with suitable sampling (time series) .

- It is shown that the anomalously high concentrations of various ions in the Brahmaputra water sample collected on 15 June 2000 is sourced primarily from the Tibetan drainage.

- The flood was a result of a dam burst in one of the tributaries of the Tsangpo.

- Observatories should be maintained for tracking and monitoring of Fluvial extremes➔ Save life and property of the citizens.

Roadmap for studying Climate change

(1) Ice coring and archiving facility at CFG.

(2) Hydro-chemistry of Snow melt & River water

(3) Isotopic studies & Instrumentation

(4) Cloud and Aerosol (Black Carbon) studies

(5) Counting of layers (For Dating) & Ice flow modelling

(6) Establishing a modelling group covering data reduction & processing algorithms for existing data like GRDC, GPCC, TRMM & Other Satellite data and related to Himalayan meteorology.

(7) Natural Hazard (snow avalanches) Studies group

(8) Synchronisation of the existing manpower

(9) Identifying good research problems in Himalayan Glaciology.

(10) MOUs with leading labs./Institutes in the field of Glacier Research.

(1) Coring and Archiving facility at WIHG

1. Snow content studies including chemical composition of seasonal snow and ice cores covering 100-200 years.

2. Recovery of such ice cores from the accumulation zone of the Himalayan glaciers is one of the challenging and crucial aspects of our ongoing efforts.

3. Steeper slops and inaccessibility in Himalaya is different than those in ice sheets from Antarctic & Greenland and relatively flat regions like Tibet.

4. It is proposed to identify the suitable place [with GPR at CFG] for permanent ice in accumulation zone (Siachin Glacier?) for raising core ➔past record of climatic signals up to 200 years.

5. Transport of ices core to the laboratory ➔ Suitable Containers.

6. Simultaneously, to develop a *Core archiving facility* at the Centre for Glaciology.

7. The first ice core from Indian Himalaya, becomes a reality in coming two years!!

(2) Hydro-chemistry of Snow melt & River water

1. Effect of Lithology/Debris cover on melting of Glaciers are common in many mountain regions ➔observed retreat of glaciers is linked with extent of debris cover on glacier Tongue [Scherler et al., 2011].

2. Glacial weathering & erosion fluxes and their contribution to Rivers.

3. Snow melt water contribution to Himalayan Rivers with major and trace ions [Maurya et al 2011].

4. Isotopic ($^{87}Sr/^{86}Sr$) and major ion studies to track the flash floods and Cloud bursts in the I-G-B River system [Rai & Singh, 2007]

5. Fluvial observatories (with portable equipments) for the time series measurements of composition & discharge.

(3) Isotopic studies & Instrumentation

1. Stable Isotope ($\delta^{13}C$, $\delta^{13}C$, δD etc) study and Cosmo-nuclide dating (^{32}Si, ^{210}Pb etc.) of ice cores to understand the past climatic conditions and their causes.

2. Stable /artificial radioisotopes and major ions in fresh snow, shallow snow pits, ice cores ➔ reconstruction of past climatic variations on short-term climatic changes (up to 1000 years).

3. Device methods to sample the extreme events (Cloud bursts) ➔ Compare their composition with normal rain events.

4. Development of State of the art Laboratory and associated Instrumentation [Coring equipments, CRDS, IC, Auto Titrator, spectrophotometer, Q-ICPMS, Milli-Q water system, Deep freezers etc.)& Clean Lab (Class-10000) etc.]

(4) Cloud and Aerosol sampling

1. Moisture source and their transport to understand the dynamics of extreme events (dust storms).

2. Aerosols including Black Carbon (BC) are important to understand their effect on melting ➔ Radiative forcing ➔ loss of Albedo of ice and snow.

3. Effect of the cloud condensation nucleation process and variations in the stable isotope compositions.

4. Study on seasonal snow and snow bound regions by setting up an aerosol sampler and rainfall sampling units.

5. Effect of droplet size in their isotopic composition.

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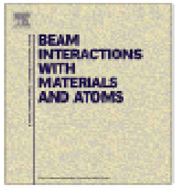

Progress in AMS measurement of natural ^{32}Si for glacier ice dating

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ABSTRACT

AMS measurement of ^{32}Si can allow for ice core dating over the last thousand years. Technique developments are reported. Necessary negative-ion yields of 20–30% can now be consistently achieved, and permit an overall efficiency from ice sample to detector of ~1%. A ^{30}Si-spike technique has overcome the problem of extremely low intrinsic silicon concentration, with the added benefit of allowing determination of ppb-level silicon via isotope dilution. Improvements have also been made to the ionization detector in the gas-filled magnet that separates the accelerated ^{32}Si ions from the intense flux of ^{32}S ions. Preliminary ^{32}Si AMS results of snow and ice samples from Mt. Cook National Park, New Zealand, are reproducible, and with ^{32}Si concentrations 1.2–7.2 mBq/m^3 comparable to results from mid-latitude snow samples measured previously via the radiometric technique, demonstrating the feasibility of the method. With these developments, the potential of ^{32}Si as ice core dating tool is close to being realized, and attempts to determine chronologies for both alpine and Antarctic glaciers are underway.

1. Introduction

Silicon-32, with a half-life of about 144 years, can be used for dating in the time range 30–1000 years and hence has the potential to fill the gap between the shorter-lived or recently introduced isotopes, both natural (^{210}Pb and tritium) and bomb-produced (tritium, ^{14}C, ^{137}Cs, and ^{239}Pu), and cosmogenic ^{14}C. This time range spanned by ^{32}Si dating covers three important epochs that are poorly covered by other dating methods: the impact of European colonization and industrialization during the last 300 years, the Little Ice Age between 1650 and 1850 AD, and the last part of the Medieval Climatic Optimum. The principal applications of ^{32}Si are in the dating of environmental archives such as ice and sediment cores, where often there is no unambiguous annual layering.

Since its first detection by Lal et al. in 1960 [1], cosmogenic ^{32}Si has been employed with limited success to study environmental

Clearly, the case for a more precise and more accurate determination of the ^{32}Si half-life remains a compelling one.

Two complementary detection methods are available for the extremely low ^{32}Si concentrations of environmental samples, each with its own specific area of application. Radiometric counting is essential for sediments, sponges, and groundwater where concentrations of silicon are high and therefore ^{32}Si/Si ratios are low, typically between 10^{-15} and 10^{-18} [3]. AMS is essential for ice cores where only a small number of ^{32}Si atoms are available. Rarely is a single sample of more than two kilograms of ice available, which will typically contain only 10,000 to 50,000 atoms of ^{32}Si. On the other hand, the concentrations of stable silicon are generally also very low. A kilogram of ice from a dust-free environment such as Antarctica or New Zealand will generally contain only 1–5 μg of silicon, and hence ^{32}Si/Si ratios will lie in the range 10^{-13} to 2×10^{-12}. This range is readily accessible to AMS provided that

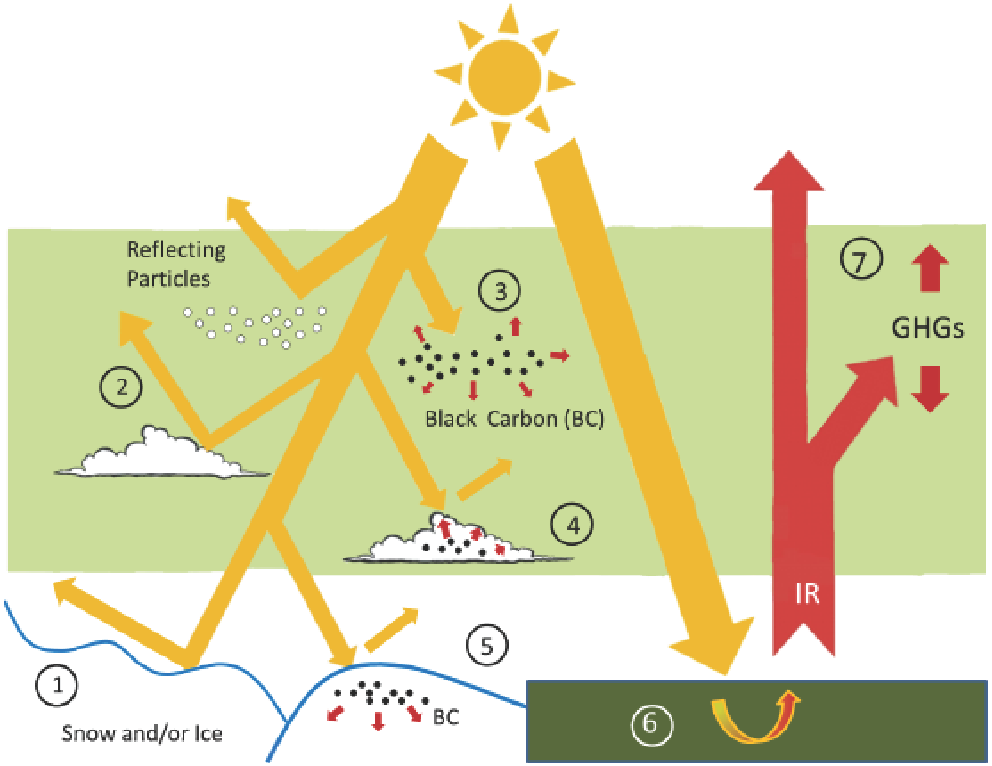
Black Carbon (BC) & its effect on climate

The most strongly light-absorbing component of particulate matter (PM), and is formed by the incomplete combustion of fossil fuels, biofuels, and biomass.

1.Sunlight that penetrates to the Earth's surface reflects off bright surfaces, especially snow and ice.

2.Clean clouds scatter or reflect sunlight, reducing the amount of solar energy that is absorbed by the surface.

3. BC suspended in the atmosphere absorbs some incoming solar radiation, heating the atmosphere.



4. Clouds containing BC inclusions in drops can absorb some incoming solar radiation➔ Clouds warmed ➔ have shorter atmospheric lifetimes and may be less likely to precipitate.

5. BC deposited on snow and/or ice absorbs some of the sunlight that would ordinarily be reflected by clean snow/ice, and increases the rate of melting.

6. Most solar radiation is absorbed by the Earth's surface and warms it. Part of the absorbed energy is converted into infrared radiation that is emitted into the atmosphere and back into space.

(5) Counting of layers (For Dating) & Ice flow modelling

1. Use of optical means for fast and reliable measurements of distinct layers present in the ice core.

2. Oxygen isotope stratigraphy (Seasonal variation of $\delta^{18}O$)

3. Ice flow modelling is required where heavy load causes it to flow➔ loss of layers➔ Error in Counting of layers.

4. OSL dating of dusty layers (as a result of sand storm) trapped in the ice core ➔ on the reliability of layer counting.

5. Can be used an independent check of cosmogenic nuclides for dating.

(6) Natural Hazard (avalanches) Studies group

1. Establishing a Natural Hazard (mostly avalanches) Studies group.

2. Research studies directed towards its Prevention and Mitigation.

3. Worked out with SASE, Chandigarh.

4. Broaden the purview of existing MOU with WIHG.

(8) Synchronisation of the existing manpower

1. Considerable number of Scientists, RAs/JRFs/SRFs, TOs/JTOs/STOs engaged in R & D activities.
2. They have contributed in Field and extension activities like expeditions/workshops.
3. Establishment of research grade laboratories appears to be impeded➔ Potentials is not fully utilized
4. *Even after 5 years, being a long time, the first PhD of this centre is yet to be produced!!*
5. Closer interaction of CFG researcher with Scientists of other institutions in terms of internal reviews and discussion on the research problems and their feasibility.
6. Distribution of responsibility with sense of freedom ➔ The group could form *a cohesive Team*!!➔ Future of this Center

(9) Training & collaboration with Leading Lad

1. With the fact that First ice core from Himalayan Ice is yet to be recovered from India, CFG may need support in this count.

2. Centre for Glaciology, being first fully dedicated institution in India in the field of Glacier research, it may aspire to establish suitable dating methods for ice cores. This include the ^{32}Si (Half life 144 years; Pioneered by Prof. D. Lal in 1960) and ^{210}Pb etc.

3. Presently, ^{32}Si dating is not established in India.

4. Collaboration is required for CFG scientists Institutions which are engaged in similar work. Towards this, *The Southern Alps ice core project* is lead by Dr. Uwe Morgenstern, GNS Science, the New Zealand with other institutes:
   (2) Climate Change Institute, University of Maine and Shichang Kang,
   (3) Institute of Tibetan Plateau Research (TPI), Bejing
   (4) Niels Bohr Institute for Ice and Climate - University of Copenhagen

(Four New Laboratories (one in progress))


Ion Chromatograph


LA-MC-ICPMS (Lab Development in Progress)


Snow/Rain/Aerosols/Rock/Soil/Water/Chemical precipitates (Non Metallic)

Clean Lab (Class-10000)


Sample attachments for the IRMS

Thank you