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A discussion on the paper “Proportions of convective and stratiform precipitation revealed in water isotope ratios”

Pradeep K. Aggarwal et al.,2016

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Outline

- Introduction
- Methods
- Results
- Discussion

Introduction

- Tropical and midlatitude precipitation

➢ Convective precipitation

—— spatially limited and high-intensity

➢ Stratiform precipitation

—— widespread and lower-intensity

- Precipitation partitioning into rain types is critical for understanding how the water cycle responds to climate changes.

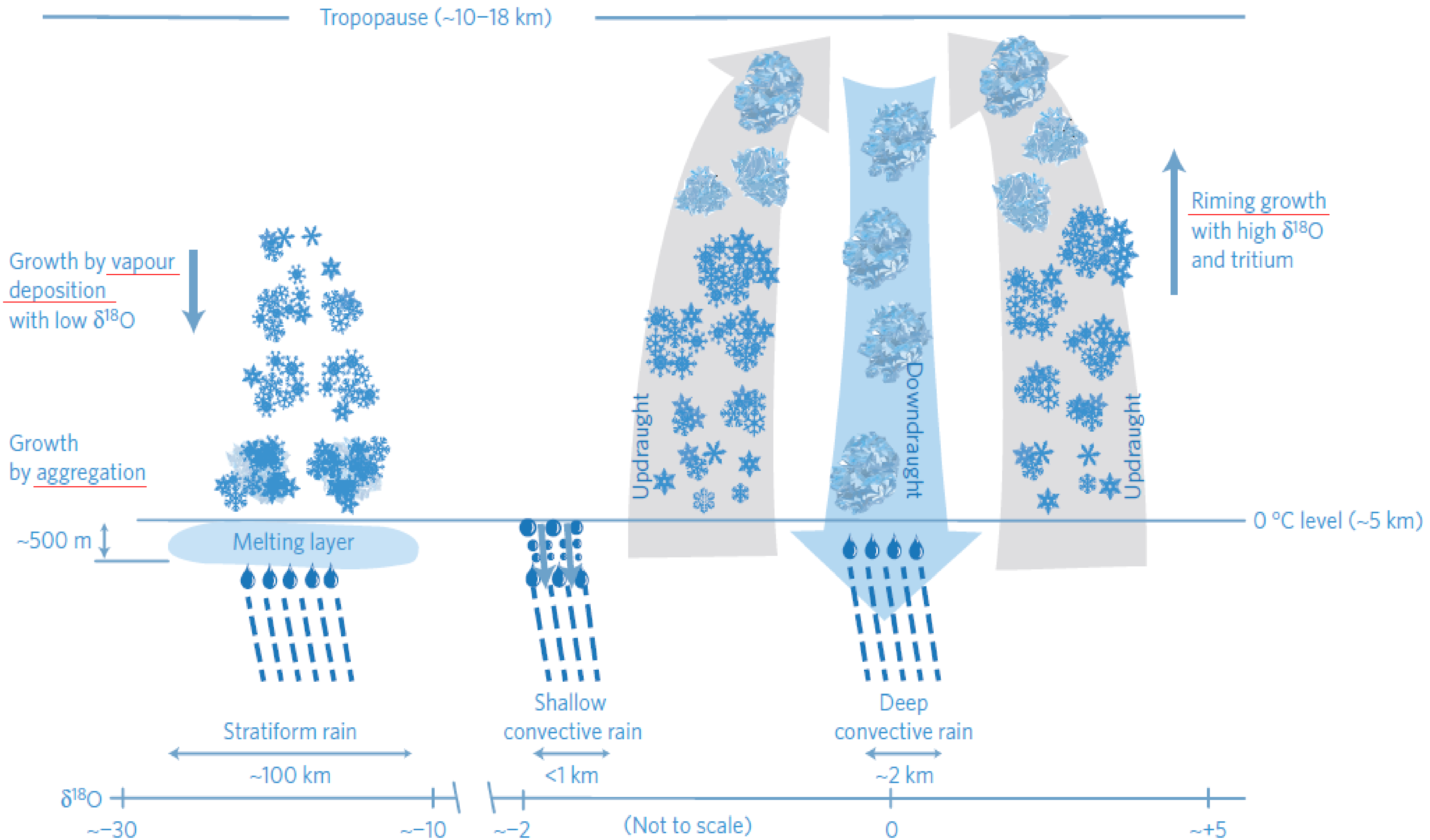


Figure 2 | Schematic representation of differences in dynamical and microphysical processes in convective and stratiform precipitation resulting in isotope variations. (Adapted after refs 18,19.) The upward air motion above the 0°C level is ~5–10 m s^{-1} in convective updraughts and ~0.2 m s^{-1} in stratiform clouds. Hydrometeors in convective clouds grow as they are lifted in updraughts, while in stratiform clouds, they grow as they fall slowly towards the surface.

Introduction

Precipitation type	Stratiform rain	Shallow convective rain	Deep convective rain
Precipitating cloud	Stratiform cloud	Convective cloud	
Upward air motion	Weak	Strong	
Hydrometeor formation	Cloud top	Cloud base; Below the freezing level	Cloud base; Above the freezing level
Hydrometeor growth	1) Vapour deposition 2) Aggregation	Collision and coalescence	Riming
Melting location	Melting layer ('bright band')	Below the 0°C level	
Descent to surface	Partially evaporate or growby accretion and coalescence	No significant evaporation or growth	
Duration	1-3h	30min	

Introduction

- Observational facts

➢ Stable isotope ratios are different in precipitation from different clouds.

➢ Lower $\delta^{18}O$ occurs in precipitation from stratiform clouds under certain circumstance.

- Problems faced

➢ Rayleigh distillation theory presents a few defects when differentiating precipitation types.

➢ A comprehensive framework that adequately explains observed isotope distributions is still lacking.

Introduction

- Precipitation isotope distribution

➢ Key assumption: A change in $\delta^{18}O$ of precipitation directly represents a change in one or more of the parameters that may influence isotopic composition.

➢ $\delta^{18}O$ of 50° N–50° S precipitation normally has a range of ~0‰ to ~−30‰ despite potentially large differences in above-mentioned parameters.

➢ Only $\delta^{18}O$ are considered because hydrogen isotope ratios are proportional to those of oxygen.

Introduction

Different precipitation types and varying proportions of them

Differences in dynamical and microphysical processes during rain formation

Different isotope signatures and precipitation isotope variability

Methods

- Locations selected
- 28 tropical and two midlatitude locations
- These locations span a broad latitudinal range (50° N–21° S) and hydro-meteorological conditions.
- Tropical locations selected in this study require at least four consecutive years of isotope data in the 1998–2014 period.

Table 1 | Geographical coordinates and related information for locations used in this study.

Code	Location	Lat. (° N)	Long. (° E)	Alt. (m)	Average annual		Months with precip. > 50 mm*
					Precip. (mm)	T (°C)	
6345000	Addis Ababa	9.00	38.73	2,360	954	16.7	May-September
6708301	Antananarivo	−18.91	47.56	1,295	1,263	19.4	January-April; November-December
6190000	Ascension Is.	−7.92	−14.42	15	166	25.8	March-August
4845500	Bangkok	13.73	100.50	2	1,661	28.5	March-November
8400101	Bellavista	−0.69	−90.33	194	763	22.5	January-May
8358301	Belo Horizonte	−19.87	−43.97	857	1,190	22.5	January-April; October-December
8022200	Bogota	4.70	−74.13	2,547	1,029	13.3	February-December
9616301	Bukit (Sumatra)	−0.20	100.32	865	2,005	21.9	January-December
6534403	Cotonou	6.42	2.33	14	1,084	27.1	March-July; September-November
9412000	Darwin	−12.43	130.87	26	1,902	27.3	January-April; October-December
4192300	Dhaka	23.95	90.28	14	1,545	26.7	April-October
6491001	Douala	4.04	9.73	18	3,787	27.2	February-December
7870802	El Jaral	14.94	−88.02	652	3,586	22.6	January-December
8004401	El Tesoro	9.34	−75.29	175	1,299	27.4	March-December
6370500	Entebbe	0.05	32.45	1,155	1,575	21.7	January-December
4500400	Hong Kong	22.32	114.17	66	2,221	23.0	April-October
8404400	Izobamba	−0.37	−78.55	3,058	1,380	11.7	January-June; August-December
9674503	Jakarta	−6.29	106.67	45	1,945	26.9	January-September; November-December
9619500	Jambi	−1.63	103.65	25	2,126	26.9	January-December
9842900	Manila	14.52	121.00	14	1,737	27.3	April-December
9644901	Mulu (Sarawak)	4.05	114.81	24	5,026	27.0	January-December
6756100	Ndola	−13.00	28.65	1,331	347	20.6	January-February; November-December
4218200	New Delhi	28.58	77.20	212	802	25.3	May-October
7880602	Panama	8.98	−79.53	5	1,853	27.1	April-December
8437701	Puerto Almendras	−3.82	−73.38	98	3,703	26.1	January-December
8407301	Quito	−0.17	−78.48	2,789	808	15.2	January-May; October-December
6198001	St Denis	−20.90	55.48	70	1,599	24.7	January-December
4190000	Sylhet	24.91	91.85	20	4,012	25.7	March-October
1256500	Krakow	50.06	19.85	205	668	8.3	January-December
1103500	Vienna	48.25	16.36	198	684	10.3	January-December

*Except for Ascension Island, Vienna and Krakow, where all months with consistent data over multiple years were included.

Methods

- Data and resource

➢ Stratiform precipitation fractions (1998-2014)

For tropics: TRMM PR 2A23 and 2A25 (V7) data products

For midlatitudes: 3-h Synoptic cloud observations (MIDAS)

➢ Stable isotopes, precipitation amount and tritium contents

IAEA/WMO GNIP database

➢ 40-dBZ echo maximum height

TRMM PR (no similar data available for midlatitudes)

Methods

- Related knowledge

➢ Stable isotope abundance and isotope ratio (R)

➢ $\delta^{18}O = (Rx/Rstd - 1) * 1000$

R: $^{18}O/^{16}O$ ratio in a sample (x) or standard (std)

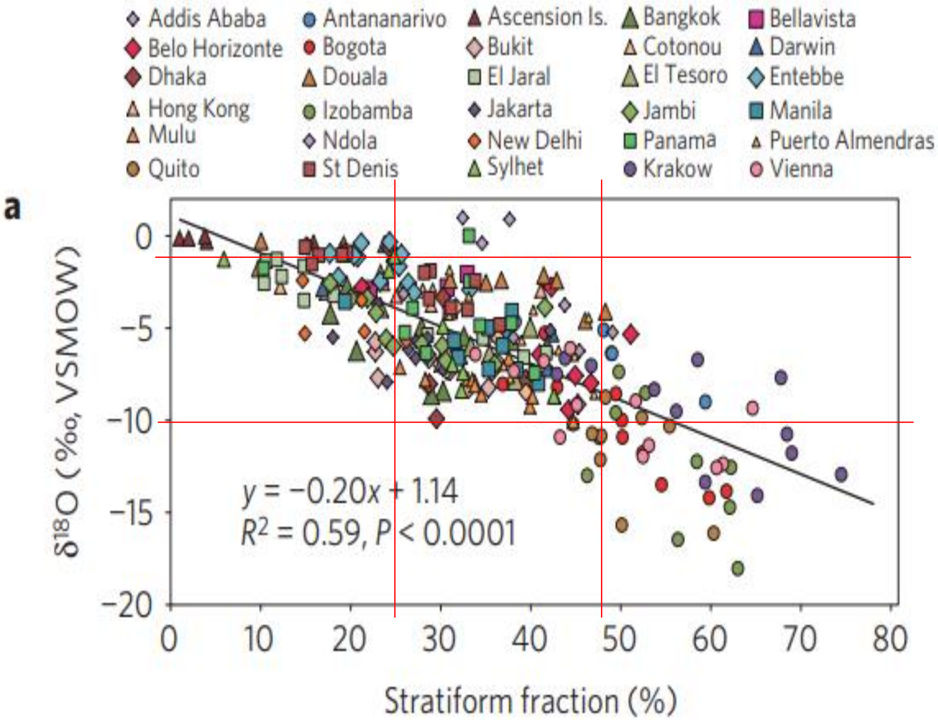
Isotopic standard: VSMOW

➢ Tritium units (TU): 1 TU = 10^{-18} $^{3}H/H$

➢ Stratiform fraction: Ratio of stratiform volumetric rainfall to total volumetric rainfall

➢ Note: 0% stratiform is essentially 100% convective with the exception of no-rain cases, for our purpose.

Results



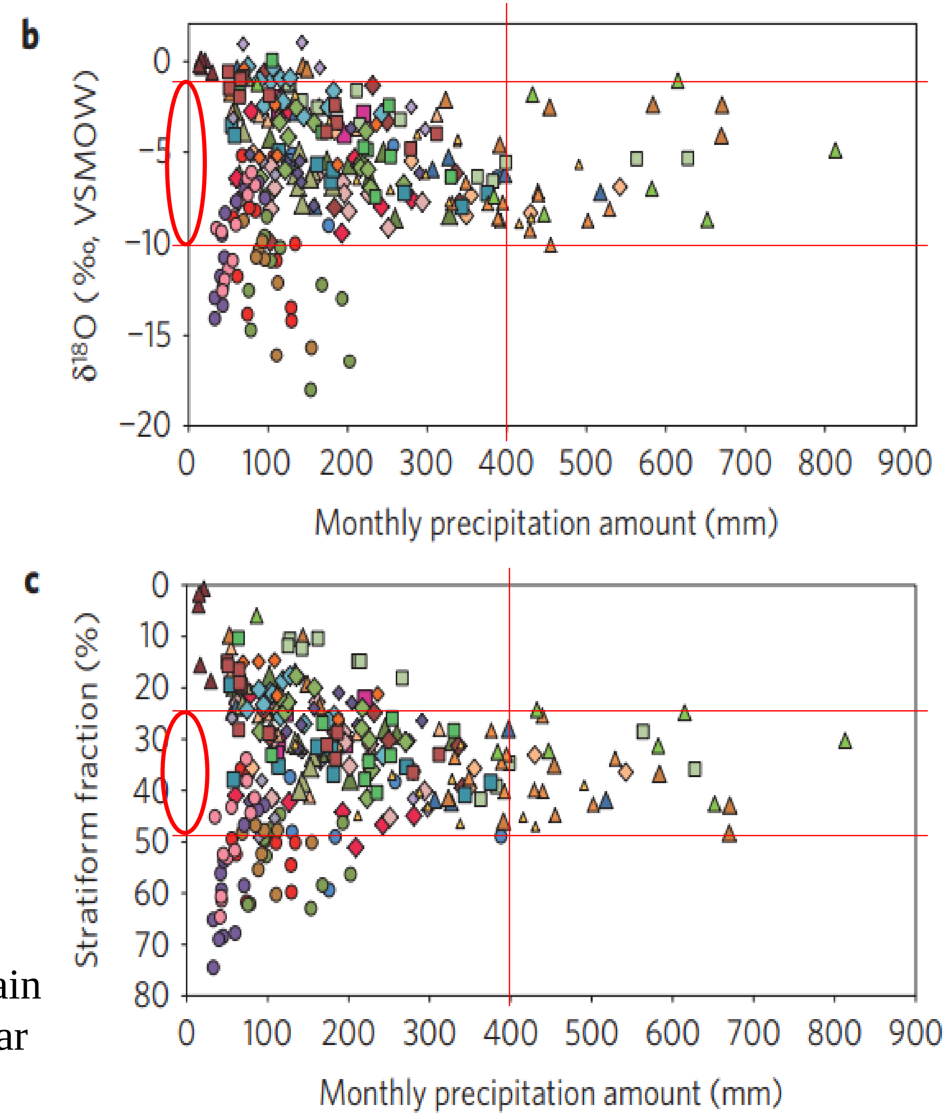


Figure 1 | Correlation of mean monthly $\delta^{18}O$, stratiform fraction and precipitation amount in tropical and midlatitude precipitation.
a, $\delta^{18}O$ and stratiform fraction. The remainder of the rain fraction is convective. The solid line is based on a linear regression of all data points shown.
b, $\delta^{18}O$ and precipitation amount. Note the limited change in $\delta^{18}O$ with the highest precipitation amounts.
c, Stratiform fraction and precipitation amount. The vertical axis is shown in reverse scale. Note the similar but opposite trends in b and c, and the narrow range of stratiform fractions with highest precipitation amounts.

Results

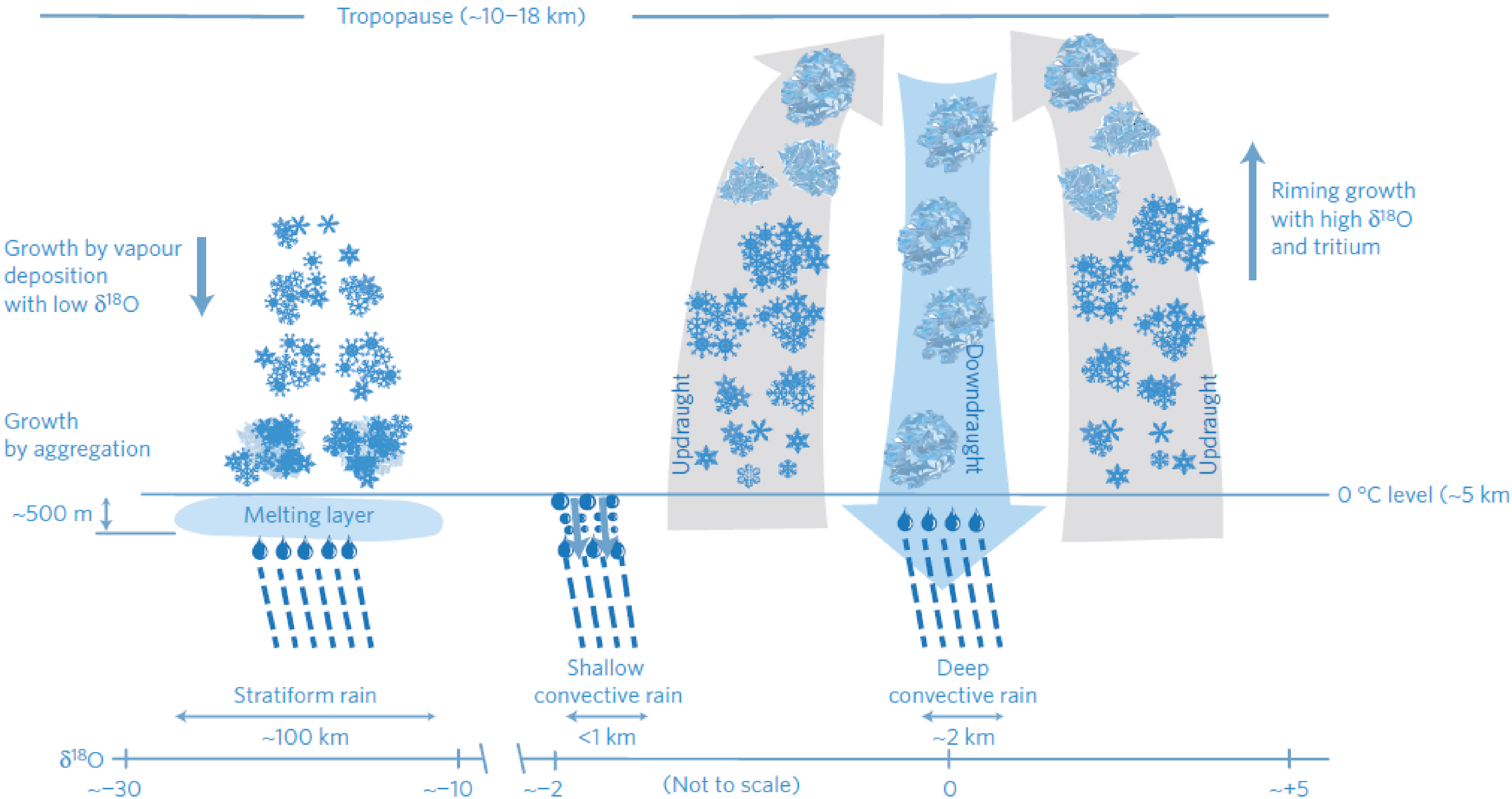


Figure 2 | Schematic representation of differences in dynamical and microphysical processes in convective and stratiform precipitation resulting in isotope variations. (Adapted after refs 18,19.) The upward air motion above the 0°C level is ~5–10 m s^{-1} in convective updraughts and ~0.2 m s^{-1} in stratiform clouds. Hydrometeors in convective clouds grow as they are lifted in updraughts, while in stratiform clouds, they grow as they fall slowly towards the surface.

Results

Precipitation type ($\delta^{18}O$ content)	Hydrometeor growth			Raindrops falling	
	Growth mechanism	Moisture source	$\delta^{18}O$	Raindrop size	Processes in relation to isotope change
Stratiform rain (Low)	Vapour diffusion	Tropospheric moisture	~-40 to -50‰	~1mm in diameter	1) Isotopic homogenization in the melting layer 2) equilibration with lower-altitude moisture
Convective rain (High)	Accretion (riming)	Boundary layer moisture	~-12 to -10‰	>2mm diameter	High $\delta^{18}O$ are preserved due to inhibited isotopic exchange with ambient moisture

Results

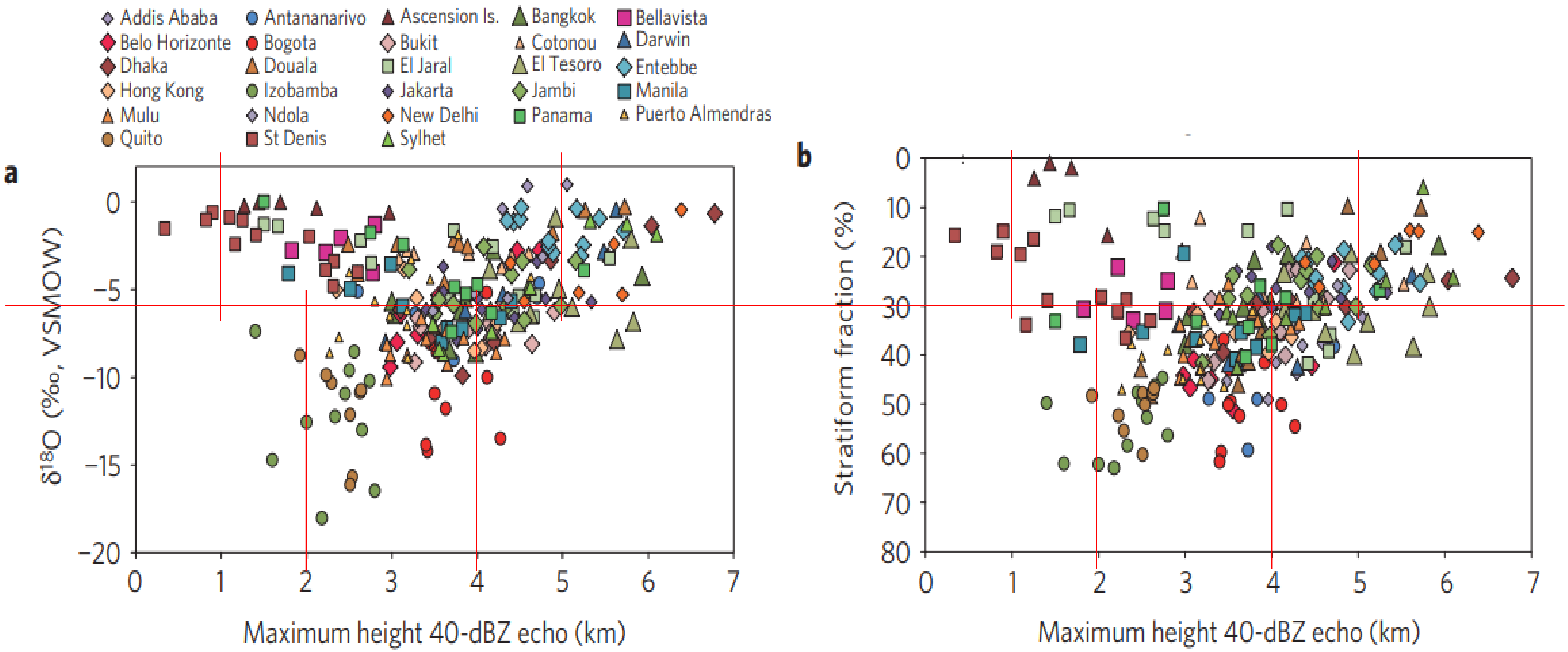


Figure 3 | Correlation of mean monthly $\delta^{18}O$, stratiform fraction and maximum height of 40-dBZ echo. **a,b,** Precipitation with higher $\delta^{18}O$ and low stratiform fractions occurs with high or low 40-dBZ echo heights, reflecting deep or shallow (warm rain) convection, respectively.

Precipitation with lower $\delta^{18}O$ and higher stratiform fraction has lower echo heights, consistent with a melting layer in stratiform clouds below the 0◦C level.

Results

$\delta^{18}O$	**Stratiform fractions**	**40dBZ echo height**
High	Low	>5km (deep convection)
		<~1km (warm rain)
Low	High (>~30%)	~2-4km

- High reflectivity

➢ Large ice particles above the 0°C level (~5 km in the tropics) lifted in strong updraughts

➢ A melting layer of ice particles just below the 0°C level exhibiting a bright band characteristic

➢ Intense rain near the Earth's surface (~1-2 km)

Results

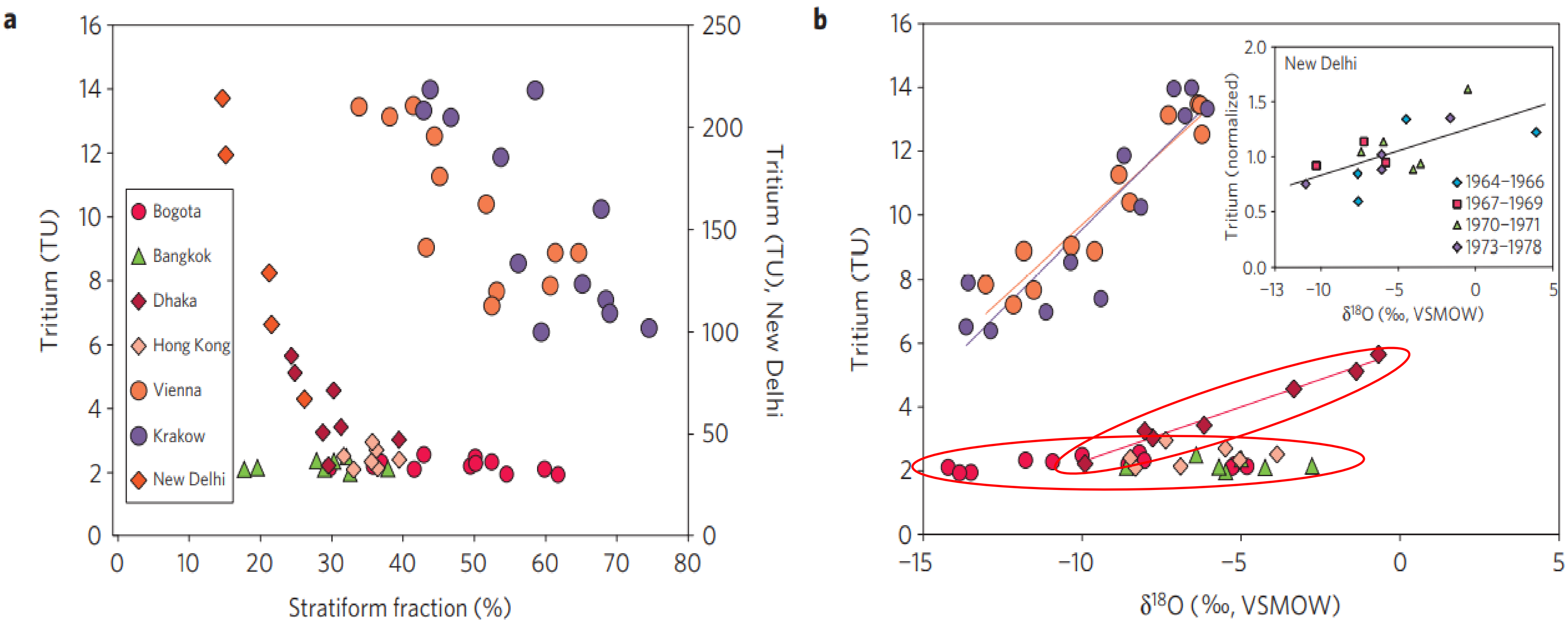


Figure 4 | Correlation of monthly precipitation tritium (^{3}H) content with stratiform fractions and δ^{18}O. **a,** Note the much higher tritium contents at New Delhi because 1964–1978 data are used, while 2000–2012 data are used for the other stations. **b,** New Delhi tritium values (inset) are normalized by the mean annual average for each period and the regression line has an R^2 of 0.42 with P<0.001. Other regression lines have R^2 of 0.81 (Krakow), 0.90 (Vienna) and 0.98 (Dhaka), all with P<0.00001.

Discussion

- Conclusions

- $\delta^{18}O$ in tropical and midlatitude precipitation can reflect the proportions of convective and stratiform rain and exhibits a negative correlation with stratiform fractions.
- The $\delta^{18}O$ - stratiform fraction correlation for monthly data is found also at storm event or interannual timescales.
- Stable isotope ratios can be used to monitor changes in the character of precipitation in response to periodic variability or changes in climate.

Discussion

- Conclusions

➢ Precipitation partitioning based on isotope distributions can improve climate models and the simulation of convection and provide a better understanding of isotope variations in proxy archives of palaeo-precipitation.

Discussion

- Inspirations and further work

Using related data of Nanjing Station for verification

Expanding research area to the whole midlatitudes

If there is such a universally applicable correlation between $\delta^{18}O$ and stratiform rain fractions, maybe a comparative database is feasible.

Thank you for listening!