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Seasonal variations in isotopic content (^{18}O–^{2}H) of rainfall over an intertropical humid island (Reunion Island, southwest Indian Ocean)

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Abstract Oxygen-18 (^{18}O) and deuterium (^{2}H) contents from seasonal precipitation collected over 31 raingauge stations on Reunion Island (2500 km^2) point to climatic variations typical of an intertropical island with strong relief: (a) a geographical variation with leeward and windward slopes, and (b) a seasonal contrast between dry and wet periods. The relation between oxygen-18 and deuterium shows an important depletion, more or less sharp according to the slope of the island, in strong rainfalls in the wet season; this depletion is particularly stronger during wet seasons with cyclonic events. During the dry season raindrops are evaporated in an unsaturated atmosphere along dry slopes when the evaporated or evapotranspirated continental vapour is acting along wetter slopes. During tropical depression events, geographical and seasonal distribution of isotopic contents are strongly disturbed.

Variaciones estacionales de los tenores isotopicos de las precipitaciones en una isla intertropical humeda (isla de la Reunion, sur-oeste del Oceano Indico)

Resumen Los tenores en oxigeno-18 y deuterio medidos en las precipitaciones recogidas en 31 puestos pluviométricos de la isla de la Reunion (2500 km^2) dan cuenta de las variaciones climáticas tipicas de las islas tropicales con importante relieve: (a) variaciones geográficas con dos vertiendes "cara al viento" y "bajo el viento", y (b) variaciones estacionales con estación seca y estación húmeda. La correspondencia ^{2}H–^{18}O revela un importante empobrecimiento, mas o menos marcado según los vertientes de la isla, de la fuertes precipitaciones de la estación húmeda; este empobrecimiento es particularmente acusado en la estación ciclónica. En la estación seca en la que los tenores estan menos empobrecidos, se observan fenómenos de evaporación de las gotas de lluvia en una atmósfera desaturada en los vertientes "bajo el viento" y una participación de vapor continental evaporado en los vertientes mas regados. Durante las depresiones tropicales las reparticiones geograficas y estacionales de los tenores isotopicos estan fuertemente perturbadas.

GEOMORPHOLOGICAL AND CLIMATIC ENVIRONMENT

Located in the southwestern Indian Ocean (21°S, 55°30'E), the tropical Reunion Island (2500 km^2) consists of two juxtaposed volcanoes: the now extinct Piton des

Neiges (3069 m) and, on its eastern flank, the still active Piton de la Fournaise (2632 m) .

The central part of the island displays a rugged topography with deep entrenched valleys and three internal cirques, resulting from strong erosion guided by volcano-tectonic structures. The cirques are bordered by subvertical ramparts, more than 1000 m high. The external sides of the volcanoes typically have 7–15° slopes down to the littoral cliff.

The island climatic regime is characterized by two contrasting seasons. From May to October, the austral winter is dominated by trade winds generated by the Indian Ocean anticyclone, usually located south of Reunion Island. During the austral summer, equatorial low pressions push the anticyclone southward, so that tropical depressions may reach the island. Because of the trade winds regime, rainfall amounts vary from 2000–7000 mm $year^{-1}$ on the windward east coast, with a maximum >10 000 mm, but averaging 9000 mm, to 500–2000 mm $year^{-1}$ on the leeward south and west coasts. On both mountainsides, altimetric gradients of precipitation amounts are disturbed by a thermal inversion layer. This limit fluctuates between 2000 and 2500 m elevation and is characterized by a sharp decrease of humidity (70–80% to 40%) (Barcelo & Coudray, 1996). Among the five identified types of rainfall (Robert, 1986) only tropical precipitations at the island scale are not affected by the inversion layer.

EXPERIMENTAL CONDITIONS

Seasonal precipitations were collected from November 1985 to March 1987 at 31 gauging stations scattered over the island. The locations of the stations were selected in order to represent the climatological and topographical diversity of Reunion Island: leeward and windward slopes, coastal areas and highlands on external slopes, cirques, etc.

Precipitations were cumulated at seasonal intervals (dry season from April to October, rainy season from November to March) into 200-litre tanks, with a small layer of paraffin oil to prevent evaporation. Stations were monitored during three semesters covering two rainy seasons: November 1985–March 1986 (SEM1), November 1986–March 1987 (SEM3), and a dry season: April 1986–October 1986 (SEM2) (Fig. 1). Isotopic data (^{18}O and ^{2}H) were collected all over the island during the three semesters, except for ^{2}H data from Piton des Neiges that are missing only for the third semester (SEM3). Isotopic analyses were performed with a mass spectrometer, after CO_2 equilibration for ^{18}O (Epstein & Mayeda, 1953) and a 800° water reduction on uranium for ^{2}H (Biegeleisen *et al.*, 1952). Results are expressed in δ unit with respect to the standard V-SMOW (Vienna Standard Mean Ocean Water). Analytical errors are estimated at around 0.15% for ^{18}O and 1% for ^{2}H. The original data are from Grünberger (1989) and Nicolini *et al.*, (1990).

^{18}O–^{2}H RELATIONS

The ^{18}O–^{2}H contents of the precipitations for the three semesters (Fig. 2) appear well correlated, following a straight line: $\delta^{2}H = 8\delta^{18}O + 11$, $r = 0.99$, 1% significance.

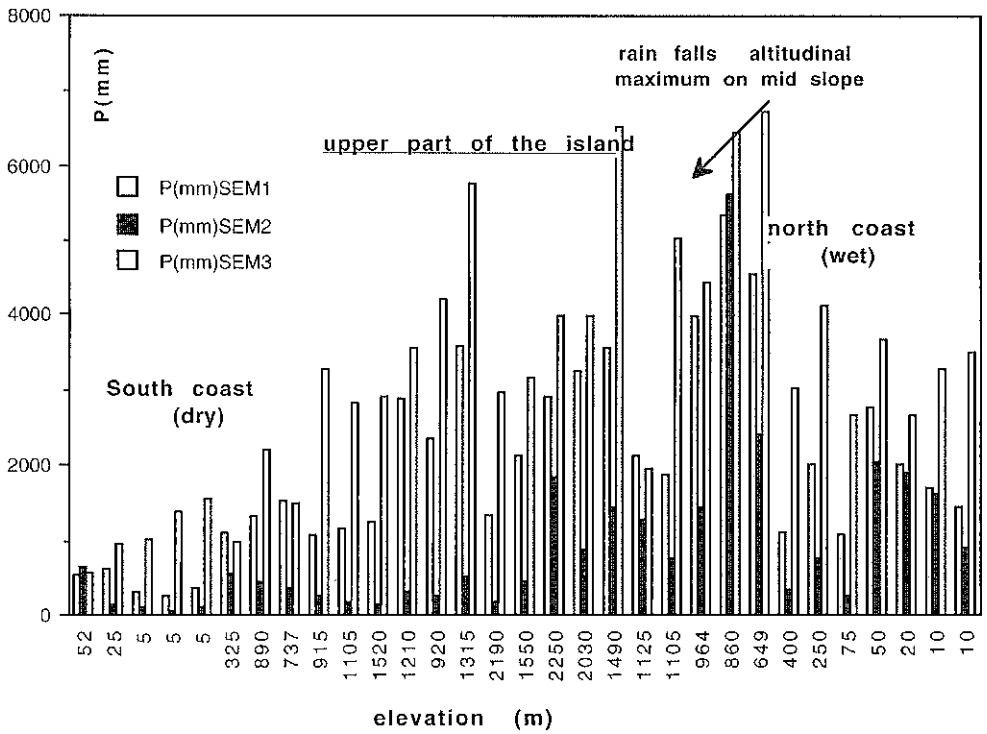

Fig. 1 ^{18}O–^{2}H relationship for three running semesters.

The good correspondence with the world meteoric water line (Craig, 1961) indicates that condensation is related to a pattern of simple oceanic disturbances. Precipitation amounts during each of the three semesters depend on (a) the season, (b) the distance of the station from the coast, and (c) the prevailing ENE-ESE winds (Fig. 1). Dry season rainfalls (SEM2) are evidently weaker on any slope. Precipitation (*P*) related to a cyclonic event (Clotilda, 11–14 February 1987) are stronger than those of the previous rainy season that did not experience tropical depressions (Fig. 1).

P SEM3		*P* SEM1		*P* SEM2
rainy season + Clotilda depression	>	rainy season	>	dry season

On the correlation line, isotopic contents seem in direct proportion to precipitation amounts following the well known "amount effect" (Dansgaard, 1964). Gonfiantini (1985) has shown a very good correlation (more than 99.9% for 15 stations) between rainfall amounts and mean weighted isotopic contents in tropical stations. Unlike stations with temperate climates, where isotopic contents are related to the outside temperature of the geographic location, in tropical areas the amount effect hides the thermal dependence.

Looking closely at Fig. 2, isotopic contents of the dry season are more scattered than those of the two rainy seasons. The ^{2}H–^{18}O correlation line is characterized by a 5.6 slope, and most of the dry season values are located above the Craig line. Either raindrops underwent an evaporation during their fall in an unsaturated atmosphere (the case of leeward stations), or the evaporation and evapotranspiration of

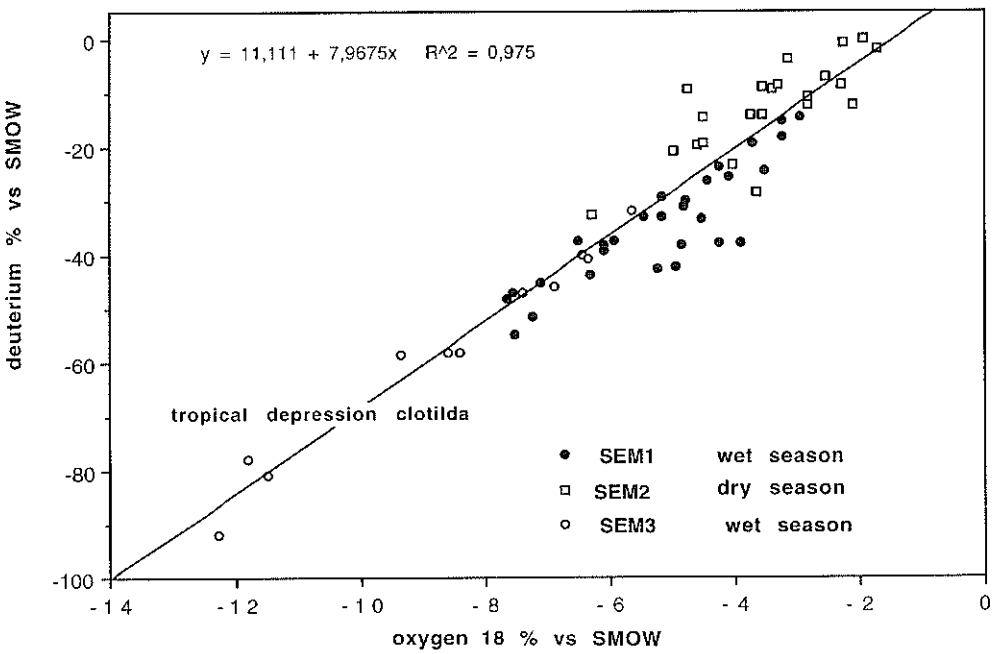

Fig. 2 Rainfall amounts (three running semesters for 31 gauging stations) as a function of elevation.

continental origin are acting along the windward slopes. The latter processes release into the atmosphere an isotopically steady state water vapour with an isotopic composition close to the one of local mean precipitations (Bariac *et al.*, 1990). On windward slopes vegetation is luxuriant and rainfall more abundant than on the other slopes, even during the dry season.

Very low isotopic contents of the third semester are well fitted with the Clotilda tropical depression event (11–14 February 1987). A two-hour sampling (Nicolini *et al.*, 1989) of rainfall amounts was performed at station no. 30 (1125 m elevation) in the southern part of the island. The corresponding ^{18}O contents reached very depleted values such as –16‰. Clotilda rainfalls represent 584 mm within 72 h and more than 25% of the semester rainfall amount (1951 mm). At each station the influence of Clotilda on ^{18}O contents was calculated for the affected season with the following subtraction:

$\delta^{18}O$ (SEM3 rainy season with Clotilda) – $\delta^{18}O$ (SEM1 rainy season without tropical depression)

Figure 3 shows depletion at the island scale.

^{18}O–ELEVATION

For each of the three semesters, ^{18}O contents were plotted as a function of the elevation of the pluviometric gauge stations (Fig. 4 (a)–(c)). On each Figure, two envelope curves join the minimum and maximum ^{18}O values. The curves delimit a band characterized by its width and the curve slope variations indicate the variation of the altitudinal isotopic gradient.

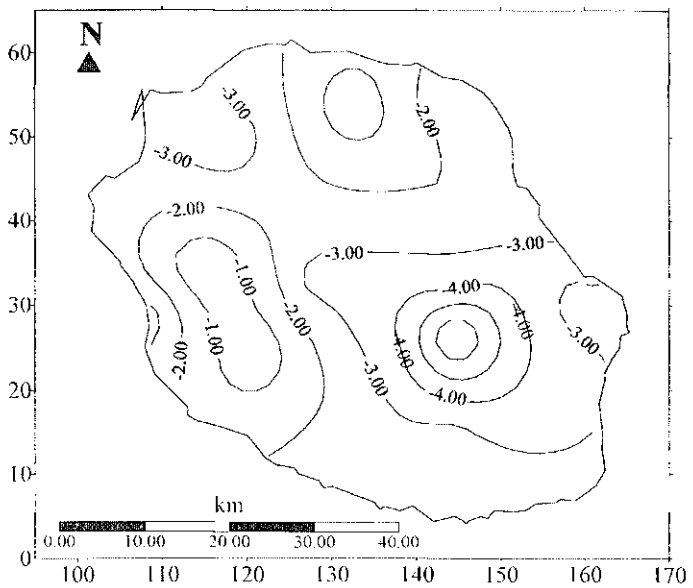

Fig. 3 Map of heavy isotope depletion in rainfall (isoline $\delta^{18}O$ SEM3 – $\delta^{18}O$ SEM1) over Reunion Island: influence of the Clotilda depression.

- ^{18}O contents at coastal stations confirm the major influence of the amount effect already observed (Fig. 2) for all island stations: the greater the amount of seasonal precipitation, the more depleted the isotopic contents.
- For semesters 1 (rainy season) and 2 (dry season) groups of stations joined by the upper curve (less depleted values of ^{18}O) cluster together on the windward slope, while lower curve groups (very depleted values) gather on the leeward slope (Fig. 4(a) and (b)). As expected, windward stations have less depleted isotopic contents than those of leeward stations (Fig. 4(a) and (b)). In fact, condensation acts along windward slopes at lower elevation (i.e. higher temperature) than on leeward slopes where precipitations of higher elevation are weaker and more depleted because of the main "föhn effect".
- On Fig. 4(a) and (b), the band width expresses the variation of ^{18}O values between two leeward and windward slopes. This variation is more important during the wet season ($>2\delta$) than during the dry season (around 1δ). Precipitations of orographic origin during the dry season are weak and the small isotopic variation between the two (leeward and windward) slopes expresses a greater uniformity in the mechanism of rainfall formation.

For the two rainy seasons (SEM 1 and 3), the stations joined by the same curve have been plotted on the map of Reunion Island (Fig. 5(a) and (b)).

During SEM1, upper curve and lower curve stations are distributed on the windward and leeward slopes respectively (Fig. 5(a)).

During SEM3, characterized by the Clotilda depression event, upper and lower curve stations are no longer distributed in the same way, but with a transverse arrangement (Fig. 5(b)). This arrangement seems to be guided by the depression trajectory. The depression eye has covered the whole island when crossing it from

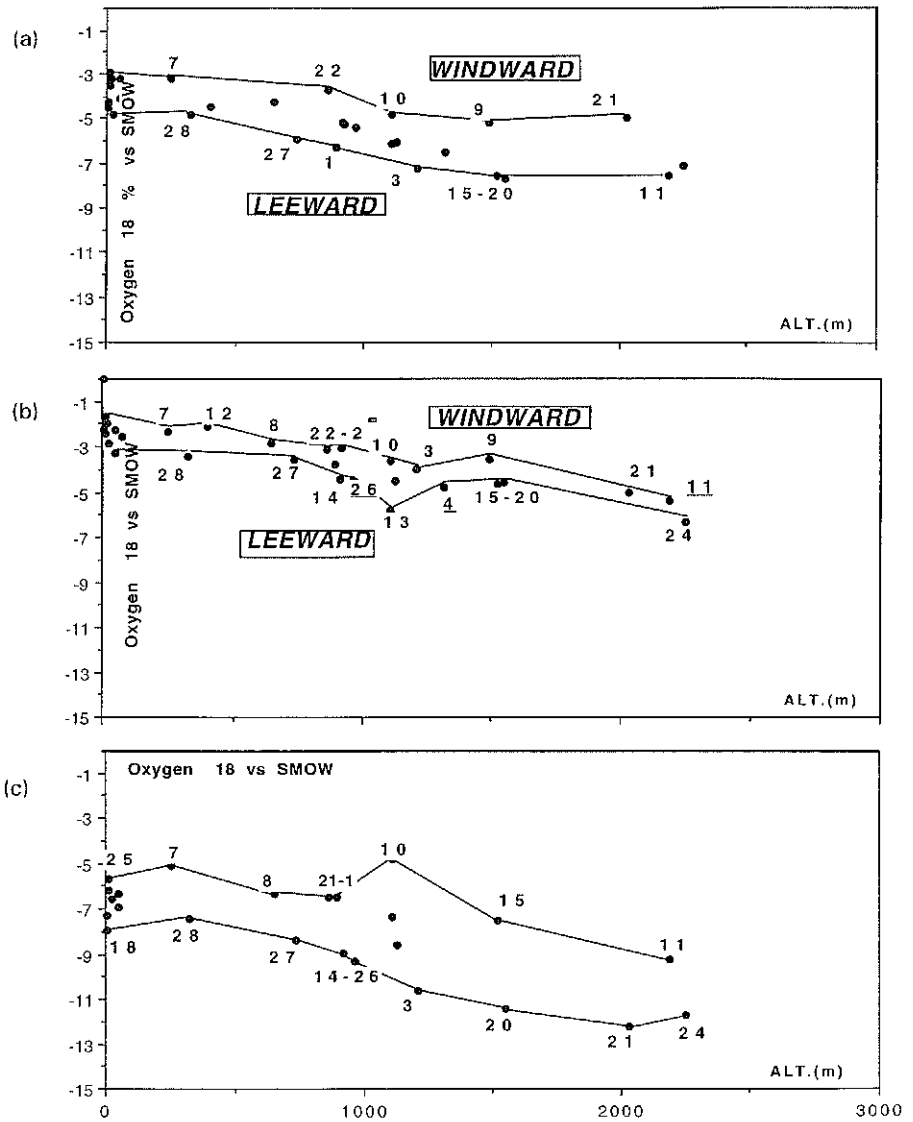

Fig. 4 ^{18}O-elevation relationship in semestrial precipitation (a) wet period, (b) dry period, and (c) wet period with tropical depression.

north to south; moreover few rainfalls and no wind are registered during this period. The band width (Fig. 4(c)) showing the isotopic variation is very large (4δ for higher stations) compared to the one (2δ) of the rainy season without cyclonic event (SEM1). Such a difference can be explained by (a) condensation processes at probable different elevations, and (b) different origin of vapour stock. In fact, rainfalls that are guided by the trajectory and the wind circulation will successively drop on the eastern sector (B), then on the western sector (A).

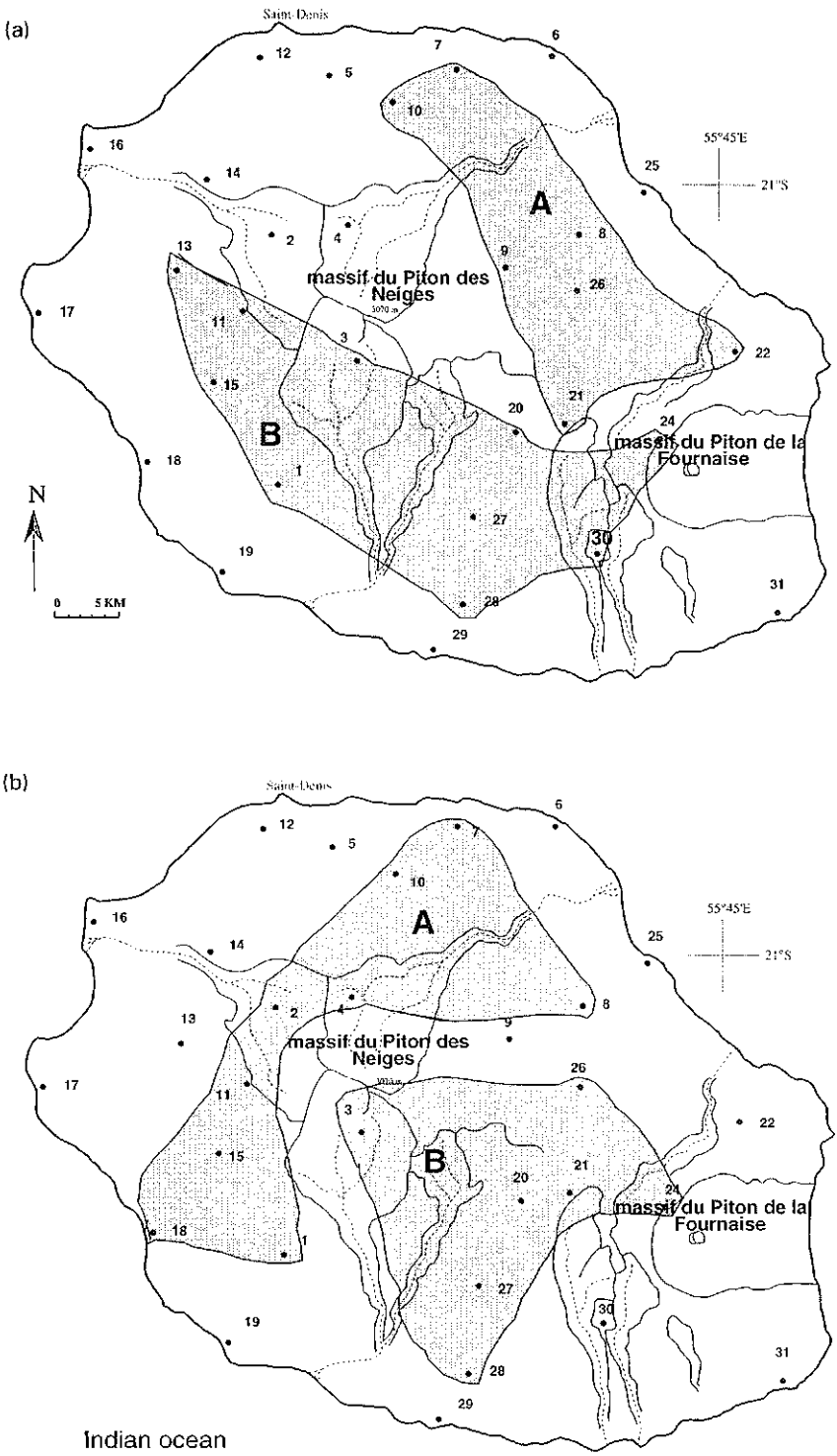

Fig. 5 Delimitation of geographical areas with relative depleted isotopic values (B *vs* A): (a) wet season, and (b) wet season with tropical depression.

CONCLUSIONS

Large variations in seasonal and spatial isotopic contents of Reunion rainfalls underline the difficulty of using environmental isotopes as water tracers in tropical islands with rugged topography.

In fact, many factors such as exposure to prevailing winds, distance from the coast, trajectory of one or several depressions etc., can modify consequent isotopic contents in rainfall.

Taking into account the isotopic variations requires special attention to sampling time steps and a good geographical definition of the studied area. For that matter, numerous data are needed. Then such variations can represent as many input events that can be used as tracers in the underground domain.

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