CHAPTER 2

GEOGRAPHY AND CLIMATE

Michel Grimaldi and Bernard Riéra

1. Introduction

The Nouragues station is located within the 'Montagnes Balenfois' massif to the Southwest of the commune of Régina. The landscape of hills covered by dense tropical rainforest is dominated by a partly denuded granitic inselberg which reaches an elevation of 430 m above sea level. The limit between the River Comté drainage basin in the north and the River Approuague basin passes across the summit of this inselberg. The Nouragues creek (a tributary of the River Approuague) flows past the foot of the inselberg, forming the boundary between two main types of geological substratum: the 'Caribbean' type granite and the metavolcanic rocks of the Paramaca series. The lithology of these terrains has an influence on the relief and on the soils. Thus, the geology, the geomorphology and the soil types are presented here in succession. Finally, an analysis is given of the climatic data that has been collected since the setting up of the station.

2. Geology

French Guiana is situated in the north-eastern part of the Guiana Shield, which is composed mainly of Paleoproterozoic terrains (2.2-2.0 Ga). The Guiana Shield is generally younger than other cratons, the only Archaean ages being found in the Imataca granulitic complex (> 3.4 Ga) in north-eastern Venezuela (Fig. 1). Volcanic and sedimentary rocks are particularly abundant in northern Guiana, where they make up the greenstone belts of the Transamazonian orogeny. The syn- and post-orogenic periods are characterised by various phases of deformation and metamorphism that accompany the progressive intrusion of the different types of pluton. Over a very long time span, erosion has exposed vast expanses of granitic terrain while reducing the importance of the intruded country rocks (volcanic and sedimentary origin).

The lithostratigraphic succession proposed by Milési *et al.* (1995) for the greenstone belts of northern Guiana is based on the recognition of two major units lying structurally above a substratum composed of highly metamorphosed volcanic rocks, the Île de Cayenne Formation:

- a lower volcanic and sedimentary unit, variably metamorphosed, comprising the volcanic rocks of the Paramaca Formation (older than 2.13 Ga and up to 2.1 Ga) overlain by flyschoid facies of the Armina Formation;
- a sand-conglomerate unit, known as the 'Upper Detrital Formation', which was laid down after 2.02 Ga in the 'North Guiana Trough'.

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The Paleoproterozoic also contains granitic and metamorphic terrains of medium and high grade, including gneisses and amphibolites, as well as granitoid intrusions of 'Guianan' and 'Caribbean' type dated at between 2.14 and 2.09 Ga in the Régina area. The 'Guianan' granitoids are generally transformed into gneisses, which are associated with migmatites. Their compositions vary between quartz-dioritic and a granitic end-members. Among the 'Caribbean' granitoids, it is possible to distinguish disparate types of migmatitic gneiss, coarse granitoids of porphyritic affinity and two-mica granites associated with abundant pegmatites.

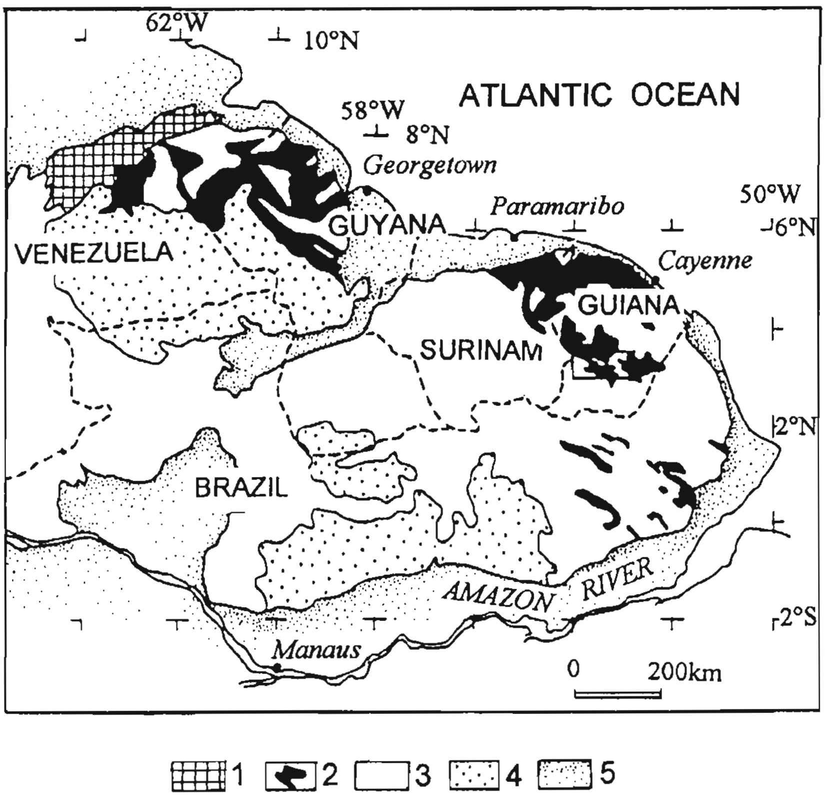

Figure 1. Geological sketch map of the Guiana shield (after Gibbs & Baron 1983, and Gruau *et al.* 1985). Legend: 1: Imataca granulitic complex; 2: Greenstone belts; 3: Paleoproterozoic granitoid and metamorphic terrains; 4: Mesoproterozoic volcanic and detrital formations; 5: Younger sediments.

The 'Montagnes Balenfois' massif is made up of metavolcanic terrains of the Paramaca Formation which are cross cut by 'Guianan' and 'Caribbean' type granites (Fig. 2). The Nouragues inselberg is composed of a tabular outcrop of 'Caribbean' granite. The table-topped hills on the other side of the Nouragues creek, situated to the south and east of the inselberg, are formed of rocks belonging to the Paramaca Formation. These volcanic rocks (lavas and pyroclastic deposits) cover a wide range of composition from basaltic to rhyolitic, and are generally metamorphosed in the greenschist facies. Sericitic schists are intercalated within the metavolcanics. However, the relative abundance and distribution of the different volcanic members remains poorly known. The observed metamorphic recrystallization is very irregularly developed and is interpreted as a contact metamorphism related to the emplacement of the granites. Some dolerite veins, accompanied by small massifs of gabbro and basalt, are seen to cut across the Paleoproterozoic basement (Fig. 2). These bodies are unaffected by any metamorphic or tectonic transformation, and their emplacement is associated with Permo-Triassic distension linked to the opening of the Atlantic Ocean.

The Nouragues inselberg is made up of a pinkish monzonitic-type granite, containing 27%K-feldspar (orthoclase) and 37% plagioclase, along with 33% quartz as coarse-grained crystals and 2% accessory minerals (pyroxene, corundum, apatite). The whole-rock chemical analysis (Sarthou 1992) shows that the granite is highly siliceous (76.4% SiO_2) and rich in alkalis (4.6% K_2O, 4.2% Na_2O). The granite has a non-negligible surface porosity as measured by water absorption, attaining 3.1% of the total rock volume in a slightly weathered sample and 7.8% in a more weathered sample (Sarthou 1992).

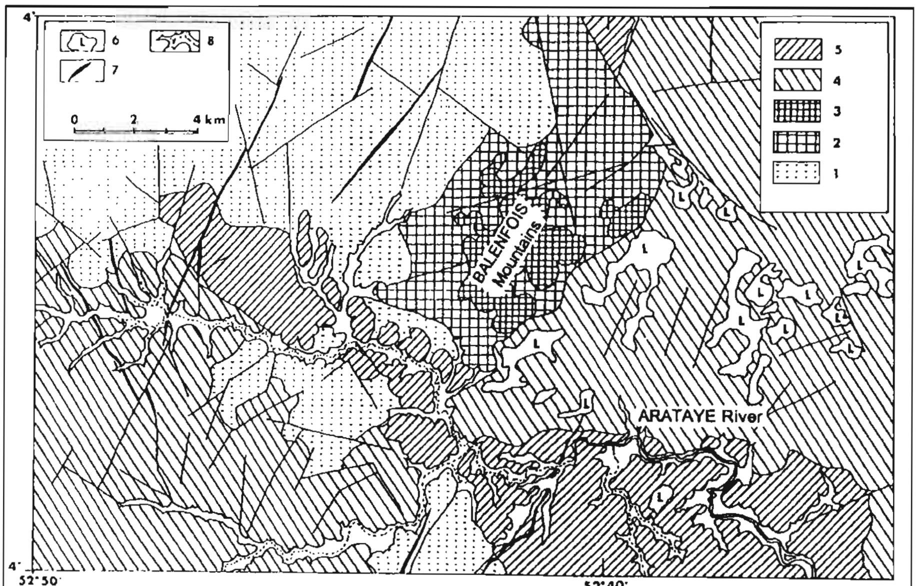

Figure 2. Geological map of the Balenfois Mountains region. Legend: 1: 'Guianan' granites; 2: 'Caribbean' migmatites; 3: 'Caribbean' granites; 4: 'Paramaca' Formation; 5: 'Ile de Cayenne' Formation; 6: Lateritic domains; 7: dolerite veins; 8: alluvial deposits.

3. Geomorphology

Although the Guiana Shield has been a stable block since 1.7 Ga, it has nevertheless been affected by slow and non-deformational uplift (epeirogenic movements). According to Bigarella and Ferreira (1985), these movements occurred in several different phases: around 100 Ma (end-Cretaceous), at 23 Ma (Oligocene/Miocene boundary) and at 2 Ma (end- Pliocene). The shield also underwent repercussions from the Andean orogeny, especially between 25 and 20 Ma, and again between 8 and 2 Ma (Bourgeois & Jeanjou 1981, Haffer 1987), thus producing the reactivation of faults, as well as the horizontal and vertical movements of certain blocks. These epeirogenic phases produced renewed episodes of erosion by lowering of the marine base level (tectono-eustatic effects). According to Bigarella and Ferreira (1985), the present-day inselbergs of the Guiana Shield began to form following the epeirogenic phase that occurred 23 Ma ago.

The Quaternary glaciations are the cause of the glacio-eustatic variations in marine base level. These climatic variations also led to changes in vegetation cover produced by alternations of moist conditions associated with expansion of the forest during interglacials, and dry conditions associated with expansion of the savanna during glacials. This alternation of climatic regimes may explain the lightly weathered accumulations of sand and gravel at the foot of the continental rise (Damuth & Fairbridge 1970, Damuth 1977, Pujos & Odin 1986), as well as the formation of inselbergs by a process of etchplanation (Twidale 1980, Sarthou 1992). This process comprises two stages:

- intense weathering under prolonged tropical humid conditions in a forest environment, forming a cover of loose weathered deposits (regolith) of variable thickness according to variations in the tectonic and textural characteristics of the parent rock.
- The weathered and decayed rock is incised and the more resistant core-massifs are dismantled by erosion during one or more phases of oscillation in base level. The relief is then enhanced by runoff which dries out the denuded rock massif and leads to a concentration of humidity around its rim. The weathering is also much less intense by runoff on a bare rock surface than beneath forest cover in gently sloping terrains.

Apart from having different elevations, the hills around the Nouragues station show quite distinct landforms according to whether the substratum is granitic or metavolcanic (Fig. 3). The average slopes for these different terrains are 32 and 11%, respectively. The hills on the south-eastern side of the Nouragues creek, which are underlain by metavolcanic rocks, and are termed plateaus due to their wide flat summits. They display convex-upward profiles on their flanks with gentle and regular slopes. By contrast, the inselberg and the surrounding granitic hills make up a terrain with many breaks of slope. A series of benches ring the inselberg to the south and east, continuing up to an elevation of 100 m above the Nouragues creek.

The inselberg is dome-shaped and elongate about an E-W axis. It lacks any forest cover on the eastern flank, where a particular type of denuded or rock-savanna vegetation is developed (Sarthou 1992, Larpin 1993). On one of the first transects studied by Sarthou (Fig. 3), the base of the inselberg is made up of two gently sloping areas that are termed terraces: the lower one, at an elevation of 80-100 m, has relics of a lateritic crust and is covered by low-canopy forest, while the higher one (at 120-200 m) is characterized by rock savanna vegetation. An abrupt break of slope separates this latter terrace from the denuded flank of the inselberg, which forms a veritable cliff rising from 200 to 320 m where rainwater runs of in deeply scoured grooves. The gradient then flattens off from 320m to the summit of the inselberg. Here, grooves are less abundant than on the cliff face, channelling the sheet wash into initial branches of the drainage network. Thenorth-eastern flank is covered with forest and is undergoing soil formation processes, while the southern flank is subject to runoff. Erosion on the rock gives rise to a chaotic pattern of domes and troughs that are several metres in size. Exfoliation and flaking of the granite have produced slabstones that appear to rest on the rock surface as well as smaller slabs with a tendency to slide.

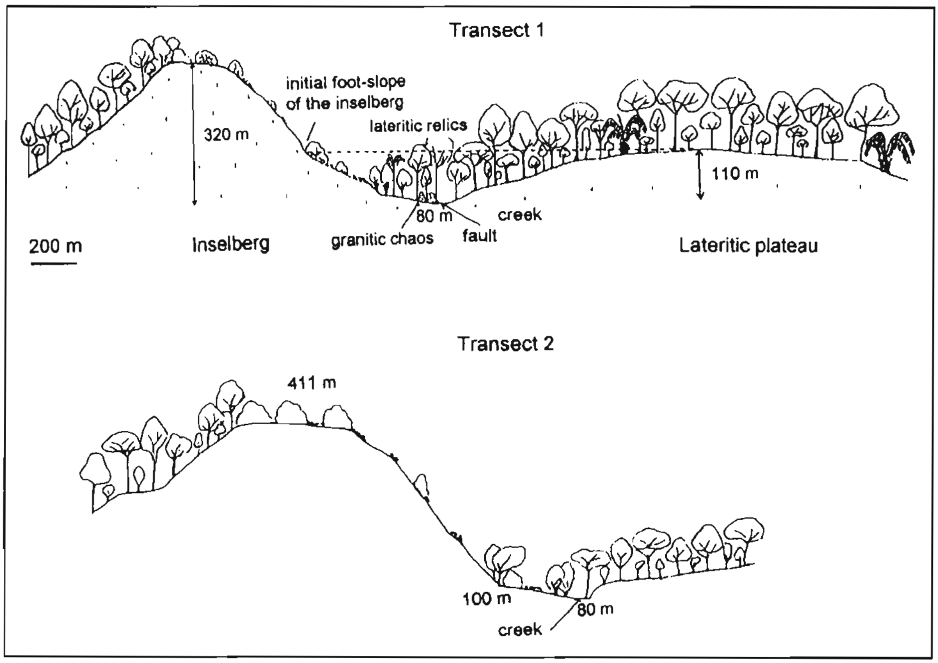

Figure 3. Topographical transects (after Sarthou 1992).

The lateritic relics developed on granite at the foot of the inselberg may represent part of an ancient weathering mantle whose surface could have attained the same level as the lateritic plateaus developed on the metavolcanics. In fact, the highest point of this plateau is at the same elevation as the second break of slope on the inselberg at the foot of the cliff (Fig. 3), thus possibly corresponding to the extent of the initial inselberg. In this way, the terrace areas would have been cleared by headward erosion. On the other hand, the upward-convex slope of the cliff would correspond to an area that had been denuded by prior erosion.

4. Pedology

The soils developed on the rocks of the Paramaca Formation are termed ferralsols; they are yellowish brown in colour under a thin litter and grade progressively into yellowish red varieties. These soils display a clayey texture (Table 1) and are very rich in ferruginous nodules a few mm to several cm in size occurring at all depths in the profile (abundances greater than 35% by weight), except at the tops of hills. Blocks of iron pan are common on the valley sides. The microaggregate structure of biological origin, which is a characteristic feature of ferralsols, is generally well developed to a depth of several metres. This structure ensures a deep vertical drainage of the soil as well as a deep penetration of tree roots. Thus,

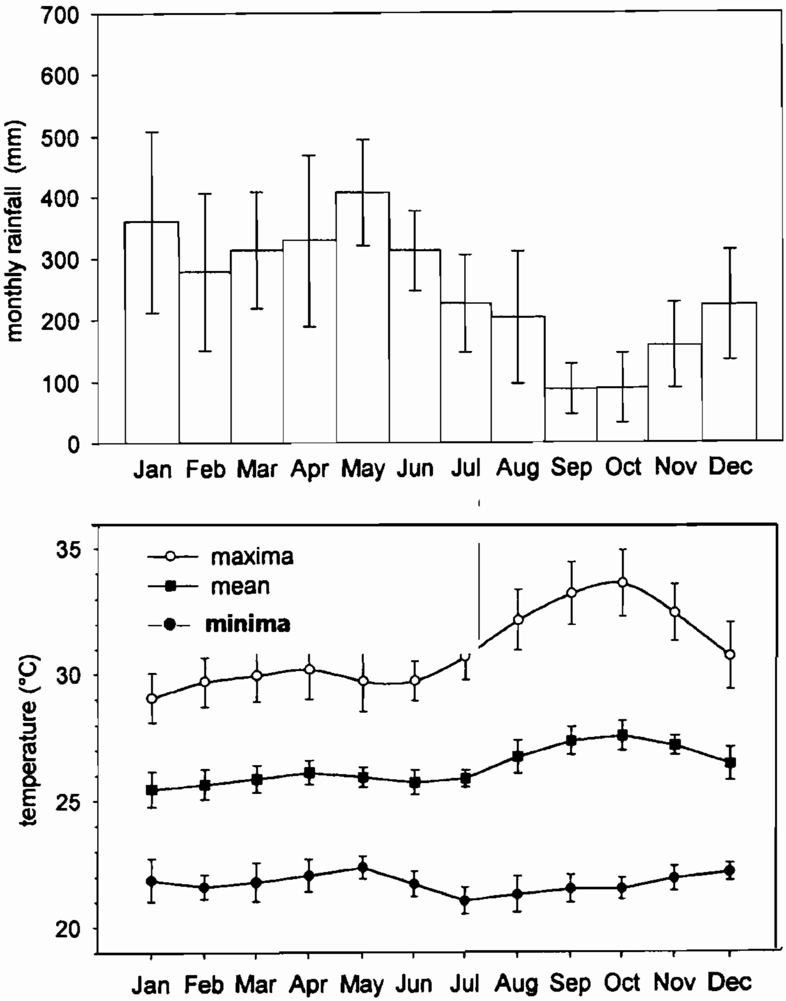

Figure 4. Mean monthly rainfall (a) and temperature (b) between 1987 and 1997 at the Nouragues station.

the trees are not subject to excess water during the wet season and can find sufficient water reserves stored in the void space between microaggregates (representing more than half the total porosity). These soils are acidic, having an average water pH of 4.5, while exhibiting a strong depletion of bases with a low cation exchange capacity varying from 15 down to 1 meq/100 g between the humic horizon and a depth of 50 cm (Table 1).

TABLE 1. Chemical and granulometrical properties of two pedological profiles at the Nouragues station.

	Depth	Water pH	CEC (a)	Gravels >2mm	Organic Mater	Clay <2μm	Fine Silt 2 - 20μm	Coarse Silt 20 – 50μm	Fine Sand 0.05 - 0.2mm	Coarse Sand 0.2 – 2mm
	cm		meq/100g	g/100g		g/100g (100 g of fine earth: < 2mm)				
Ferralsol	0 - 5	3.9	16.3	51.7	12.4	44.4	16.9	1.2	2.7	9.3
on	5 - 10	4.3	8.6	59.8	4.9	69.5	8.2	1.2	2.2	7.2
Paramaca	10 - 20	4.5	5.6	62.8	3.1	70.6	11.9	1.6	2.6	5.0
formation	20 - 30	4.8	3.7	33.7	2.2	52.3	9.2	3.5	17.1	14.6
	30 - 40	4.8	1.9	42.0	1.5	42.8	8.4	4.8	20.9	20.5
	40 - 50	5.1	1.5	38.5	0.9	37.5	11.2	7.7	27.4	14.7
	90 - 100	5.3	1.5	72.5	0.4	43.1	20.7	13.4	16.7	4.7
	140 - 150	5.3	1.5	78.9		40.5	20.0	13.8	16.7	9.0
	190 - 200	5.1	1.5	42.6	0.7	72.4	15.2	3.5	2.8	5.0
	290 - 300	5.5	1.4	43.9	0.3	46.9	14.9	6.0	8.8	22.9
Ferralsol	0 - 5	4.3	8.4	33.3	7.9	26.4	3.7	1.9	5.7	51.1
on	5 - 10	4.3	6.6	25.7	5.5	34.8	4.3	2.1	6.2	45.5
granite	10 - 20	4.1	4.7	16.5	4.1	38.5	6.0	2.9	7.1	40.7
	20 - 30	4.4	4.2	18.3	2.8	47.9	5.9	3.4	7.4	32.0
	30 - 40	4..5	3.4	17.9	2.4	49.7	6.7	4.0	8.0	28.7
	40 - 50	4.8	3.1	21.4	1.9	38.9	9.3	5.2	11.3	32.9
	90 - 100	4.6	2.4	28.1	0.6	53.4	6.7	3.2	6.7	29.2
	140 - 150	4.6	2.6	25.9	0.6	51.1	7.9	3.7	6.9	29.6

(a) Cation exchangeable capacity determined at pH 7

The soils of the granitic terrain have a highly variable thickness that shows no relation with slope or topographic position except at the summit of the inselberg. Here, a relatively gradual transition is observed between the bare rock and the forest-covered zone, with commonly organic–rich cambisols passing laterally into ferralsols. The spatial variability in soil thickness is the result of the spheroidal weathering of the granite as well as the influence of erosive episodes. The cambisols are black to dark brown in colour and are very sandy. With increasing thickness, the soil acquires a yellowish brown to intense brown coloration and a sandy clayey to clayey texture (Table 1). These soils are practically devoid of ferruginous nodules; constituents coarser than 2 mm make up 15-30% of the total soil, being composed of quartz grains and partially weathered fragments of granite. The intergranular porosity (or void space between clayey microaggregates) is high. During rain showers, there is no slowing down of percolation through the soil before the water reaches the parent rock. On steep slopes, the infiltrating water flows over the sharp boundary between soil and parent rock. In the case of gentle slopes, water stagnates within the profile and the soil becomes more or less waterlogged above the rock. At the summit of the inselberg, on gently sloping surfaces, a particular type of forest is developed on a greyish brown sandy soil of variable thickness which is saturated with water during the rainy season. To summarise, the hydric behaviour of soils on granite, particularly regarding the risk of hydric excess or deficit, is mainly dependent on the local topography and the depth to unweathered bedrock. The soils developed on granite are chemically very poor, being more acidic than soils on metavolcanics and comprising an even more strongly depleted cation exchange complex (Table 1).

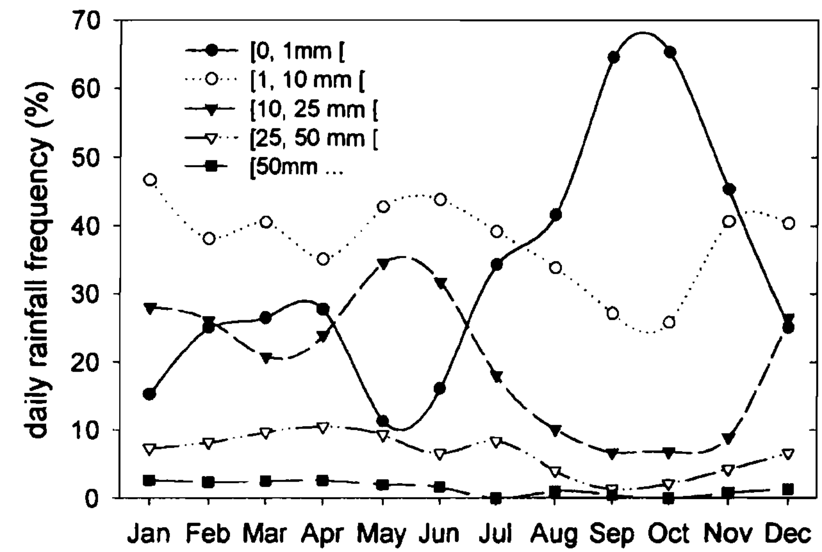

Figure 5. Monthly distribution of daily rainfall frequencies for five different rainfall classes.

5. Climate

The climate of French Guiana is of equatorial type (Boyé *et al.* 1979). Situated in the equatorial zone of the Northern Hemisphere between latitudes 2 and 5°N, this region is subject to trade winds from the Northeast and Southeast that are controlled by the Azores and Saint-Helena anticyclones, respectively. These two trade wind systems come together along a low-pressure zone known as the Inter-tropical Convergence Zone (ITCZ) which is characterized by intense cloudiness. The movements of the ITCZ depend on the relative activity of both anticyclonic systems and determine the seasons in the region. The rainy season starts in November when the ITCZ moves over French Guiana from the north, and ends in August when it moves away towards the Lesser Antilles. During the rainy season, French Guiana experiences periods of fine weather due to oscillations of the ITCZ across the region, especially when the ITCZ approaches to the Equator between February and

April; this is the little dry season, which is marked to a variable degree in different years. The main dry season is characterized by low precipitations, with local precipitation of stormy type, and sometimes there is a total absence of rain for more than a month. The annual rainfall varies widely throughout French Guiana, from 2 000 mm in the north-west (Saint Laurent) to 4 000 mm in the north-east (Kaw area). The variability between years is of the same order of magnitude, in such a way that the average values (whether monthly or annual) are only a partial reflection of the true rainfall regime.

The meteorological station at Nouragues enables the daily recording of precipitation, minimum and maximum temperatures, as well as evaporation (Picheevaporometer). The nebulosity, or amount of cloud expressed in oktats, is noted at 7h and 18h local time. Although the available series of data runs since November 1987 to December 1996, only 88 months out of a total of 110 in this period have a complete record. The least well recorded months are January and December.

On the annual rainfall map published in the Atlas of French Guiana (Boyé*et al.* 1979), the Nouragues station is located between the 3000mm and 3250mm isohyets. Over the period of records, the measured annual precipitation attains an average of 2990 mm, the total being spread over 310 days of rainfall. The nearest meteorological station, which is at Régina, has one of the highest rainfalls in French Guiana, yielding an annual average of 3940 mm between 1971 and 1990. The mean seasonal distribution of rainfall at Régina is comparable with that observed at Nouragues. The driest months at Nouragues are September and October, with a mean precipitation of 88 and 89 mm, respectively. By contrast, May is the wettest month here with a total rainfall of 407 mm.

In statistical terms, the transitions with the two main seasons take place during July and August on the one hand and November (as well as December to a lesser extent) on the other. However, it should be noted that the limits of the dry season have varied appreciably over the nine years of records, starting between mid July and late September and ending between early November and early December. The distribution of daily precipitation in 6 water-level classes over 9 years yields an average of 55 days without rain, 67 days of very low rainfall (<1 mm), 139 days of low rainfall ($1 \leq P < 10$ mm), 74 days of medium rainfall ($10 \leq P < 25$ mm), 24 days of heavy rainfall ($25 \leq P < 50$ mm) and 6 days of very heavy rainfall ($P > 50$ mm). This distribution pattern is a function of the season (Fig. 5): the frequency of days with very little or no rain (<1 mm), as well as the frequency of days with medium rainfall can be used as good discriminants of the most characteristic months in each season. These are May and June for the rainy season, and September and October for the dry season.

The mean annual temperature calculated for Nouragues is 26.3°C. The mean monthly temperature varies from 25.5°C in January to 27.5°C in October, the difference being due to an increase in the maximum temperature during the dry season (Fig. 4). On average, the daily temperature range varies from 7°C in May to 12°C in September. The absolute minimum and maximum recorded temperatures are 17.8 and 37.0°C, respectively. It is noteworthy that extreme temperatures are observed in exposed environments, especially on the bare hillslopes of the inselberg facing south (Sarthou 1992) where maximum temperatures can attain 60°C. According to aspect, the daily temperature range on the inselberg (rock savanna) can vary from 18 to 33.1°C during the dry season and from 16.1 to 20.8°C during the rainy season. Under these same conditions, the relative humidity of the air is negatively correlated with temperature (Sarthou 1992), with a minimum of 22%

during the dry season and 65% during the rainy season. The daily range in humidity varies from 61-69% during the dry season to 27-35% during the rainy season.

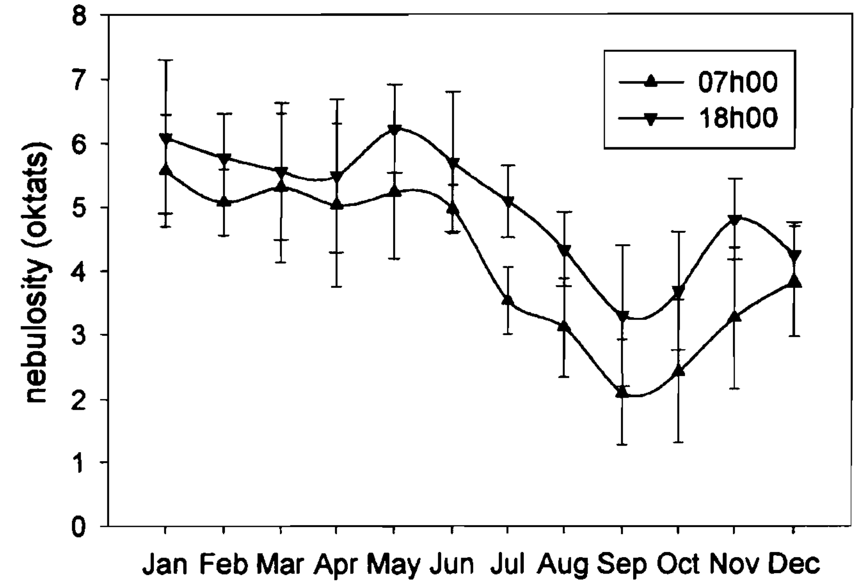

Figure 6. Mean monthly nebulosity at the Nouragues station.

Nebulosity is correlated with the amount of precipitation. Throughout the year, nebulosity is more marked at the end of the day (Fig. 6). During the rainy season, the average value is greater than 5 oktas, while the lowest values are observed in September (2.1 oktas at 7 h and 3.3 oktas at 18h).

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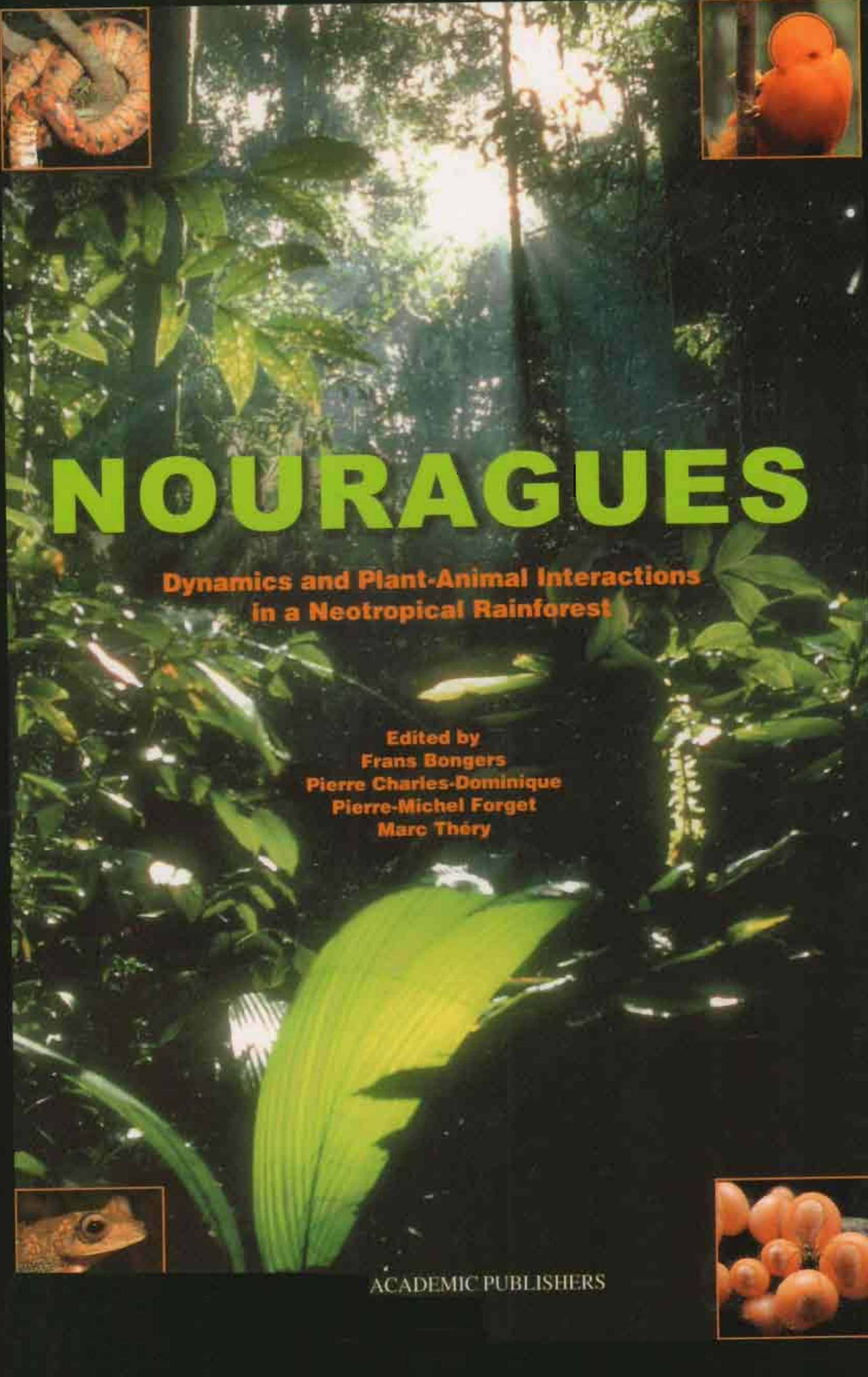

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