The Weather Pattern in one of the Oldest Forest Ecosystems on Earth – Dragon`s Blood Tree Forest (*Dracaena cinnabari*) on Firmihin – Soqotra Island

Hana Habrova, Kamil Kral, Petr Madera

Abstract

Many authors have provided information about climate of Soqotra, but this information seems to be based on individual experience from short-term stays on island or considering wider climatic characteristics from Indian Ocean or nearby mainlands. Only one consensus among all authors exists: Soqotra climate is strongly influenced by the southwest summer monsoon and the northeast winter monsoon. In this paper, we would like to contribute to the discussion with information based on data from automatic weather station placed on Firmihin plateau in Dragon`s Blood Tree forest.

The key issue of climate of Soqotra is the extreme variability of the climate caused by monsoon effect and specific topography of the island. Consequently, two sites distant just few kilometres may have completely different distribution of rainfalls and shifted vegetation seasons. Due to this fact, presented conclusions are valid mainly for south part of Soqotra.

Our team installed a weather station including an automatic data-logger at Firmihin in November 2000 at an approximate altitude of 440 m above sea level. According to our observations, the conclusion can be following:

Summer monsoon is linked with strong southwest winds (– daily means reach up to 8 m/s in July and August), clouds and rains on southern part of the island. This period usually starts between April 20th and May 10th by strong rains (often more than 50 mm per day) and increasing wind speed. Rains are more common during May and June and then at the end of September, when heavy rains may also occur (i.e. 305 mm in 26-28th September 2002). Summer monsoon usually ends between September 25th and October 15th.

After short transition period, winter monsoon linked with rains on northern part of the island starts between October 25th and November 15th. Wind blows from northeast, rains occur mainly during November and first half of December, some precipitation can fall until first half of February. Winter monsoon usually ends between February 1st and 25th. Spring transition period between winter and summer monsoon is very dry without any rains, winds are caused only by night and day differences in temperature (breeze).

Regarding the air temperature, the lowest record was 8.2 °C in 30th of January 2005 in Skant area (1450 m a.s.l.). The highest record was 43.5 °C in 10th of June 2005 in Hadibo (27 m a.s.l.). Mean annual air temperature ranges between 17.9 °C in Skant and 28.0 °C in Hadibo while mean annual air humidity ranges between 67 % in Hadibo and 87 % in Maaleh (690 m a.s.l.) thought it vary greatly through the year. Daily means of air humidity can fall down to 7-15 % at the end of transition period in April while during July and September, daily means of air humidity are usually higher than 85 % in southern part of Soqotra. On the contrary, northern part is the most humid and cloudy during winter monsoon in December and January.

Keywords: **Soqotra, climate, weather pattern**

Introduction

Few and discontinuous climatic data are available for Soqotra. Several authors tried to make some general comments about the climate of the Soqotra archipelago, newertheles, their conclusions especially about a distribution of rainfalls – a critical environmental variable of the region - were often rather discordant. One fact is certain according to all of them: The climate of the ecoregion is strongly influenced by both the southwest (summer) and northeast (winter) monsoons. However, precise timing of the monsoons as well as their impact on the distribution of rainfalls are judged differently.

Davis et al. (1994) write about the summer southwest monsoons (April-October), which bring extremely strong, hot and dry winds from Africa. Accordingly, there is little precipitation and extreme desiccation during these months. The winter monsoon begins in November and lasts until March. Similar references are made by Evans (2001); Wranik (1999) and Hunting Technical Services Ltd. (1993). According to them, Soqotra gets its main rains during the winter monsoon, while the summer monsoon winds are rather dry and stormy. A little progress in description of the climate was made by Miller et al. (2004). They still describe the summer (June-September) monsoon as hot and dry with extreme desiccating effect on the development of the vegetation. However, they suppose that at higher elevations and particularly in areas facing the southwest, the season brings drizzle and cloud. The opposite winter monsoon is described to blow from November until January.
Concerning the distribution of rainfalls, for example Popov (1957) alleges the highest precipitations in November and December, while Gwynne (1968) mentions maximum rainfalls in August and September. Mies and Beyhl (1996) place a main rainy season between August and October and a secondary rainy season in April and May, however, they incorrectly associate the secondary rainy season with the winter monsoon. Miller et al. (2004) say that most rain falls between November and January.
KOPP (1999) concluded all the inconsistent findings in a statement that an irregularity is probably the sole rule in precipitation regime of the island. He also mentioned an extreme temporal and spatial variability of the climate, which can be described only by number of climatic stations and long continuous measurement period.
One can agree with above stated extreme temporal and spatial variability of the climate, nevertheless, according to the latest more than 6 years measurements on Firmihin locality and according to the analyses of a time series of satellite based NDVI images (Kral 2004, 2005), a serious causality of the seasonal climate and rainfalls has been discovered and described.

Materials and methods

Site description

Soqotra Island (politically belonging to Republic of Yemen) is situated in the Indian Ocean between 12°19´-12°42´ N latitude and 53°18´-54°32´ E longitude and from the viewpoint of geography, it is the most eastern part of Africa. The most western point of the island, Cape Ras Sha'ab is 235 km from the Africa coast (Cape Guardafui in Somalia). Remainders of a former continental Afro-Arabian shelf probably form the island; its area is about 3600 km^2. The highest peak of Soqotra lies in Haggeher Mountains and ranges an altitude of 1540 m. The island together with smaller Abd-al-Kuri, Samha and Darsa isles forms the Soqotra Archipelago.

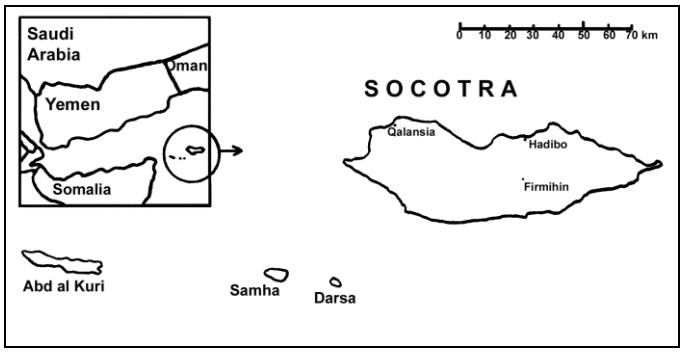

Fig. 1

The geological bedrock of the island - Haggeher mountains with the altitude of 900-1540 m a.s.l. - is formed of igneous and metamorphic rocks of pre-Cambrian age (Beydoun et al. 1970). The sea has never flooded this central mountain range. Vulcanites (basalt) border with Haggeher from south but main part of the island is covered by sedimentary rocks, mainly

limestone and sandstone. The highest part consists of grey limestone layer of Eocene and Cretaceous age, it is more than 400 m strong and reaches altitudes nearly 1000 m a.s.l. (Dixam plateau). Deep valleys divide this layer. Coastal parts of Soqotra on the north and south consist of unconsolidated sands and gravels.
From the viewpoint of natural science, the Soqotra Archipelago is one of the most interesting places in the world, which is also documented by a fact that it was declared Biosphere Reserve in 2003, added to UNESCO´s World Network of Biosphere Reserves (www.unesco.org). The unique character of Soqotra is the result of a long-term separation from the Africa continent characterized by high endemism of plant and animal species. From 825 species of vascular plants recorded and described so far 307 species belong to endemic species; 14 endemic genuses were also described (Miller et al. 2004).
According to various sources, there are 40 to 80 thousand inhabitants on the island occupying both coastal and the highest mountain parts of the island. It is evident that in the recent period, a rapid increase in the number of population occurs. The main way of the livelihood of local inhabitants is extensively practised pastoralism and to a lesser extent also fishing.

Field measurement

A weather station, including an automatic data-logger MiniCube, has been installed at Firmihin (12°28,450´N and 54°00,900´E) in November 2000 at the approximate altitude of 440 m above sea level (even before a pilot measurement had been carried out at Shibhon locality from March to October 2000). This locality represents the medium elevated sites (ca 5-10°) of the limestone plateaus in the southern part of the island, exposed to the summer monsoon.
The climate measurements were amended by four temperature/humidity sensors installed in 2004 at different places of the Island – Hadibo, 27 m a.s.l. (the capital in north part of the island), Maalah, 690 m a.s.l. (west part), Momi, 520 m a.s.l. (east part) and on Skant, 1450 m a.s.l. (mountain area). One station has been installed also in south part of Soqotra in December 2006 in Noh Sail nursery – see figure no. 2.

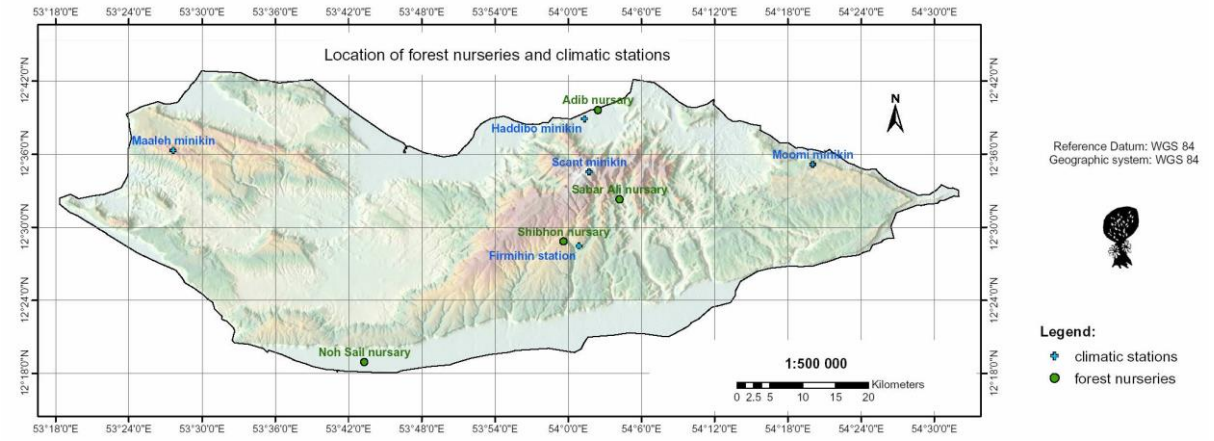

Fig. 2 – Location of weather stations on Soqotra

The Firmihin station is equipped by datalogger MiniCube (http://www.emsbrno.cz/) which is battery-supplied device for automatic data recording in demanding field applications. It is designed for easy connection of wide range of different sensors and it has the waterproof case. The datalogger has high storage capacity (220 000 values), the accuracy up to 0,01 % of full scale, measuring and averaging interval between 3 seconds to 24 hours, operating range -20 to 60 °C and memory size 512 KB.
The Firmihin station automatically recorded, the following variables at 30 min intervals: Global radiation [W.m^{-2}] (sensitivity is typically 20 mV per 1000 W.m^{-2}, calibration error under the daylight condition max. 7 %); Air temperature [°C] (accuracy ± 10 mV/°C); Wind

direction [deg] (ac. ±5 $m.s^{-1}$); Wind speed [$m.s^{-1}$] (ac. ±0.1 $m.s^{-1}$); Relative air humidity [%] (ac. ± 2%); Rainfall [mm/averaging interval] (collecting area is 320 cm^2, resolution 0.2 mm per pulse); Soil water potential [bar] in depths of 5 cm and 30 cm (measuring range -0.1 to -15 bar).

Data processing

All data from Firmihin station were merged into one file, evident mistakes were erased (e.g. experimental testing of raingauge function), untrustworthy data were not considered too.
From all measurements one-hour means were counted, from which a real daily means were counted (except of the precipitation, where sums instead of means were counted). From all available data of daily means, long-term daily means were calculated for each characteristic.

Results + Discussion

Timing of monsoons

According to our findings, the weather patter of the common year can be divided into four main seasons with different length – 5 months long summer monsoon, 4 months long winter monsoon and 2 transitional periods lasting one (autumn) respectively two (spring) months.

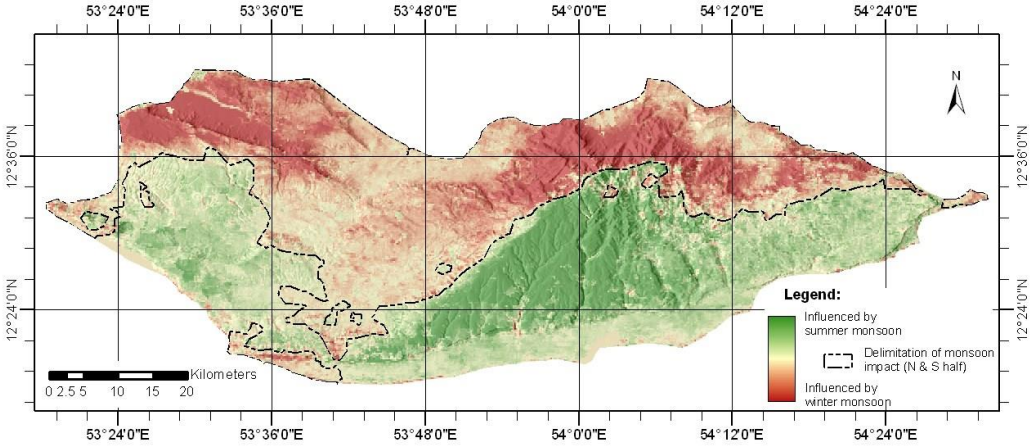

Fig. 3 – Impact of monsoons on different parts of the island

A typical summer monsoon usually starts between April 20th and May 10th. It is linked with strong southwest winds, clouds and rains on south part of the island (see fig. 3). Rains in south part of Soqotra are more common during May and June and then at the end of September, when heavy rains may also occur. Summer monsoon usually ends between September 25th and October 15th.
After short transition period, winter monsoon linked with rains and clouds on north part of the island starts between October 25th and November 15th. Wind blows from northeast, rains occur mainly during November and first half of December, some precipitation can fall until first half of February. Winter monsoon usually ends between February 1st and 25th. Spring transition period between winter and summer monsoon is very dry without any rains, winds are caused only by night and day differences in temperature (breeze).

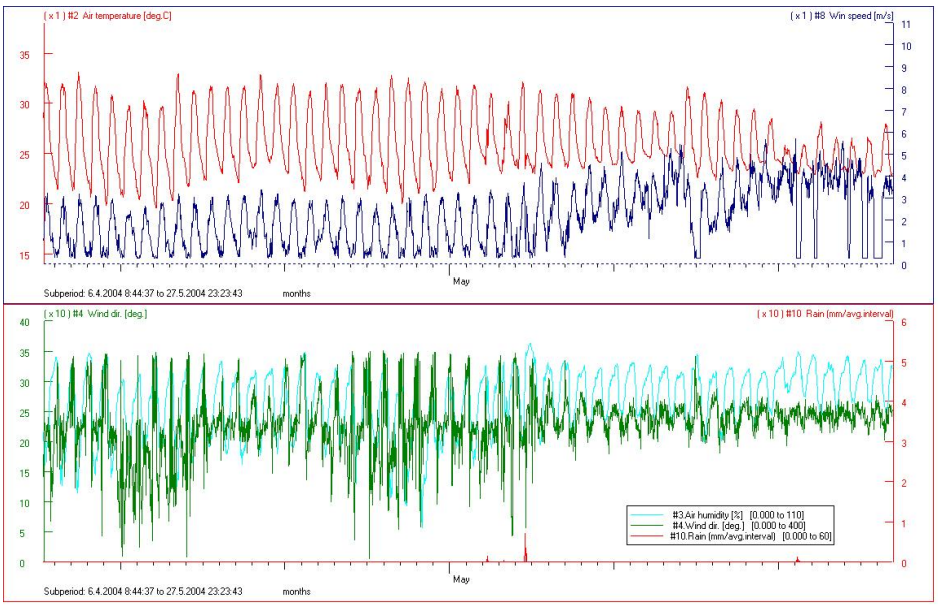

Fig. 4 - Example of start of summer monsoon in 2004

Air temperature

Annual mean temperature on Firmihin is 23,4°C, daily means ranges between 20°C in February and 29°C in May. Minimum temperature recorded on Firmihin was 14,35°C in January 23rd 2004, recorded maximum 36,26°C in May 8th 2002. Data from other stations are shown in table 1.

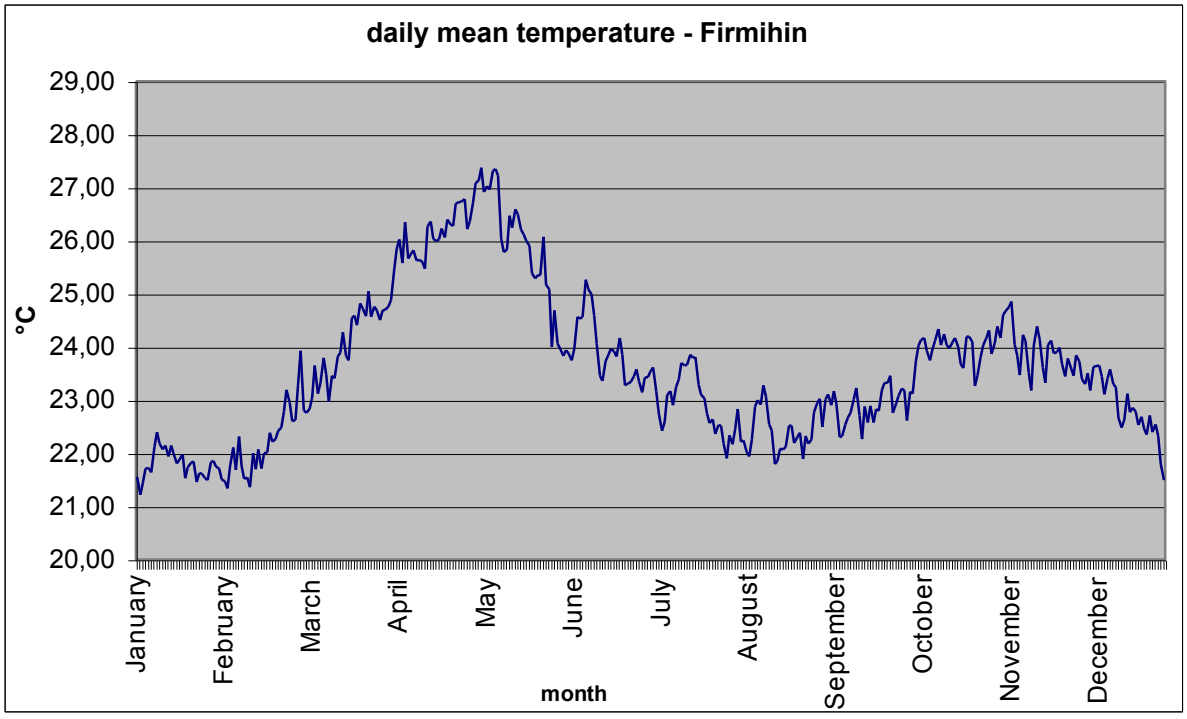

Fig. 5 – Daily means of temperature on Firmihin

The daily mean temperature reaches annual minima in January and early February at the end of winter monsoon. At Firmihin, monthly mean in January reaches 21.8°C as well as in first 10 days in February. Minimum temperature recorded on Soqotra was 8,16°C in Skant area in January 30th 2005. During spring transitional period, the mean daily temperature evenly increases from ca 22°C in mid-February up to 27°C in first decade of May, daily amplitudes oscillate around 10-11°C. Monthly means reach 21,8°C in January, 22,2°C in February, 24,2°C in March and 26°C in April.

With start of summer monsoon, daily mean temperature starts to decrease; daily amplitudes also decrease from 11-12°C in first decade of May to 1-6°C in whole period of summer monsoon. Monthly means reach 26°C in May, 23,9°C in June, 23°C in July and 22,4°C in August. At the end of summer monsoon, in late September/early October, daily amplitudes abruptly increase as well as daily mean temperatures start to grow. During autumnal transitional period, daily amplitudes of temperature ranges between 9-10°C, mean monthly temperature is 22,9°C in September and 23.9°C in October respectively. In November, mean monthly temperatures at Firmihin reaches 24°C, before decreasing - in December, mean monthly temperature reaches 22,9°C. Daily amplitudes also decreased to 5-7°C, on cloudy days to 3°C.

locality				temperature			humidity			
name	lat	lon	altitude	average	min	max	average	min	max	subperiod
Hadibo	54°01,422´	12°38,661´	27	**27,95**	18,69	**43,45**	**66,63**	16,45	100	15.6.04-2.6.06
Firmihin	54°00,900´	12°28,450´	440	23,39	14,35	36,26	71,87	7,95	100	28.11.00-6.6.06
Momi	54°19,802´	12°34,434´	520	23,45	13,32	33,43	83,64	15,45	100	30.4.04-2.6.06
Maalah	53°28,585´	12°35,459´	690	21,35	14,21	33,75	87,26	**23,83**	100	7.11.04-4.6.06
Shibhon	53°59,446´	12°29,218´	700	21,35	15,59	28,94	82,24	11,13	100	12.3.00-21.10.00
Skant	54°01,642	12°34,592	1450	**17,85**	**8,16**	31,96	80,03	**7,34**	100	21.1.05-8.11.06

Tab. 1 – Humidity and temperature characteristics from various parts of Soqotra

Relative air humidity

Annual mean relative air humidity on Firmihin is 71,87 %; daily means range between 43 % in late February and 97 % in September. During rains, daily means get on 100 %. Minimum relative humidity recorded on Firmihin was 7,95 % in April 9th 2005, minimum recorded on Soqotra 7,34 % in January 24th 2006 in Skant.

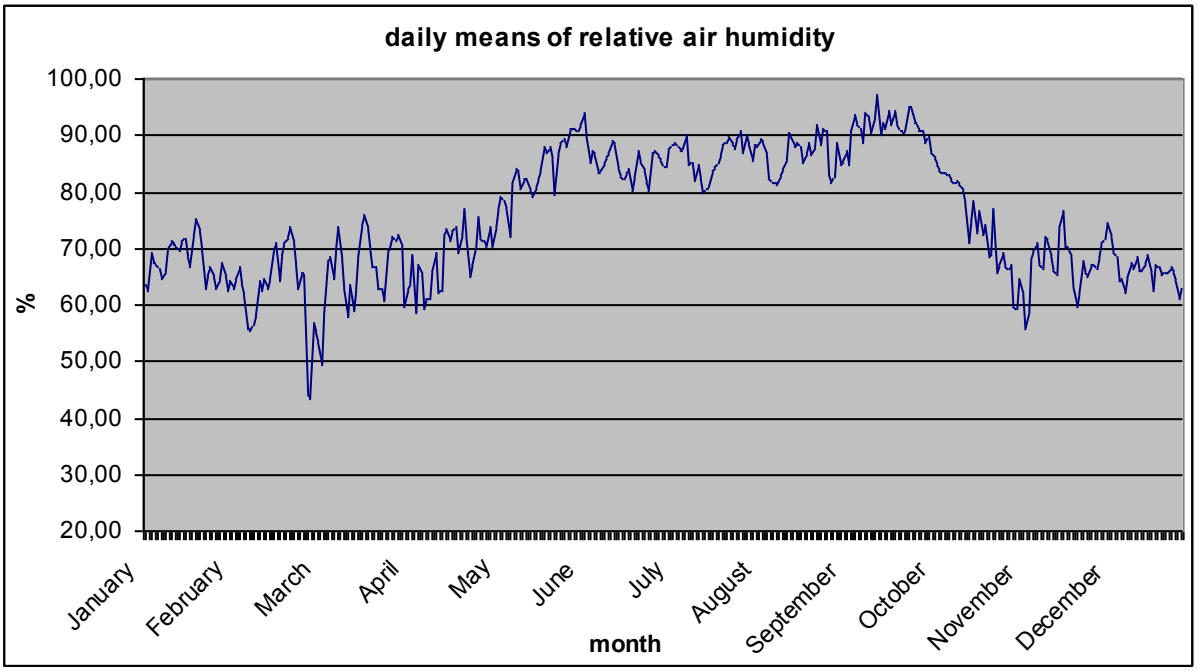

Fig. 6 – Daily means of relative air humidity on Firmihin

The daily mean air relative humidity reaches annual minima during spring transitional period in late February and early March thought sometimes falls down until the end of April. During spring transitional period, the mean daily humidity ranges between 55-73 % with wide daily amplitudes being 40-60 %. With start of summer monsoon, daily mean humidity starts to increase; daily amplitudes decrease to only 15-25 %. During summer monsoon from May to August, daily means of humidity range between 80-90 %; at the very end of the summer

monsoon, usually in second and third decade of September, mean daily relative humidity exceeds 90%.
During autumnal transitional period, daily means of relative humidity are slowly decreasing to 60-70 % while daily amplitudes are increasing to 30-50 %. With start and whole period of winter monsoon, relative humidity on Firmihin ranges between 60-75 %, daily amplitudes oscillate around 30 %. Humidity is now dependent on wind direction, increasing with east winds while decreasing sharply with winds from the north.

Precipitation and solar radiation
Rain in south part of Soqotra, where Firmihin station is placed, is linked mainly with summer south-west monsoon (for north part just opposite is the true). Start of the summer monsoon is usually linked with the decreasing average daily intensity of solar radiation as a consequence of the predominantly overcast sky, and with intensive rains. First rain falls just before ultimate change of wind direction, usually between April the 20th and May 10th. Daily totals of this first rain often exceed 10 mm and sometimes reach more than 50 mm (e.g. 52,3 mm in April 25th 2006).

month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
temperature (°C)	21,80	22,20	24,21	26,37	25,82	23,87	23,12	22,24	22,88	23,88	23,97	22,92
humidity (%)	67,6	63,3	65,4	67,8	81,8	85,9	86,2	86,6	91,3	77,9	66,3	66,7
precipitation (mm)	11,6	0	0	26,1	68,2	18,0	8,9	5,9	131,5	2,6	67,4	4,2
wind speed (m/s)	1,6	1,5	1,3	1,4	2,7	5,2	5,9	4,7	2,8	1,2	1,5	1,7

Tab. 2 – Monthly means of some characteristics from Firmihin

In summer monsoon, solar radiation is very low as the sky is overcast, some precipitations can fall during whole period. Daily totals of precipitation are low, usually oscillating around 1 mm and exceptionally exceed 10 mm. Rain probability is decreasing from half May till half of September. At the end of summer monsoon, some precipitation usually falls, sometimes reaching incredible amounts – e.g. 211,3 mm in September 27th 2004.
The highest intensity of solar radiation is during both transitional periods when no rain falls. Winter monsoon in south part of Soqotra is influenced by a rain shadow with no or less precipitation than in northern part. Mean solar radiation is of about 10 % lower than in transitional periods being influenced by sporadic cloud cover. Only very strong rain events reach these parts during November and first half of December, some precipitation can occur until the end of winter monsoon but the intensities and amounts are rather minimal.
Total amount of precipitation on Firmihin is 344 mm.

Wind speed and wind direction

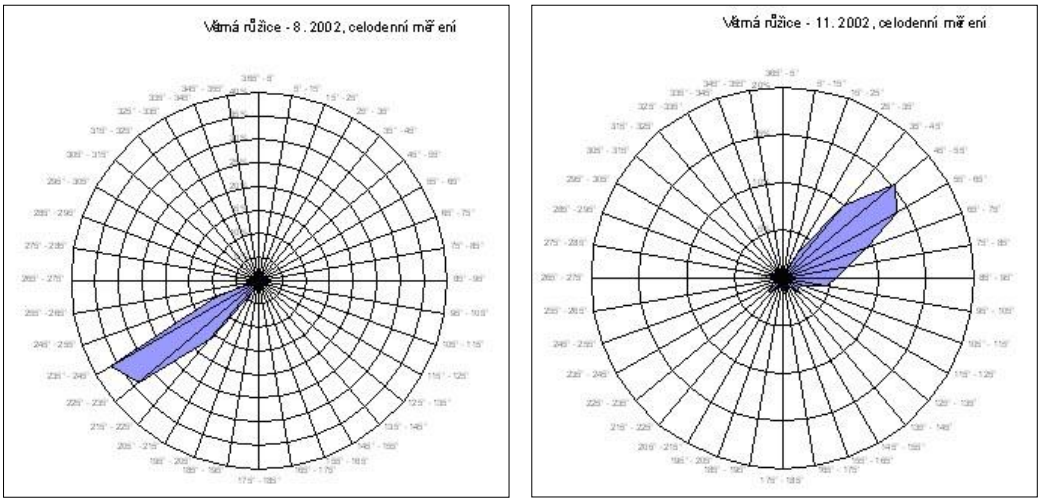

Fig. 7-8 – prevailing direction of winds during summer (left) and winter (right) monsoon (after Adolt 2001)

Wind direction is the most typical characteristics of both monsoons. During summer monsoon, winds blow strictly from south-west (ca 230-240°), typical for this monsoon is quite high wind speed. From beginning of May, daily means of wind speed are quickly increasing from ca 2 m/s up to 6,2 m/s at the beginning of July. Then the velocity of winds stays stable for ca one month with daily means between 5 and 8,5 m/s. In August, daily mean of wind speed is slowly decreasing from 5 m/s at the beginning to ca 4 m/s at the end, to 3-4 m/s in first half of September and to around 2 m/s in second half of September.
Autumn transition period is characterized by very slow winds being on its annual minima (daily mean is under 1 m/s). Winds blow from virtually all directions, being influenced partly by ending summer monsoon, partly by starting winter monsoon, but mostly by daily breeze.

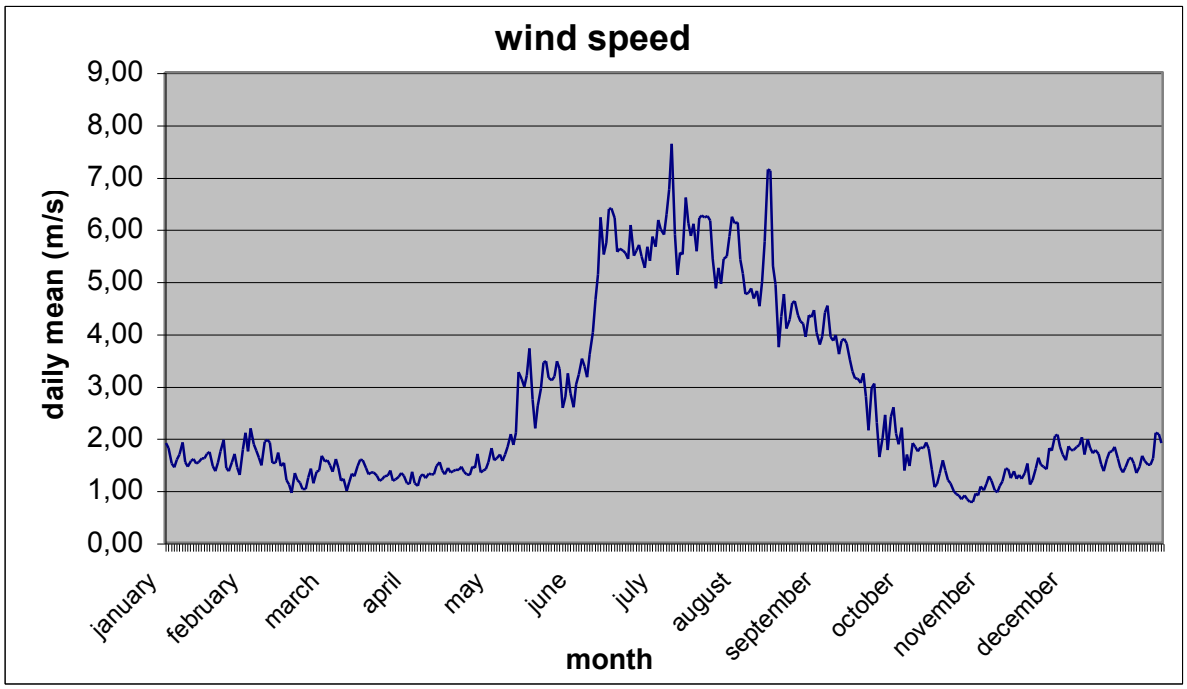

Fig. 9 – Daily means of wind speed on Firmihin in 2002

With start of winter monsoon, winds turn to north-east (around ca 55°) but because of influence of daily breeze from just opposite side, there is not only one typical direction. It is well visible when the monsoonal winds abruptly increase and daily breeze is then nullified.

Then wind direction is strictly between 45-75°. Daily means of wind speed during winter monsoon usually oscillate around 1,5-2 m/s with less often increase to more than 3 m/s.
After mid of February, a spring transition period begins. Winds shifted direction, blowing from both south-westerly and north-westerly courses, representing day and night breezes at the Firmihin station. This signalled the weakening of winter monsoon circulation. The mean daily wind speed decreased to 1-1,3 m/s.

Conclusion

As a matter of fact, all the authors describing the climate of Soqotra (e.g. Popov 1957; Davis et al. 1994; Mies et Beyhl 1996; Wranik 1999; Evans 2001; Morris 2002 and Miller et Morris 2004) may have been partly right. The key issue is just the extreme variability of the climate caused by monsoon effect and specific topography of the island. Consequently, two sites distant just few kilometres may have completely different distribution of rainfalls and shifted vegetation seasons.
On the other hand, some former statements have to be revised. For example Mies and Beyhl (1996) incorrectly associate the secondary rainy season in April and May with the winter monsoon, although in reality it refers to the beginning of the summer monsoon (rather May and the first half of June) and it causes the secondary peak of vegetation activity on the southern side of the island. Similarly, some assumptions of Gwynne (1968) were found incorrect. For example, he reported that: 'the whole island is frequently obscured by complete cloud cover during the monsoons, particularly during the period of north-east (winter) monsoon.' On contrary, according to current findings, the whole summer monsoon period and in particular August and September is the cloudiest period of the year, characterised by pertinent cloud cover over southern side of the island.
Of course, the most serious account is the misleading statement quoted more or less by all previous authors, that the winds of south-west monsoon are very dry causing desiccation to plants and animals alike and seldom bring rain. For the 'south half' of Soqotra and in particular for high limestone plateaus and Haggeher Mts. just the opposite is true.

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