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The Climatology of Namib Fog

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Abstract: Fog is an important characteristic of the western Namib Desert. Its climatological mechanisms are, however, as yet relatively poorly studied. Several different approaches present an initial picture of the temporal and spatial distribution of Namib fog. We examine the patterns that are emerging from analyses of fog records made at a network of weather stations in the Namib over a period of 35 years. Initial indications are that Namib fog appears to be complex. While the main fog at the coast is advective, the Namib interior is affected by a low stratus cloud that intercepts the land to form high fog. While the possibility of harvesting fog water is being investigated, it is becoming more pressing to gain a better understanding of the climatology of fog in order to be able to predict the spatio-temporal availability of this potential water source. Climatologists are invited to contribute towards this knowledge.

1. INTRODUCTION

Namibia is a desert country with a decreasing gradient of rainfall from NE to SW. The west coast is hyperarid Namib Desert which receives only a few millimeters of rain per year. It lies along the cold, upwelling Benguela Current of the Atlantic Ocean from where fog originates. The Central Namib Desert is essentially a flat plain with a gradual slope of 5-8 m per km up to the foot of the Great Escarpment. Despite a few isolated Inselbergs, and dunes, there are few major landscape features that would influence the macro-climate. These physical characteristics make the Namib unique among deserts of the world (Taljaard, 1979).

Fog is important in the Namib. It affects the climatic pattern of the western part of the desert (Schulze, 1969; Seely & Stuart, 1976; Lancaster *et al.*, 1984). Its precipitation is five times more that of rain and it is much more predictable than rain (Pietruszka & Seely, 1985). It is therefore not surprising that fog serves as a major water source for lichens, plants and animals that could otherwise not occur in this area (Seely, 1979; Seely *et al.*, 1998) and it may also affect geological processes (Martin, 1963; Goudie, 1972; Eckardt, 1996). Changes in fog patterns, for instance caused by El Niño events, or global climate change, could have major implications for the availability of this important source of water for the desert biota.

Measurements of Namib fog have been conducted with standard meteorological recorders at Gobabeb since its inception. A variable network of such gauges has been used over an area of 20 000 km^2. The DRFN recently conducted a project to evaluate the possibility of harvesting fog water (Mtuleni *et al.*, 1998). This project emphasised the need to understand the patterns and dynamics of Namib fog. In the current paper, we describe the various types of fog in relation to wind patterns and we present hypotheses on the dynamics of the fog types. This is done by drawing on previous literature as well as examining the initial results of our ongoing analyses.

1.1 Methods

Between 1962 and 1996, the weather station at Gobabeb used a cylindrical wire mesh screen (10 cm diameter, 22 cm height) above a rain gauge to collect fog and recorded on a chart. The autographic weather station also had an anemometer and thermohygrograph. Similar weather stations were at nine places (Lancaster *et al.*, 1984), of which four are still maintained, namely, Gobabeb, Kleinberg, Vogelfederberg (Vfb), and Ganab. In 1990-1993 these were furnished with electronic data loggers. During 1997, these were fitted with Standard Fog Collectors (Schemenauer & Cereceda, 1994) that correlate with the cylindrical collectors (r^2=0.62).

Olivier (1992, 1995) attempted to use remote sensing to study the spatial distribution. However, satellite imagery does not reveal precipitating fog in the Namib (Gut & Seely, in prep.) nor elsewhere (Gurka, 1975). Furthermore, our hourly records of fog precipitation at weather stations show that some fog events occur only at night. Satellite imagery is therefore not a good correlate of fog precipitation, but can be used to study the extent of cloud cover over the Namib.

1.2 Spatial and Seasonal Variation of Fog

Olivier (1992) showed how stratus clouds penetrate from the Atlantic up to 100 km into the Central Namib. There are indications that these clouds are associated with the upwelling cell off Walvis Bay (Shannon, 1972; Shannon *et al.*, 1989; Olivier, 1995) from which they drift inland. The frequency of stratus cloud cover declines from >100 days at the coast to <10 days at 100 km inland.

Lancaster *et al.* (1984) indicated how fog precipitation changes from the coast inland (Table 1). There was an increase in the fog day frequency and in fog precipitation from the coast to 20-60 km inland beyond which the fog declined. Highest precipitation was at two stations situated at altitudes of 340 and 500 m amsl at distances of 33 and 60 km from the coast.

Table 1: Average fog day frequency (FDF) and quantity of fog (ml) recorded with cylindrical screens at seven locations along two transects monitored for 3-15 yrs (after Lancaster *et al.*, 1984).

Place	Distance (km)	Altitude (m amsl)	Annual Fog	
			FDF	ml
Transect 1 (across gravel plains)				
Swakopmund	1	20	65	34
Vogelfdrberg	60	500	77	183
Ganab	120	1000	3	3
Transect 2 (along Kuiseb valley)				
Rooibank	18	63	76	80
Swartbank	33	340	87	183
Gobabeb	54	407	37	31
Zebra Pan	106	780	16	15

The monthly distribution of fog differs between the coastal and inland areas (Nieman *et al.*, 1978; Lancaster *et al.*, 1984). At the coast, the peak months are May-September, while inland the peak months are around August-October with a secondary peak around March.

1.3 Surface Winds

Four winds predominate in the Central Namib (Tyson & Seely, 1980; Lancaster *et al.*, 1984; Lindesay & Tyson, 1990). A SW sea-breeze (5-10 $m.s^{-1}$) occurs throughout the year with peaks in September and March. It begins at the coast during the late morning and can penetrate inland across the entire Namib by evening, typically ceasing at nightfall. The strength of the sea-breeze declines with distance from the coast. A fairly strong (10-15 $m.s^{-1}$) NW plain-mountain wind begins in the late afternoon and continues until around midnight. This wind is driven by a thermal gradient between the cool western part of the desert and the hot eastern part. This wind dominates in summer and often undercuts the sea-breeze. The counterpart of the plain-mountain wind is the moderate (5-10 $m.s^{-1}$) SE mountain-plain wind that begins at night and peaks at sunrise. This wind is driven by a reversal of the thermal gradient caused by the eastern part of the Namib cooling more rapidly under a clear sky than the coastal region and ocean. Mountain-plain wind strengthens in winter. Occasionally during winter, very strong, dry easterly berg winds (Föhn) interrupt the pattern of the other three winds.

1.4 Types of Fog

At the coast, the dominant wind direction during fog on the ground is SW, while it changes to NW at 20 km away from the coast and to NNE beyond 40 km. This reflects changes in the fog types occurring in the Namib.

It has been recognised for some time that the Namib has several kinds of fog (Taljaard, 1979; Lancaster *et al.*, 1984; Vendrig, 1990; Olivier, 1995), including advective, radiation, and frontal fog, as well as intercepted clouds or high fog. Advective fog arrives at the coast during the afternoon with the southwesterly sea breeze. This fog is usually <200 m high and occurs mainly within 15 km from the sea for >100 days annually (e.g. all 15 fog events recorded near Vlozkasbaken during August 1997 were accompanied by SW wind). On rare occasions, it can penetrate as far inland as Gobabeb. Advective fog forms when moderate southwesterly wind transports humid air from the Atlantic across the cool Benguela current. Another type is frontal fog with drizzle that can accompany cold fronts for some distance across the Namib coast, but this is a relatively infrequent phenomenon (Vendrig, 1990; pers.obs.). Occasionally radiation fog develops, most likely when clear, moist coastal air meets the cool easterly mountain-plain wind, mixes, and forms a cloud at ground level (Jackson, 1941; Nagel, 1962; Vendrig, 1990; Olivier, 1995; Eckardt, 1996; pers.obs.). In the Namib interior, the major source fog are low clouds that intercept the land, called high fog.

1.5 High Fog

High fog is a low stratus and strato-cumulus cloud that is formed by vigorous air turbulence over the Benguela current (Lancaster *et al.*, 1984; Vendrig, 1990; Olivier, 1995). The resulting cloud sheet is situated at 100-600 m height below a strong inversion layer. It is transported inland by a northwesterly wind, possibly enhanced by the plain-mountain wind. Depending on its height, the low stratus cloud may intercept the land at 20-120 km inland (and sometimes even reaches the escarpment), but its interception area is most frequently situated between 20-60 km from the coast (altitude 200-500 m amsl). Weather stations usually record this fog coming with fairly strong wind (>10 $m.s^{-1}$) from NNE (Fig. 1).

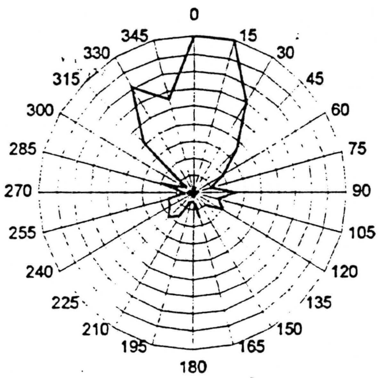

Figure 1: Wind direction during fog events at Gobabeb in 1997. Each circle marks 2 events.

The NNE fog direction is preceded by northwesterly wind, often with a SE wind between the NW and NNE. We interpret these observations as follows. Easterly mountain-plain wind rises during the late hours of the night and this cool air mass hugs the land on its way to the coast. The stratus cloud, coming from the northwest, penetrates this air mass coming from the east, while the stable inversion may prevent the cloud from rising above this layer. Mixing occurs and the resultant wind direction is NNE. This direction is oblique to the isobar from the interception point with only a slight decline in altitude as the fog progresses. The fog thus has a different direction on the ground than the higher winds that transport the cloud that feeds it.

This hypothesis is supported by records of the wind direction switching within hours from NW (plain-mountain) to SE (mountain-plain) before the weather station records fog from NNE (Fig. 2). This was also illustrated by Lancaster *et al.*, (1984; p. 25: Fig. 39 & 40) and Lindesay & Tyson (1990; p. 68: Fig.5a-top).

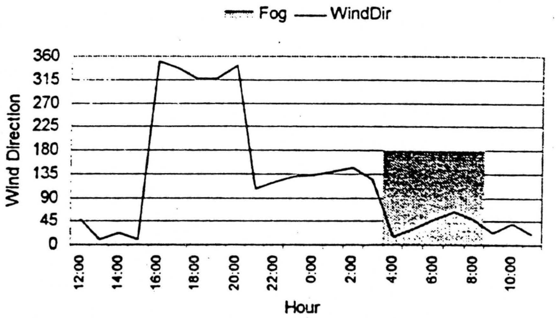

Figure 2: Time progression of wind directions recorded at Vfb prior to (clear) and during a fog event (shaded) on 17-18 April 1997.

Ongoing monitoring at the DERU weather stations confirm that this is the normal succession of wind directions (e.g., in 74% of the 65 events recorded in 8 months at Vfb in 1997, and nearly all of the events with >0.6 litres.m^{-2}). The E-SE wind intervening between the NW and NNE winds was of variable duration (0-8 h). The marine origin of the low stratus cloud that forms the interception cloud is well-established (Jackson, 1941; Lancaster *et al.*, 1984; Olivier, 1995). Its content of dimethyl sulphide, formed by marine phytoplankton, appears to reflect this (Eckardt, 1996). Furthermore, a marine origin is consistent with the appearance of this cloud on satellite images (Olivier, 1992). The occurrence of high fog is independent of advective fog at the coast and the two types of fog can simultaneously occur at different altitudes (Olivier, 1995; pers.obs.).

The observed direction of the fog is consistent with the spatial distribution of the fog precipitation. Although Vfb lies much further from the coast than Swartbank, the precipitation is similar (Table 1). The direction of line joining these two places is NNE and a fog that crosses Vfb is moving directly towards Swartbank. By contrast, Gobabeb is situated at a similar distance from the coast as Vfb, but gets much less fog. The fog isohyets cross the Namib interior in a NNE direction.

The seasonal distribution of peak periods of high fog around September and March is consistent with the association of these fog events with both plain-mountain (NW) and mountain-plain (SE) winds. Plain-mountain winds are weak in mid-winter (May-July), and mountain-plain winds weaken in mid-summer (December-February) (Lindesay & Tyson, 1990), and both wind types are well developed during the peak fog period. Furthermore, there may be seasonal variation in the development and the height of stratus clouds formed at sea. The climatic mechanisms of stratus cloud formation and transport beg study.

1.6 Conclusions and Recommendations

There are two major types of fog in the Namib, namely, the coastal advective fog and low stratus cloud that is intercepted inland, also called high fog. Although the advective fog occurs frequently, its precipitation of water is only moderate and SW wind speeds are mild. By contrast, the high fog involves the dynamic interaction of two air masses, causing an oscillation of wind directions from NW to E, and then to NNE when the fog arrives. High fog results from a low stratus cloud of 100-600 m height that moves from the Atlantic Ocean across the Namib in a NW direction until it intercepts the easterly mountain-plain wind, mixes with it and precipitates as fog. Two other minor fog types of the Namib are radiation and frontal fog.

The importance and the nature of the high fog have often been overlooked. For instance, we mistakenly oriented a network of SFC's towards NW based on the general belief that inland fog comes from this direction (Mtuleni *et al.*, 1998). We now suggest that an orientation of the SFC's to NNE (or N) would substantially increase the yield. This would increase the viability of potential fog water supply schemes at Topnaar villages. Furthermore, the knowledge that the coastal fog may differ fundamental from the inland fog studied by Mtuleni *et al.* (1998), supports the need for a separate evaluation of the potential of harvesting the coastal fog. Some previous authors may not have distinguished between the coastal and the inland fog types.

The climatology of Namib fog may not have enjoyed the attention it warrants because of the depth of understanding that has been gained in detailed studies of fog in the cross-continental South American counterpart (Schemenauer *et al.*, 1988; Cereceda & Schemenauer, 1991). The current indications are, however, that there are important differences, and that the Namib fog may be more complex than previously believed. The high fog of the Namib warrants much more detailed study than it has received to date, especially if there are intentions to tap this water source more extensively. The Desert Research Foundation of Namibia wishes to invite climatologists to improve the understanding of Namib fog.

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