# FOG OCCURRENCE AND MEASUREMENT IN NAMIBIA

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## ABSTRACT

The occurrence of fog inland from the coastal regions in Namibia is shown to be an unlikely product of advection processes alone but rather combinations of different fog forming processes. The possibility that inland fog may have its origins in coastal stratus and stratocumulus cloud is found to be likely with additional moisture being obtained from easterly sources. The fog measuring system employed in Namibia is found to be inaccurate and a possible alternative is suggested.

## Introduction

An understanding of the mechanisms responsible for the formation of fog along the coast of Namibia is of importance not only because of the influence the fog has on transport but also as it represents the predominant form of precipitation in this arid area. In this sense the inland areas that experience fog will be similarly affected with the added need for information pertaining to the formation processes and precipitable value of the fog being required due to the activities of the Desert Ecology Research Unit of Namibia (DERUN).

## Fog classification

If a cloud is enveloping the observer on the ground and the visibility is less than 1000 m the condition is known as fog, whereas if the visibility is greater than 1000 m the condition is known as mist (Nurminen, 1956; Petterssen, 1941; Pye, 1944). Fog can be further subdivided into varying categories determined by the visibility of objects at known distances from the observer. (Table 1). Fog is unlikely to occur as a homogenous cloud of equal density though, as isolated pockets of varying density will develop, suggesting that table 1 is only a general guide to fog classification.

Source: Presented Paper 1990



| Classification | Day Observation Object not visible at | Night Observation Light of 100 cp becomes obscured at |
|---|---|---|
| Dense fog | 50 m | 100 m |
| Thick fog | 200 m | 330 m |
| Medium fog | 500 m | 740 m |
| Moderate fog | 1000 m | 1340 m |
| Thin fog or mist | 5000 m | >1340 m |
| Dense haze | 10000 m | ---- |
| Light haze | 16000 m | ---- |
| Clear | >16000 m | ---- |

Table 1. The relationship between day and night visibility with fog type (Adapted from Nurminen, 1956; Meyer *et al.*, 1980).

Fog is the result of a condensation process near the earth's surface when the air is cooled below its dew-point temperature (Petterssen, 1941).

Dew-point temperature can be defined as the temperature to which air of constant pressure and water vapour content should be cooled in order to become saturated and for dew to precipitate (Preston-Whyte and Tyson, 1988). With the cooling of an air mass, however, there will be a proportional increase in the relative humidity of that air mass, suggesting that saturation will be more easily achieved (Byers, 1953). The lowering of air temperature to below the dew point temperature may be achieved in several different ways, non-adiabatic cooling which is due to air moving over cold bodies, adiabatic cooling where a localized decrease in pressure results in a cooling, or a drop in temperature due to upward movement of air on slopes, or the response to pressure gradient with air crossing the isobars (Myers,1968; Petterssen, 1941; Pye, 1944; Swinbank, 1943). Of the previous list the cooling due to non-adiabatic processes and upslope movement are by far the most important (Petterssen, 1941). The mechanism by which the cooling takes place offers a useful form for fog classification (Durst, 1940).

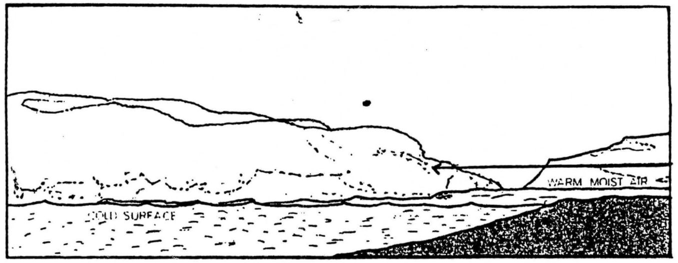


Figure 1. Advection fog (Myers, 1968).

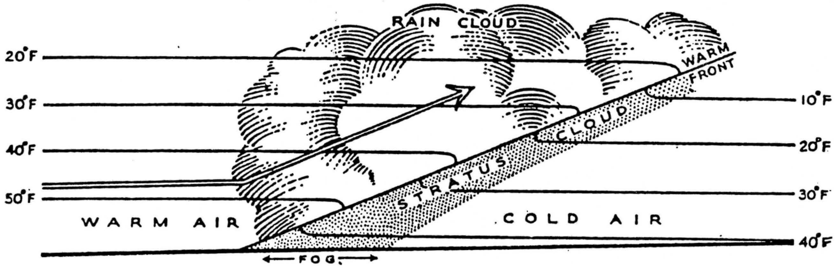


Figure 2. Frontal fog (Pye, 1944).

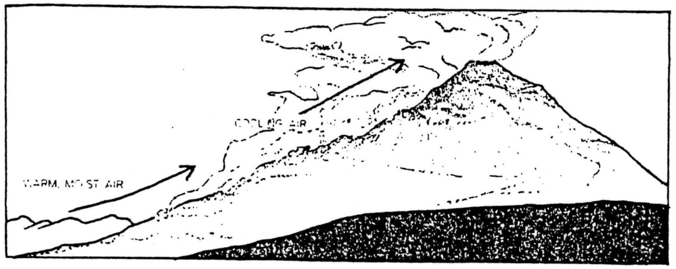

Figure 3. Radiation fog (Myers, 1968).

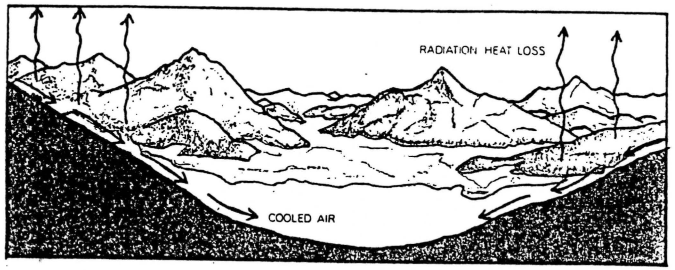


Figure 4. Upslope fog (Myers, 1968).



## Advection fog

Under advective conditions warm moist air moves over a cold surface where the rate of cooling is dependent on the difference in temperature between the air and the underlying surface and the speed of movement of the air mass over that surface (Durst, 1940; Petterssen, 1941). (Fig 1). Wind velocities greater than 10 $m.s^{-1}$ with an extreme limit of 13 $m.s^{-1}$ are unfavourable for advection fog formation as turbulence and vertical mixing result. The turbulence tends to make the air relatively drier at low levels and more moist aloft and to dilute the cooling influence near the ground (Myers, 1968; Nurminen, 1956). At the lower end of the scale, wind velocities of lower than 2 $m.s^{-1}$ tend to be too slow for advection fog formation as thermal equilibrium is reached. Thermal equilibrium tends to destroy the thermal gradient causing only a thin layer of air near the ground to become cooled hence preventing the deepening of the fog layer. From this it is evident that advection fog is most likely to occur with wind speeds between 2 $m.s^{-1}$ and 10 $m.s^{-1}$.

Due to the daily temperature cycle over the land with cooling occurring during the night period, land fogs could be caused by advective and radiative cooling. Sea fogs on the other hand, cannot be formed as a result of radiative cooling as the sea surface does not cool off sufficiently at night, and these fogs are subsequently a result of advective cooling and frontal disturbances (Durst, 1940; Petterssen, 1941; Pye, 1944). (Fig 2).

## Radiation fog

Under longwave reradiative conditions on cloudless nights, radiation fog will occur providing that a sufficient amount of water vapour is present in the air (Durst, 1940; Hensman, 1971; Swinbank, 1942a). The loss of heat from the earths surface tends to cool the layer of air directly above the surface. (Fig 3). This suggests that radiation fogs will be of limited vertical extent initially with a tendency to grow deeper with longer periods of time for development. Wind speeds are very low, less than 2 $m.s^{-1}$, with calm conditions often prevailing (Durst, 1940; Pye, 1944).

Radiation fog is purely a land phenomenon that occurs mainly over low-lying flat country and in valleys where cold air can stagnate, suggesting that the occurrence of radiation fog is influenced by local topography (Byers, 1953; Hensman, 1971; Pye, 1944; Swinbank, 1942b). In addition the areas where this form of fog occurs frequently display large daily fluctuations in temperature and are regularly inundated with moist maritime air (Petterssen, 1941). The scenario described above where the air near the surface tends to cool as the earth surface reradiates longwave radiation suggests an increase of temperature with height or an inversion. Depending on the height of the inversion layer fog can be further classified as high fog if the layer occurs considerably above the surface or ground fog if the layer occurs nearer the ground (Hensman, 1971; Pye, 1944). Radiation fog can thus be closely associated with pollution potential.

### Upslope fog

When a moist body of air moves upwards on slopes it tends to cool at a rate of 1°C per 100 m representing an adiabatic cooling and frequently results in the formation of fog (Means, 1927; Oberlander; 1956; Parsons, 1960). (Fig 4). The decrease in temperature is due to a decrease in the pressure on the air parcel (Durst, 1940). As the air mass is moving upwards a certain amount of turbulence due to the motion could be expected which if too great could inhibit the formation of the fog (Petterssen, 1941). Turbulence may also result as an effect of the unevenness of the underlying topography. To overcome this problem the air would have to be stably stratified or else convective currents would form (Petterssen, 1941).



## Physics and chemistry of fog formation

### Condensation nuclei

Condensation nuclei can be divided into three main types; combustion nuclei, sea-salt nuclei and soil materials (Kuroiwa, 1956; Wright, 1940a). These types of nuclei can be further subdivided into hygroscopic and non-hygroscopic nuclei, depending on wether or not the material enters into solution with the addition of water and changes its form upon removal of the water. If the morphology of the nuclei change they are hygroscopic and if they maintain their shape they are non-hygroscopic (Kuroiwa, 1951).

The nucleus residues most commonly occur with a size of approximately 1-2 µm with weights in the range of $10^{-14}$ to $10^{-10}$ g (Kuroiwa, 1951, Petterssen, 1941; Woodcock, 1978). The amount of hygroscopic nuclei is approximately 100 mg.$l^{-1}$ of fog water which is equivalent to about 1 part in 10 000 by weight (Petterssen, 1941). These figures may be misleading as no consideration is given to the non-hygroscopic nuclei that have been identified by Kuroiwa (1951) to make up over 50 percent of the nuclei in fog. Unfortunately the work of the previous author made use of only a small sample size and the levels of pollution were not mentioned suggesting that the 50 percent figure in itself could be misleading. As most fog is of a marine origin it is reasonable to assume that the majority of the nuclei will be in the form of sea-salt if the air is not excessively polluted. (Table 2). The salt enters the air as a result of sea spray formed during wave action on rocks, the tearing off of water from the tops of waves and the bursting of bubbles from foam along the shore (Owens, 1940; Wright, 1940b).

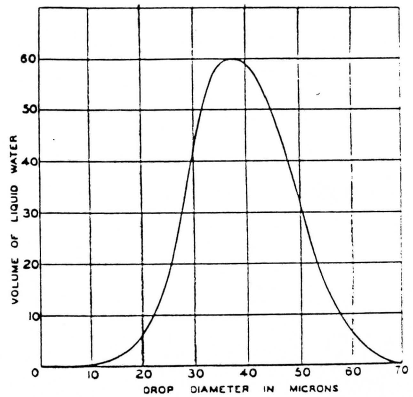


Figure 5. Fog drop size distribution (Petterssen, 1941).

| Salt | Composition by weight of 1000 parts sea water | Total weight | Chlorine content |
|---|---|---|---|
| NaCl | 27.21 | | |
| $MgCl_2$ | 3.81 | | |
| $MgSO_4$ | 1.66 | | |
| $CaSO_4$ | 1.26 | | |
| $K_2SO_4$ | 0.86 | | |
| $CaCO_3$ | 0.12 | | |
| $MgBr_2$ | 0.08 | | |
| | | 35.00 | 19.37 |

Table 2. The composition by weight of 1000 parts of sea water of normal salinity with calculation of total weight and chlorine content (Adapted from Wright, 1940a).

### Fog condensation

Once the salt is in the air it is available to act as a condensation nucleus. The speed of condensation will determine what size nuclei will be used which will in turn determine the size of the fog drop (Woodcock, 1978). This notion is supported by Petterssen (1941, p.92) who notes that

> For a given amount of water condensed the rate at which the initial condensation takes place largely determines the number of nuclei that will become active. If the rate of condensation is very slow only the larger nuclei will become active, while if the initial rate of condensation is rapid more nuclei will be required, and thus some of the smaller ones will become active.

Fog condensation is usually reasonably slow suggesting that only a small range of the available nuclei will be used. The fog is estimated to take approximately one hour to form under conditions of saturation and to reach a mean diameter of 40 µm (May, 1961; Petterssen, 1941; Woodcock, 1978). (Fig 5). If the drop were to grow to a diameter of 500-4000 µm, the average size of a rain drop it would take approximately 24 hours, indicating that the drop growth rate decreases as it increases in size and that fog drops are more likely to grow from condensation than from coalescence. It should be seen though that neither process will occur



exclusively of the other with a possibility that condensation will initiate drop formation and later growth would be by way of coalescence mainly (Petterssen, 1941; Schumann, 1940). As salt has a high affinity for water and that solutions in general have a lower saturation point than pure liquids it can be expected that condensation may occur before the air is saturated. Relative humidities of between 65 percent and 75 percent representing subsaturation, are frequently quoted as being sufficient for condensation to occur (Myers, 1968; Petterssen, 1941; Pye, 1944).

With the above background information on how fog forms it is now possible to look at the occurrence of fog in Namibia and analyze how the coastal and inland areas may receive their fog.

## Fog in Namibia

### Study area

The site from which most of the data have been derived, is the research station situated in the Kuiseb Valley at Gobabeb. The station is located 56 km west of the coastline and approximately 80 km southwest of Walvis Bay. (Fig 6). The Kuiseb valley forms a natural boundary between the gravel plains to the north and the sand dune area to the south. The Benguela current flows along the coast line to the west, whilst an escarpment of average height 1500 m forms the eastern boundary. The landscape from the escarpment to the sea is tilted gently westwards giving Gobabeb an altitude of approximately 400 m above sea level. In addition to Gobabeb, data have been obtained from Hamiltonberg and Kleinberg situated north-northwest of Gobabeb.

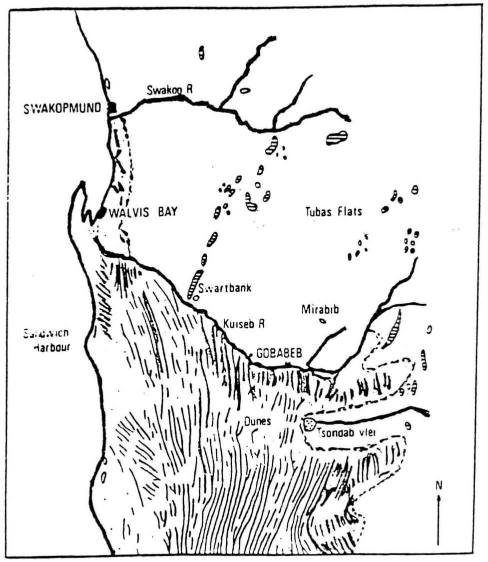


Figure 6. Location map of the Central Namib near Gobabeb (Goudie, 1972).

## Data

Data in the form of precipitation records, wind speed and direction records, temperature and humidity records have been obtained for a period extending from 1986 to the latter part of 1989 for each station. Unfortunately due to extended periods between servicing and unreliable equipment much of the data for Hamiltonberg and Kleinberg were of little use. The temporal resolution and continuity of the records for the latter two stations were considered to be too poor to be reliable and therefore minimal use was made thereof.

The emphasis of this work is therefore on the data obtained from Gobabeb, with additional information obtained from summary data in the work of Lancaster *et al.* (1984). Furthermore, work pertaining to the climate and meteorology of the Namib was considered to obtain a complete view of conditions in the area. Finally daily synoptic charts were analyzed to obtain general trends at a larger scale.

## Results of data analysis

Analysis of the records showed the maximum occurrence of fog-days (days on which fog occurred) to be in the September-October period whilst the lowest number of fog-days occurred in the period from April to June. (Fig 7). The greatest precipitable value of the fog was in the July to November period whilst the lowest occurred in the April to June period. (Fig 8).

Synoptic chart analysis was done considering the area of the Atlantic Ocean to the southwest of southern Africa, the Namibian coastal region and the land area between the coast and the escarpment. Occurrences of fog were identified and dated from the recorded data allowing for a two day period prior to and after the occurrence of fog in addition to the day of occurrence to be analyzed. Employing this technique 156 fog-days were identified over the 4 year period, resulting in the viewing of 780 synoptic charts.

Results obtained showed that in all cases of fog-days, a cold front and anticyclonic circulation were present to the southwest of southern Africa. (Fig 9). Over the coastal region a coastal low had formed on 63 percent of the days investigated, whilst a mild influence of the anticyclonic circulation was noted on 36 percent of occasions. On the remaining 1 percent of fog days cold fronts were present along the west coast region. Analysis of the land area showed that on 92 percent of fog days there was a relative reduction in the pressure over the land area of Namibia as defined above. On the remaining 8 percent of fog-days the anticyclone to the southwest had started to ridge in over the area.

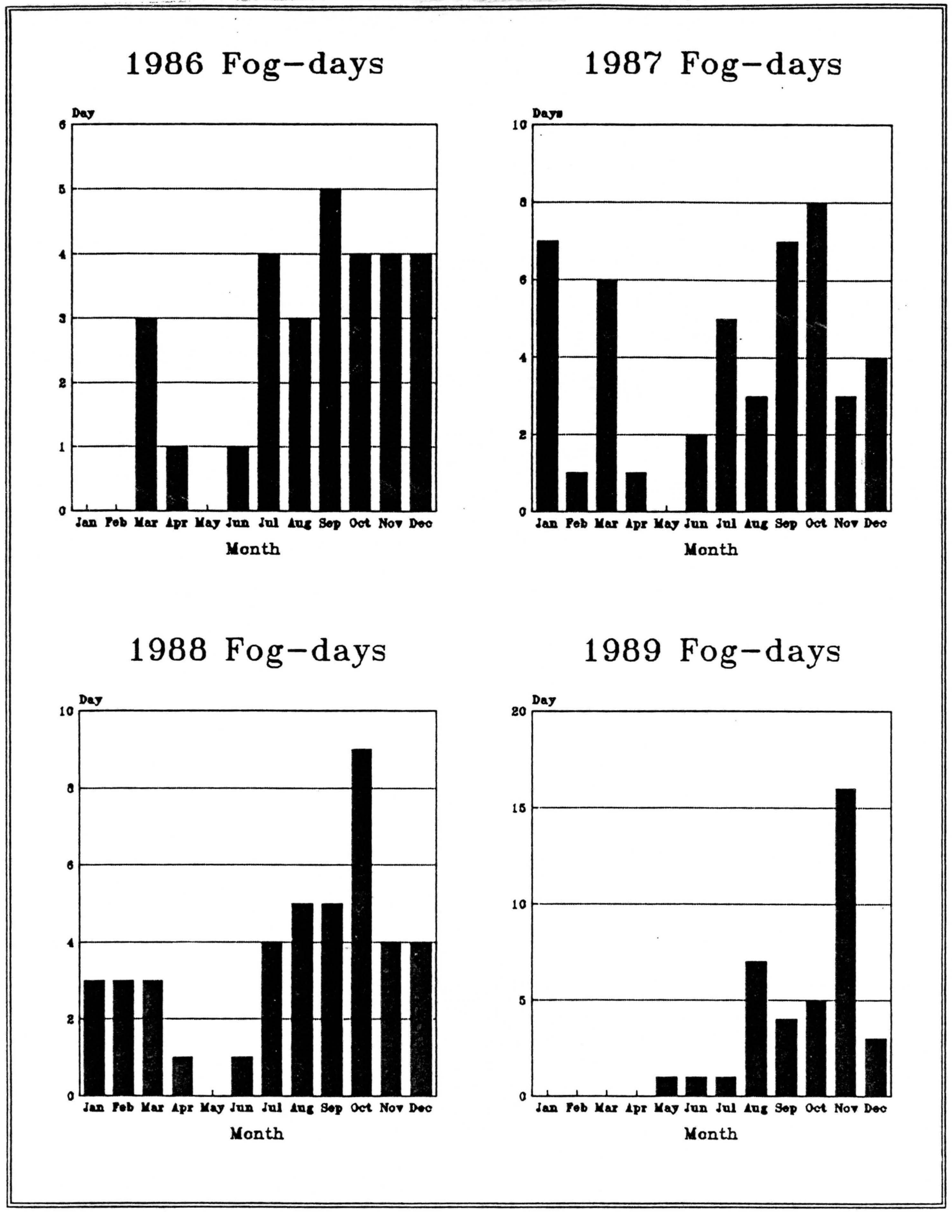


Figure 7. Graphs showing the number of fog days per month at Gobabeb.



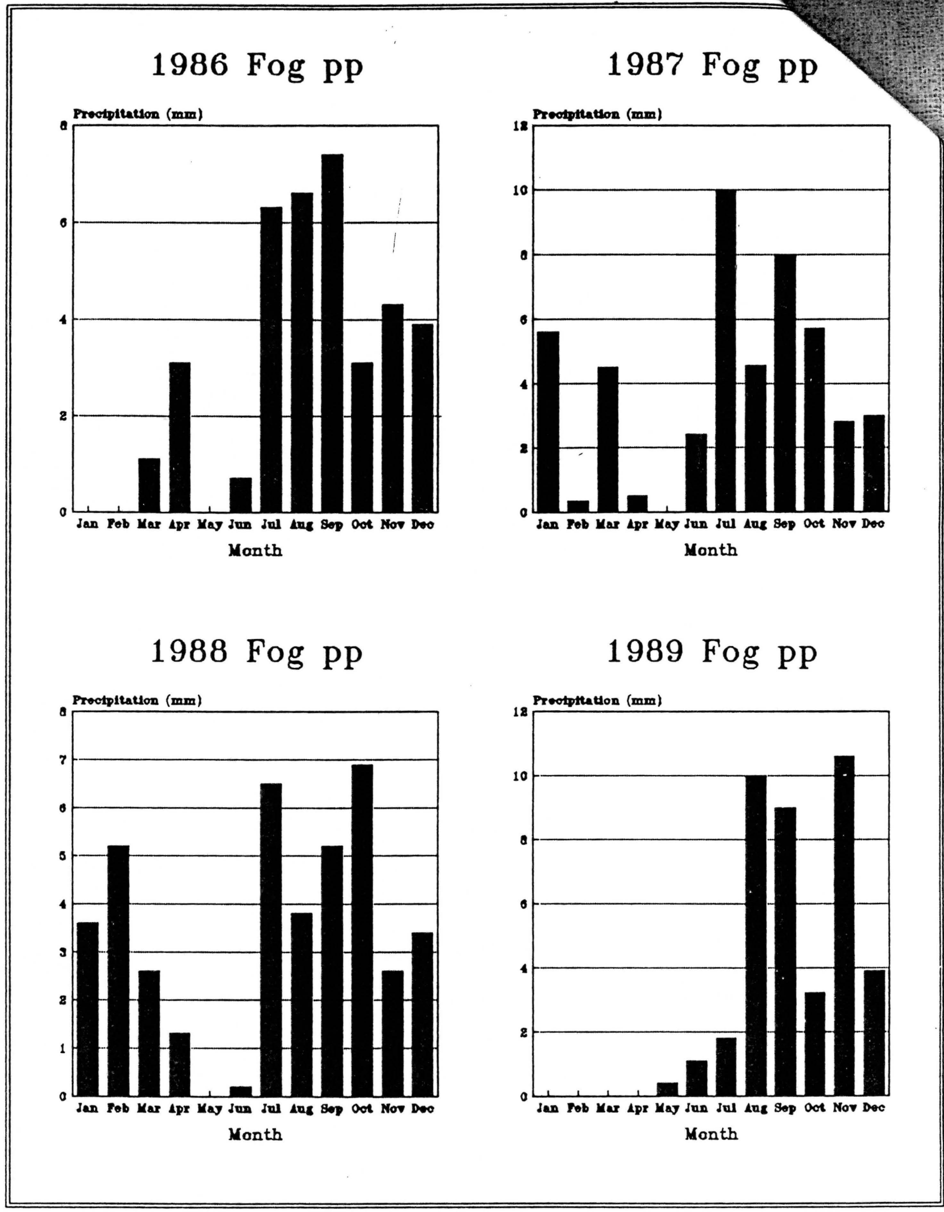


Figure 8. Graphs showing the monthly precipitation at Gobabeb.

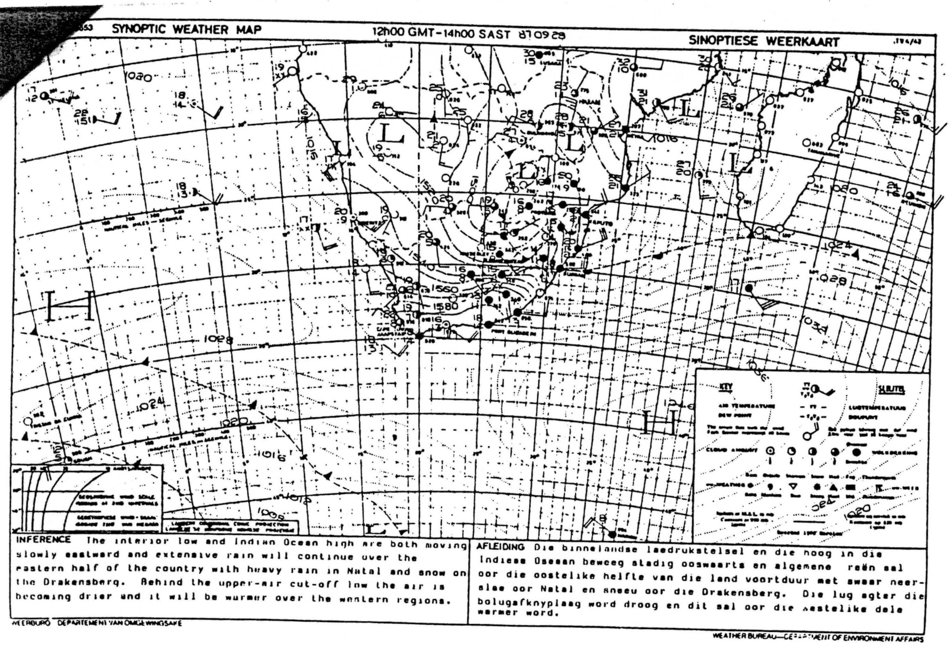


Figure 9. Synoptic chart showing the cold front and anticyclone over the ocean, a coastal low on the west coast and a relative low pressure over the land.

Analysis of the wind data for the day prior to the fog and on the day of the fog revealed the following tendencies. Most of the daytime periods are frequently characterized by south-westerly winds. (Fig 10). From approximately 16:00 on the day prior to the fog till about 20:00 the same day the wind blows from a north to north-westerly direction. Following this period from 20:00 till 06:00 the wind blows from a north to north-easterly direction. The fog precipitation on average occurred from approximately 02:00 till 06:00 which is during the period when wind tends to be north to north-easterly.

Wind speeds tended to be strong in the 16:00 to 20:00 period, followed by a slowing wind speed till about 00:00. This period of slowing is usually followed by a period of low to zero wind speed ending at about 02:00, after which the wind speeds up dramatically till about 06:00 when it tends to slow again. The period during which fog precipitation occurred was always preceded by a slowing of the wind. For the precipitation period, however, there was always a marked increase in the speed of the wind.



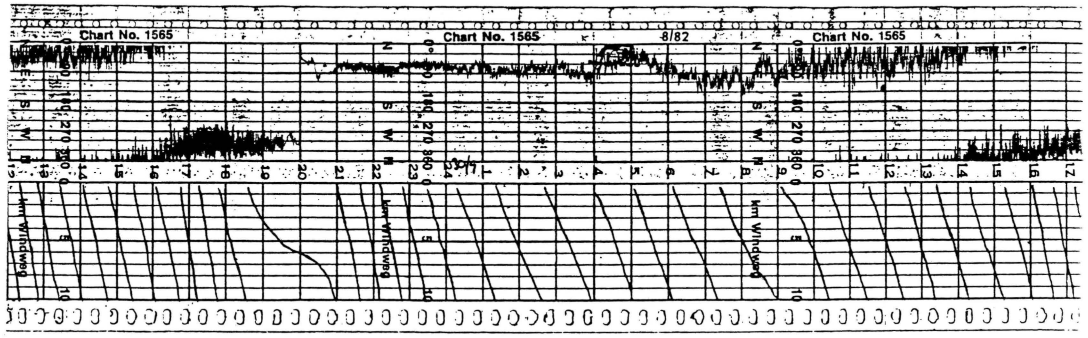


Figure 10. Record of wind speed and direction at Gobabeb during the occurrence of fog.

Temperature and relative humidity always followed a daily cycle with temperature rising from sunrise to mid-afternoon and then cooling till just before dawn. (Fig 11). When fog occurs this daily cycle is maintained but with several exaggerated periods. Temperature tends to drop rapidly from 20:00 till 00:00 often in the range of 5-10°C, followed by a period during which temperature remains almost constant till sunrise. Periods when fog does not occur generally do not show the rapid drop of temperature between 20:00 and 00:00. The fog generally occurs at temperatures below 10°C. The relative humidity tends to remain low at daytime levels below 30 percent until approximately 20:00 at which time a rapid increase in the region of 70 percent occurs to elevate relative humidities to about 95 percent. This rapid increase in humidity tends to level out at 00:00 and remain elevated till 07:00.

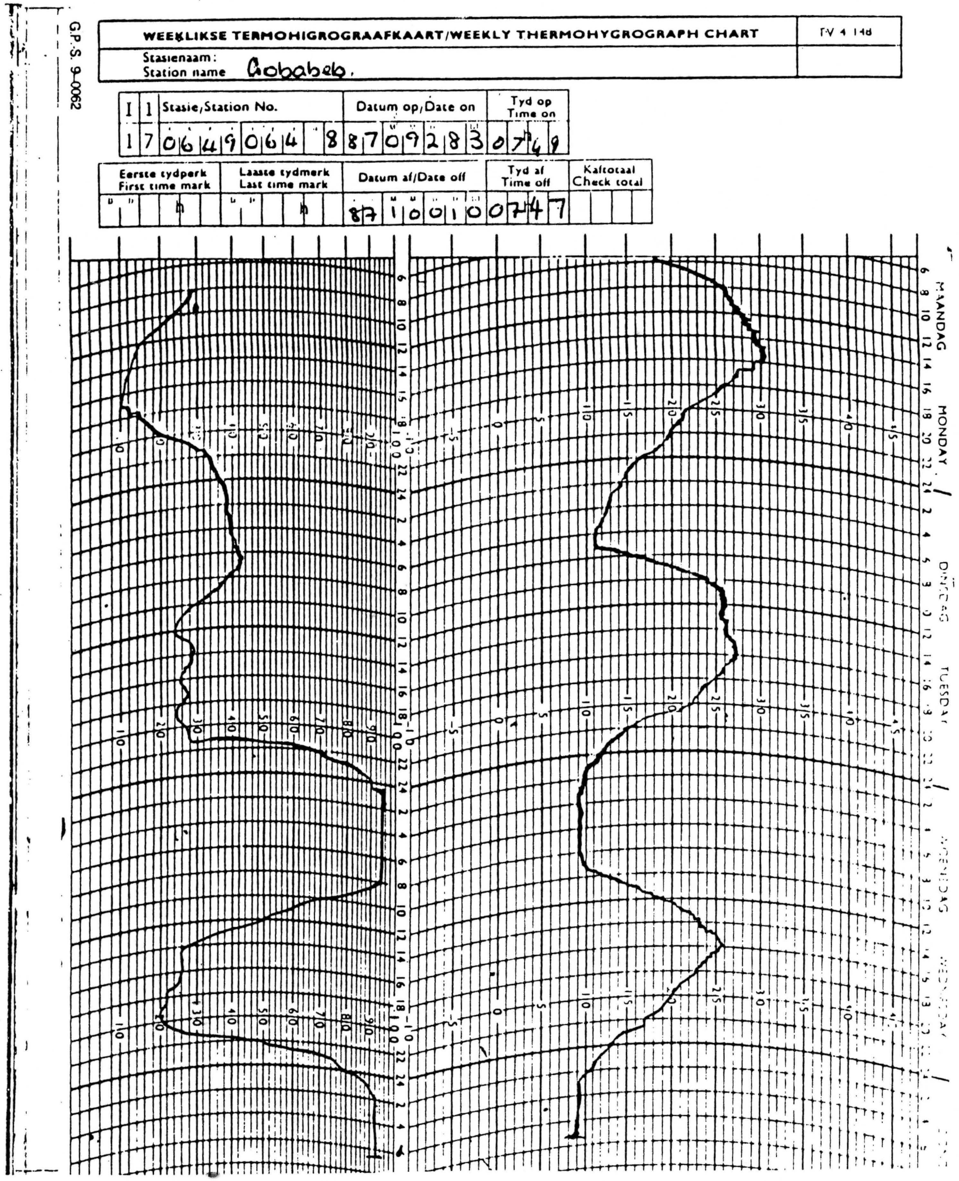


Figure 11. Temperature and relative humidity record for Gobabeb during the occurrence of fog.



## Discussion

The incidence of fog being more common in the latter part of the year is consistent with the trends identified by Lancaster *et al.* (1984). Similar results to the previous authors were also found in connection with the intensity and total precipitation of fog, with the maximum intensity occurring in July and the most precipitation occurring in the latter part of the year.

The only previous work done by looking at synoptic conditions during the occurrence of fog was done by Olivier and Stockton (1989) and there is little similarity between those results and the results presented here. The only similarity between the results is the 75.5 percent of fog-days as a result of coastal lows according to the previous authors and the 63 percent of fog-days as presented here. The difference in results may be due to the study area of Olivier and Stockton (1989) being further south at Luderitz. By virtue of the similarity in results between the different studies and the present investigation, the results obtained here are presumed to be reliable and representative of conditions occurring during fog.

With the time detailed data presented above some comparison may be possible with the theories on the different methods of fog formation. Clearly the wind conditions during the day and early evening are consistent with the requirements for advection fog but are inappropriate for this form of fog after midnight with the winds blowing from the land (northeast) during fog occurrence at Gobabeb. The conditions for radiation fog are all satisfied except for the rapid increase in wind speed at the onset of fog precipitation. The last cause for fog may be the upslope fog pattern of formation, with conditions again being satisfied excepting for the northeast wind blowing from the land. By implication then a combination of events must be occurring as no single explanation seems to account for the fog formation.

### Advection fog

Most of the work on the occurrence of fog in the Namib suggest the fog is of advective origin (Bornman *et al.*, 1973; Lancaster *et al.*, 1984; Lancaster, 1989; Olivier and Stockton, 1989). This may be true for the immediate coastal region but is not adequate to explain the occurrence of fog further inland.

The coastal regions bordering on the cold Benguela Current and the upwelling cells are ideal for formation of advective sea fogs with synoptic requirements clearly being satisfied in the form of coastal lows and ridging anticyclones (Brundrit *et al.*, 1984, Jury and Taunton-Clark, 1986; Olivier and Stockton, 1989). If the inland fogs, extending up to 110 km inland (Goudie, 1972), were of advective sea fog origin it is doubtful that the water content of the fog would be very great. Not only would the air mass over the cold ocean region loose moisture to condensation on the water surface and cooled land surface as noted by Emmons and Montgomery (1947) but moisture would in addition be lost over the land areas too, due to absorption by plants and plant material as noted by Bornman *et al.* (1973) and Tschinkel (1973). Furthermore the inland penetration of advection fog would be in direct contrast to the reported land sea breeze and is noted therefore to be an unlikely cause for inland fog formation (Lindesay and Tyson, 1990; Tyson and Seely, 1980). From the above it can be concluded that the fog moving inland may have a different origin to what is generally thought.

### Process combinations

> All the fogs cannot be attributed to the same cause, some are advection fogs, ...., some belong to a type known as "inversion fog" which may form under low clouds from which a drizzle is falling into cooler air below; and some of the winter fogs appear to be due mainly to radiation (Jackson, 1941, p.52).



The opinion of the above author seems to be consistent with the later work of Nagel (1962, p.57) who notes

> Fog precipitation from orographic fair-weather or rain clouds does not occur at places along the South West African coast only a few meters above sea level. However, precipitation from radiation and advection fogs occurs fairly frequently.

From the above it is clear that the coastal region is affected by advection fogs but as noted earlier radiation fogs cannot occur at sea. The inland areas, on the other hand do, show the large daily fluctuations and surface cooling required for the formation of radiation fogs (Nott and Savage, 1985). Furthermore the very slow winds preceding fog precipitation are ideal for radiation fog formation with the increase in wind speed (turbulence) during the precipitation being consistent with the conditions being required for a deepening of the fog layer. The northeast direction of this wind would also be fog laden if the penetration is consistent with the 110 km as suggested by Goudie (1972). The wind directions as noted above would not be consistent with the thermo-topographic winds as indicated by Lindesay and Tyson (1990) and Tyson and Seely (1980), indicating that fog is occurring in response to pressure gradients due to the relative low pressure over the land area. In addition to the above criteria it is possible that the upslope movement of the air from the north west would result in a cooling of about 3-4°C if the air mass moves from the coast all the way to Gobabeb and beyond.

The moisture in the air will be of maritime origin brought inland by the northwest and southwest winds during the earlier day period. The rapid increase in humidity may be explained by the inverse relationship between temperature and humidity and the rapid decrease in temperature of the air as noted in the data section above. The hygroscopic nuclei, as identified from aerosol studies, will be mainly in the form of sea salts and from salt encrustations inland with a proportion of sulphur and possibilities of bromine, strontium and dust particles (Annegarn, *et al.*, 1978; Annegarn *et al.*). The bimodal distribution of sulphur identified by the previous authors may be explained by the preference of fog to form on larger nuclei which would then be precipitated with the fog whilst the smaller sulphur nuclei would be moved along with the air mass movements. By implication then the larger particles will accumulate and remain in the fog areas. In addition the sulphur content in fog water would suggest that the fog would be of an acidic nature. Clearly then it is possible with the introduction of moist maritime air over the land that the fog may be forming as a result of a combination of advection, radiation and upslope processes. With the data obtained from Lancaster *et al.* (1984) for the maximum precipitation of fog being in the area of 35-60 km from the coast, it is possible to suggest that this area is common for the occurrence of advection sea fog and the fog from the combination of processes further inland. An alternative explanation of this maximum precipitation zone may be found in the analysis of the occurrence of high fog.

**High fog**

The possibility that the fog may be originating from stratus and strato-cumulus cloud is largely ignored in the literature concerning the Namib. The clouds form at a height of 150-600 m above sea level and are usually topped by a pronounced temperature inversion (Jackson, 1941; Taljaard and Schumann, 1940; Taljaard, 1979). The cloud band is formed when moist maritime air is transported upwards by turbulent mixing (Jackson, 1941). The cloud is capable of inland penetration as noted by Taljaard (1979), suggesting that the fog experienced inland may be cloud masses coming into contact with the ground. The cloud masses are most common in the spring and summer months which would be consistent with the highest occurrences of fog whilst the lowest occurrence of the cloud is in the winter period, therefore coinciding with the lowest occurrence of fog over the inland areas. In addition the heights of the cloud coincide with the area of maximum fog precipitation inland (20-70 km from the coast), which strongly suggests that the cloud masses are affecting the occurrence of fog (Lancaster *et al.*, 1984).

If the stratus and strato-cumulus clouds do not come close to the ground they will still be able to supply moisture to the lower levels by virtue of the capping inversion layer which will tend to trap moisture below it, which can be redistributed by turbulence (Swinbank, 1942). Clearly then even if the cloud is not on the ground to be recorded as a ground fog it will still tend to supply moisture to the ground level which in combination with the other processes of fog



formation may result in the occurrence of fog. The timing of this cloud penetration at night makes it likely to be an important factor in fog formation. In addition to moisture being obtained from the west there is a similar possibility that moisture may be obtained from the east, as is noted in the case of rainfall, but there is insufficient data to support this (Gamble, 1980; Sharon, 1981).

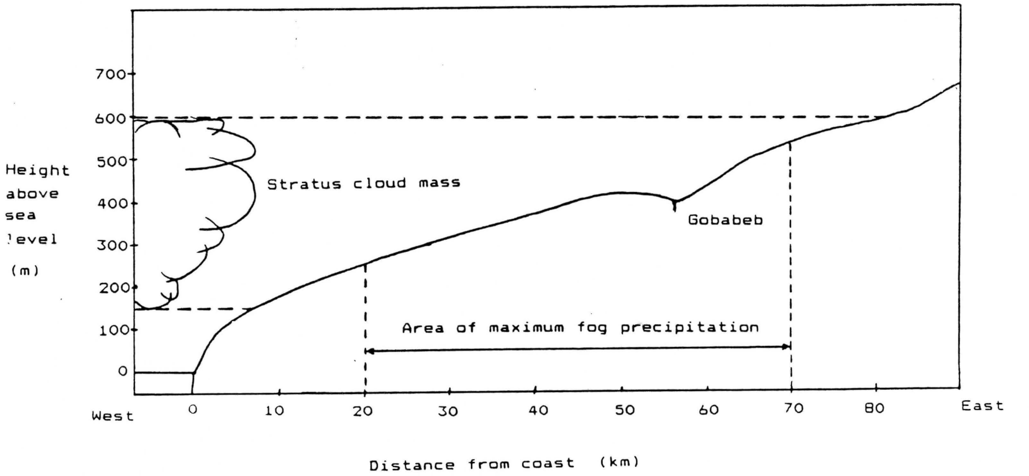


Figure 12. Cross section from the coast to 80 km inland through Gobabeb. The area of maximum fog precipitation and the area influenced by the stratus cloud masses are indicated.

To summarize the findings concerning the occurrence of inland fog the following points can be made; fog will most likely be caused by a combination of the processes of radiation fog, upslope fog and advection fog formation. Advection sea fog will be restricted to the immediate coastal areas with little inland penetration due to the occurrence of the land sea breeze. The precipitable value of the sea fog would be restricted due to condensation on cooled surfaces and the absorption of moisture by plant material therefore making inland penetration unlikely. It is probable that moisture derived from stratus cloud masses coming into contact with the ground contribute to and occasionally form fog. The altitudinal occurrence of the clouds coincides with the band of maximum fog occurrence and precipitation inland and is therefore reasoned to be a major contributor to fog formation.

## Fog measurement

As a result of the problems encountered with the records of fog measurement at Kleinberg and Hamiltonberg an analysis of the present precipitation system will be of use. Furthermore an understanding of the way in which fog behaves in the air will make it possible to identify the problems of the present system and in addition make suggestions for an improved precipitation device.

### Fall velocities

To understand how fog behaves in the air, it is essential to be aware of the forces acting on fog drops. Fog can be seen as an aerosol in which the particle diameters are small in comparison to the particle separation. If the particles were to increase in size, drops would fall as they would become too heavy for suspension. Clearly then there is an opposition between the forces of gravity (downwards) and, turbulence and Brownian motion (suspension) (Myers, 1968; Schumann, 1940; Woodcock, 1978). What is of further interest and not reported as an aid of suspension of the particles is the latent heat that is liberated when condensation takes place. The latent heat will cause 44.01 $kJ.mol^{-1}$ ($2.50 \times 10^6$ $J.kg^{-1}$ of water) to be liberated into the surrounding cool air and will cause air to have a positive buoyancy therefore imparting an upward force in the air. From this it is possible to derive a relationship between fall velocity and drop size. The velocity has been experimentally shown to be proportional to the square of the diameter of the drop (Petterssen, 1941). From the drop size distributions previously noted it is clear then, that there will be a wide range of fall velocities that always obey Stoke's law (Gunn and Kinzer, 1949).

Stoke's law

$$V = \frac{2g\,(\rho_d-\rho_a)r^2}{9\eta}$$

where V is the terminal velocity
g is the acceleration due to gravity
r is the drop radius
$\rho_d$ and $\rho_a$ are the densities of the droplet and the atmosphere respectively
$\eta$ is the viscosity of the air



From this it is then possible to calculate the velocities of fall. (Table 3).

| Diameter, μ | Velocity, $m.s^{-1}$ | Drop type |
|---|---|---|
| 5000 | 8.9 | Large raindrop |
| 1000 | 4.0 | Small raindrop |
| 500 | 2.8 | Fine rain |
| 200 | 1.5 | Drizzle |
| 100 | 0.3 | Large cloud drop |
| 50 | 0.076 | Medium cloud drop |
| 10 | 0.003 | Small cloud drop |
| 2 | 0.00012 | Small fog drop |
| 1 | 0.00004 | Fog Nuclei |

Table 3. The terminal fall velocities of different drop sizes (Adapted from Preston-Whyte and Tyson, 1988).

From the above it is clear that most of the movement of fog is in the horizontal plain, due to the wind speed during fog occurrence being far greater than fall velocity. This suggests that precipitation will occur preferentially on objects that have a large vertical dimension.

### Precipitation device development

The first recorded use of a fog precipitation device in South Africa was in 1903 by Dr. R. Marloth (Anon, 1954; Marloth, 1904; 1907). The precipitation system employed by Marloth on Table Mountain in 1903 was constructed in the following way

> .... one (rain gauge) I surmounted with a framework representing a bunch of reeds. The arrangement consisted of two rings of 5 inches diameter, which were connected by four rods of stout wire, the whole frame being one foot high. Pieces of wire netting were fixed inside the rings, and reeds were drawn through the meshes and fastened with thin wire. The frame was then inserted into the .... rain gauge (Marloth, 1904, p.405).

For fifty years there was no further use or development of fog precipitation devices in South Africa, till in 1954, when Dr. J. Grunow used a modified fog precipitator in further tests on Table Mountain. The new precipitator consisted of a "gauge screen" mounted on the top of a rain gauge (Anon, 1954). After this development no new designs appeared until 1979 when Meaden proposed the spherical or universal fog gauge and the cylindrical or chimney fog gauge (Meaden, 1979). (Fig 13). Unfortunately, however, the designs suggested by Meaden have not been adopted and hence no significant advances have been made since the introduction of the wire mesh precipitation device.

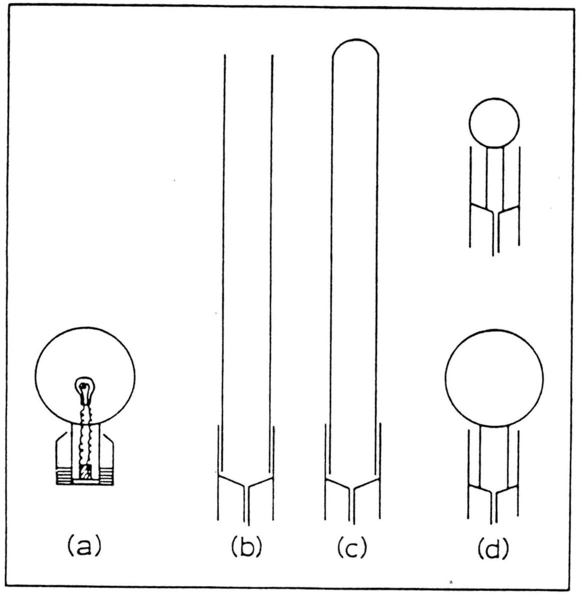


Figure 13. Various types of fog gauges. a) Universal fog gauge with heating element for use in cold climates. b and c) Variations of the chimney fog gauges. d) Universal fog gauge mounted on a rain gauge. (Meaden, 1979).



**The present system**

The wire mesh precipitation device is still widely employed as the only form of fog measurement in South Africa and in Namibia more particularly (Lancaster *et al.*, 1984). There are, however, a number of problems with the cylindrical wire mesh device which are the root cause of serious doubts about the accuracy of this system.

The wire mesh cylinder is usually constructed in such a way that the height of the mesh is twice the diameter of the cylinder and that the vertical area of the cylinder is equal to the catching area of the rain gauge (Nagel, 1956). (Fig 14). In reality, however, the surface area of the mesh is only 29 percent the area of the rain gauge catching area, due to the surface of the mesh being made primarily of open space. If wetting occurs though, the surface area becomes greatly increased due to water adhering to the mesh which therefore represents a larger surface for coalescence. The increase in surface area can potentially be in excess of the area of the rain gauge due to the spherical nature of the water drops adhering to the mesh. As a result of the variable extent of the surface area of the wire mesh system the relationship between precipitated water and unit area is meaningless.

The average drop diameter of 40 μm is far less than the space between the individual strands of the wire mesh which are approximately 1,35 mm apart suggesting that the fog drops may pass directly through the mesh. (Fig 14). By implication then, the water will not be precipitated with great efficiency, resulting in a time delay between the onset of fog and the actual recording of precipitation (Twomey, 1957). The open space nature of the mesh will also allow for the free passage of air suggesting that there may be evaporation of water that has previously been precipitated but not run off, resulting in a further delay in the recording of fog precipitation. Furthermore the open topped cylindrical shape of the wire mesh gauge will not be able to accurately record the fog which moves in a downward direction, even though it is a minor direction of motion as noted above.

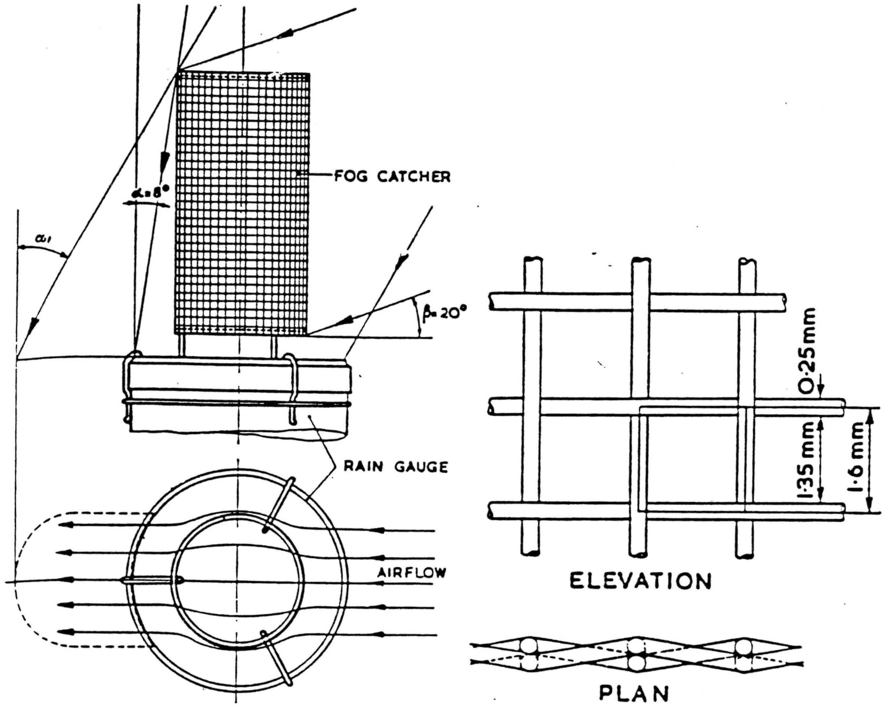


Figure 14. The wire mesh rain gauge with the angles for rainfall interference indicated. Close view of the wire gauze with dimensions added (Nagel, 1956).



A further cause for concern is the dual use of the rain gauge for fog and rain measurement in Namibia. Under conditions where wind causes the rain to fall at angle of eight degrees or more from the vertical, the fog meter will also collect rain which will tend to exaggerate rainfall amounts. There may alternatively be a decrease in the amount of rainfall if the wind speed is high, resulting in splattering of the drop on contact with the mesh. Clearly then the rain gauge cannot serve a dual purpose of fog meter and rain meter.

**New precipitation device**

A new device ("fogometer") has been designed which has several features which will overcome the problems associated with the wire mesh precipitator. The surface area is identical to the catching area of the rain gauge (323.6 $cm^2$ ±0.3 percent). The surface area does not change noticeably once precipitation has occurred due to the low wettability of the teflon surface. Water on teflon has a contact angle greater than 90°, implying that the water's cohesive forces within the droplet are stronger than the adhesive forces between the water and the teflon surface. By implication only small drops of water need accumulate to cause run off resulting in only very slight increases in surface area. The short residence time of precipitated water on the device will prevent long exposure to wind and therefore reduces the amount of evaporation.

The conical top allows for the accumulation of the water that tends to precipitate downwards but due to the low base angle of the cone, run down velocity is reduced preventing water from running across onto the supporting arms. Minute etchings above the supporting arm connections further prevent water from leaving the actual device. The lower cone has a higher base angle which tends to cause water to form drops rapidly and hence drip into the rain gauge. The drop sizes falling from the tip of the precipitation device can be further reduced by placing a pin at the tip of the lower cone though this may cause an increase in evaporation.

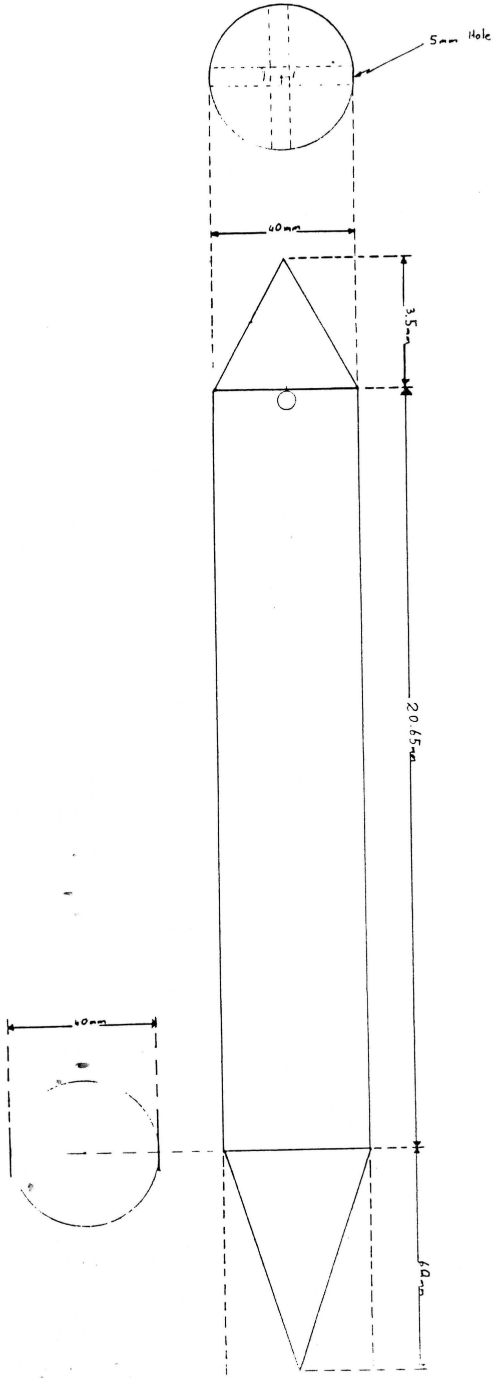


Figure 15. Diagram of new fog precipitator.



The advantage of this new device in addition to the above is the reduction in the temporal error between fog precipitation and the recording thereof, due to the rapid run off rate. Preliminary tests show an improvement of about 45 minutes for this reduction in temporal error. Clearly though the new device will still cause rainfall figures to be inaccurate if a dual function is assigned to the rain gauge.

## Conclusion

In this paper it has been argued that the advection fog process normally held responsible for fog formation in Namibia is unlikely to be the only process in operation. It is most probable that the occurrence of fog is due to a combination of advection, upslope and radiation fog processes and possibly the contact of stratus and strato-cumulus clouds with the ground at inland stations. Moisture sources for fog have been noted to be the maritime air masses from the Atlantic, stratus cloud bands and possibly moisture originating in the east over the plateau.

The design for a new precipitation device which overcomes the problems associated with a changing surface area, evaporative loss, downward fog precipitation and temporal recording errors has been proposed. The new system relies on the rapid removal of small drops to overcome these problems.

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