# ORIGIN OF THE FOG IN NAMIB DESERT IN DRY SEASON

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ABSTRACT The origin of the fog in the Namib Desert was generally considered the westerly advection fog over the Benguela cold current. When the author went to the Namib Desert in dry seasons in 2003 and 2004, the fog in the early morning, however, moved easterly from the inland to the Atlantic Ocean. It was the opposite direction of so called the sea fog. In addition to that, the fog in the Namib Desert showed the diurnal change: the fog arises in the early morning and disappeared before noon. The fog was usually driven easterly to the Atlantic Ocean. Through the climatic observation, the following were found for consideration of the origin of the fog on early August, 2004: it is not advection fog but that it is radiation fog. In the daytime, the air which is comparatively moist because of sea breeze moved to the inland, and it is solidified by radiative cooling in the night. Thus, the water vapor runs the fog and it is blown by the land wind to the westward.

Key Words: Radiation fog; Advection fog; Namib Desert; Diurnal change; Observation.

## INTRODUCTION

The Namib Desert of which width is about 140 km expands along the west of Atlantic Ocean shore in Namibia. The origin of the fog over Namib Desert is considered the advection fog by the drifting of warm westerly wind over Benguela cold current which flows from the south in the Atlantic Ocean northward.

The process of the fog around the Namib Desert is generally considered a cooling process of air being saturated with moisture from the sea. For example, Mendlesohn *et al.* (2002) describes the process in three steps: in the first phase, the cold Benguela waters cool the air to such a degree that the moisture condenses into fog and low-level clouds offshore; secondly, low desert temperatures cause moist air that has come onshore on calm nights, to condense; and, finally, air may cool sufficiently to form fog when it is pushed upwards as it moves across the Namib Desert to higher elevations.

When the observation was carried out in Swakopmund, it was confirmed, however, that the fog arises between dawn and morning as diurnal change, and the easterly wind from the inland was frequent. Sea fog arises by pressure distribution and the generation time was not constant, generally. The fog is advected in the direction to the land from the sea. The fog observed near Swakopmund did not satisfy these features, instead, they show the diurnal change. The fog arises from early morning to before noon, and the fog is advected from the inland to the seaward. The features are clearly different from what has been explained as the sea fog until now.

As a detailed summary for understanding about fog, Sawai (1982) is often referred. In this explanation, the fog was divided into six types: slope fog, mixing fog, radiation fog, advection fog, steam fog and frontal fog. In Sawai (1982), sea fog was not classified as a type of fog but it was considered as advection fog or steam fog. Zhao *et al.* (1997) analyzed the sea fog around Yellow Sea and East China Sea with atmospheric and oceanic conditions.

In Japan, Kushiro city, which is a northern city of Japan, is famous for sea fog. There are a lot of studies about sea fog at Kushiro. For example, Ueda and Yagi (1984a, 1984b), Magono (1985), Sea fog research group (1985) and Sawai (1988) observed the sea fog around Kushiro, and its distribution, movements and vertical structure in detail. They found that the prediction of the sea fog was difficult.

On the other hand, sea fog can be captured by remotely sensed images. For example, the fog in Huang Hai Sea near China was analyzed by Kikukawa *et al.* (2002) by remote sensing methods.

In Namibia, the fog in the Namib Desert was considered the important source of water for plants and animals. Lancaster *et al.* (1994) observed the fog along Kuiseb River. Barnard (1998) pointed out that vegetation in the Namib Desert effectively uses the fog water. Henschel *et al.* (1998) and Syanyengana *et al.* (2002) examined the fog water, which was collected by mesh, was usable as drinking water for people.

This paper reexamines the origin of the fog which occurs in the Namib Desert through a survey. The purpose of this research is to detect the origin and the process of the fog formed in the Namib Desert. Especially, it analyzes the origin of the fog observed around Swakopmund on the west coast in early August, 2004, and clarifies the cause of generation.

## STUDY AREA

The Namib Desert of which width is about 140 km expands along the west of Atlantic Ocean shore in Namibia. The observation of the fog was carried out near Swakopmund (Fig. 1). The climate in Swakopmund is mild throughout a year, and many tourists visit the city and many old people are spending the rest of their lives.

The mild climate is mainly produced by the Benguela cold current. Air temperature rises as it goes to inland from the seashore.

## DATA AND OBSERVATION METHOD

In this research, the climate observation was carried out from August 7 to August 10, 2004 around Swakopmund. Fog occurred, daily at dawn, for these four days in the western Namib Desert around Swakopmund and its inland. Namibian Meteorological Service carries out the weather observation and Rus-

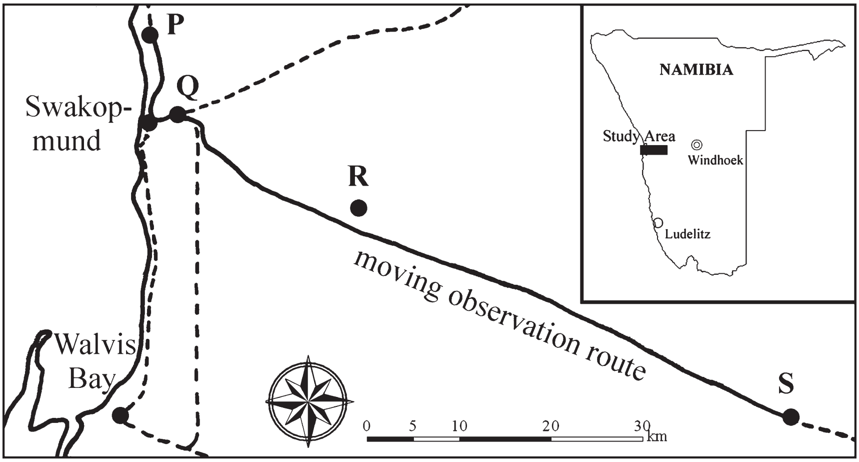


**Fig. 1.** Study area and observation points.

sian weather data center (Hydro Met Center of Russian Federation & Satellite Monitoring Technologies Department of Space Research Institute, 2005) has opened the weather data to public. There are, however, only a few observation sites along the coast in Namibia. There is no weather observation site in Swakopmund. In Walvis Bay, which is 30 km south of Swakopmund, there is a weather observation site, but no data is currently exhibited in every 6 hours. Then the weather data in Ludelitz is used. Although Ludelitz is a little far from Swakopmund, the feature of being in the Namibian western coast is common, and the data in every 6 hours in an observation period is exhibited by the Russian weather data center.

Our weather observation was carried out from August 7 to August 10 near Swakopmund. The moving observation by car is shown at Fig. 1. We observed temperature and relative humidity every 30 seconds with the thermometer and hygrometer (TR-72S by TandD Co. Ltd.).

Also we carried out the vertical observation with a kite (the Delta Conyne Spectrum by New Tech Kite Co. Ltd.), a handy GPS (the eTrex Vista by Garmin Co. Ltd.) as altimeter, and the thermometer and hygrometer (TR-72S by TandD Co. Ltd.) at the points P and R shown at Fig. 1. All observation was recorded every 30 seconds. The total weight of the GPS and the thermometer and hygrometer was about 300 g. When the wind blew over about 3 m/s, the kite and the instruments were flied. And when the strong wind blew over 10 m/s, we needed very strong power to recover down. So the vertical observation was held when the wind blew between 3 m/s and 10 m/s.

## OBSERVATION RESULTS

The fog in Swakopmund was observed every morning from August 7 to 10,

**Table 1.** Weather data at Ludelitz from August 7 to August 10, 2004 by Namibian Meteorological Agency.

| Date | Time | Wind Direction (degree) | Wind Speed (m/s) | Temperature (°C) |
|---|---|---|---|---|
| August 7 | 1:00 | 140 | 6 | 9.0 |
| | 7:00 | 160 | 2 | 6.7 |
| | 13:00 | 200 | 9 | 17.7 |
| | 19:00 | 170 | 6 | 11.0 |
| August 8 | 1:00 | 170 | 6 | 9.1 |
| | 7:00 | 110 | 3 | 6.7 |
| | 13:00 | 190 | 8 | 20.0 |
| | 19:00 | 190 | 5 | 11.8 |
| August 9 | 1:00 | 170 | 7 | 10.0 |
| | 7:00 | 100 | 1 | 8.6 |
| | 13:00 | 190 | 11 | 18.4 |
| | 19:00 | 180 | 8 | 14.5 |
| August 10 | 1:00 | 180 | 4 | 10.9 |
| | 7:00 | 70 | 1 | 8.6 |
| | 13:00 | 180 | 7 | 22.3 |
| | 19:00 | 180 | 5 | 11.9 |

: this mark is easterly breeze

2004. The fog could not be seen in Swakopmund Town along the sea shore in the morning on August 7 and 8. But the fog was found from the point Q (the junction B2-Road and C28-Road) in the inland side.

The wind data at Ludelitz from August 7 to August 10, 2004 was shown at Table 1. We also observed wind direction wind velocity which tended to be equal. Along the sea shore in Namibia, the wind at 7:00 (Namibian Local Time) was easterly every day, and the wind at other time was almost south-westerly. This is a diurnal wind change as land-sea breeze. The pressure system around Namibia was under the anticyclone area.

Our moving observation was carried out every morning for these four days. The observation course was shown in Fig. 1. The observation started at about 7:30 in the morning, and finished before noon as the fog disappeared.

The result of our moving observation of temperature from 9:27 to 10:30 on August 8, 2004 is shown in Fig. 2. Temperature is rising from the seashore toward inland. It can be classified into four zones, A to D, towards inland from near the seashore. The zone A is fluctuating in 2 °C first. Since this is near from the seashore, it is for the air current from the sea that tend to enter. Next, although the increasing rate of temperature of the zone B is small, temperature is rising gradually. A possible account is that a wind is weak and cooled down air during the night, as well as fog that occured in down, are still remaining. The rapid increase of temperature is seen at the zone C. This is because the hot and dry air mass from the inland pushes the fog to westward. In the zone D of the inland side, the temperature is reaching the ceiling. This is because

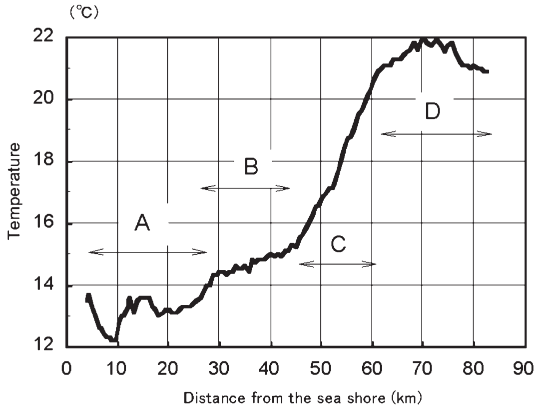


**Fig. 2.** Temperature distribution from the sea shore into the inland (from 9:27 to 10:30, August 8, 2004). A: The zone where the influence from the Atlantic Ocean is large. B: The zone where temperature rises loose. C: The zone where temperature rises rapid. D: The zone where the influence from the inland is large.

the air mass in this area is hardly influenced by the Atlantic Ocean. The boundary of the B zone and the C zone moves to east and west by time, but other boundaries do not move so much.

Although moving observation showed that air mass along the shore is cold and wet, and the air mass in inland is warm and superficially dry, in order to know the vertical distribution at point R (S22° 42’ 24”, E14° 36’ 11”) located in B zone, observation using the kite was performed. Vertical observation of temperature and humidity was performed in the morning and the afternoon of the same day (August 8, 2004), and the difference in air mass was investigated by water vapor in the air. This is done under consideration that relative humidity changes with temperature. Therefore, by setting the amount of moisture in 1 $m^3$ air mass as an index, we can explain the difference of air mass. The characteristics of the air mass in the morning and in the afternoon are different as this observation result was shown in Fig. 3. That is, air mass in the morning was wet and dry air mass had covered this area in the afternoon.

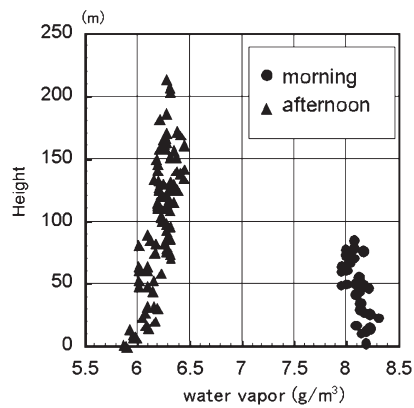


**Fig. 3.** The vertical distribution of the absolute humidity by the observation using a kite.
(S22° 42’ 24”, E14° 36’ 11”, Altitude: 90 m)
Morning: 8:26–8:50, August 8, 2004.
Afternoon: 12:05–13:00, August 8, 2004.

Thus, the origin of the fog in the Namib Desert was found in Fig. 3. In daytime, the wet air mass flows from seashore into inland about 60 km. After dawn, the radiative cooling occurs in the calm wind, and the water vapor is solidified. Since there are few amounts of water vapor, fog does not occur, but fog is washed away from east to west by easterly wind. Then, the sun rises in the morning, temperature rises from inland by sunshine, dry warm air reaches to near the seashore, and fog disappears.

## TIME CHANGE AND VERTICAL STRUCTURE OF AIR MASS

When the amount of water vapor is an index of the air mass, the air mass of the inside of fog is different from that of the upper layer of the fog, and the misty upper end forms the small-scale front. And the upper air mass over fog is the almost same air mass as that of the inland where fog has not been generated.

## A RELATION BETWEEN WIND DIRECTION AND WIND VELOCITY

Easterly wind was blowing in the morning when fog had occurred in the western coast in Namibia. This is considered land breeze in diurnal cycle. Moreover, the westerly or southern-westerly wind was blowing in daytime and it is thought that the water vapor from the sea had entered inner land by this wind. The wind direction and velocity in Table 1 suggests the distance that the water vapor from the sea runs into 60 km from the seashore, and this result has proven our moving observation.

## WATER VAPOR ORIGIN AND ITS DIURNAL MOVING MECHANIZM IN THE NAMIB DESERT

As shown by the foregoing paragraph, when fog occurred in the Namib Desert in dry season, it turned out that not a sea breeze but land breeze is blowing. Moreover, it turned out that the sea breeze is blowing the daytime when fog has not occurred. Taking this fact into account, a hypothetical model is shown in Fig. 4. That is, the water vapor conveyed by the sea breeze to inland at daytime solidifies the fog in Namib Desert by radiative cooling at night, and radiation fog generates in inland. At this time, the distance into which the sea breeze which contains moisture at daytime can enter to inland is considered to be 60 km from the seashore. Simultaneously, it is washed away more into the direction to the Atlantic Ocean by the easterly land breeze because the radiation fog was formed by strong radiative cooling at night in desert. Under this mechanism, since temperature rises gradually as the sun rises, fog disappears and moves in the direction of the seashore. And in the daytime, sea breeze blows again and it will be the origin of the fog next day.

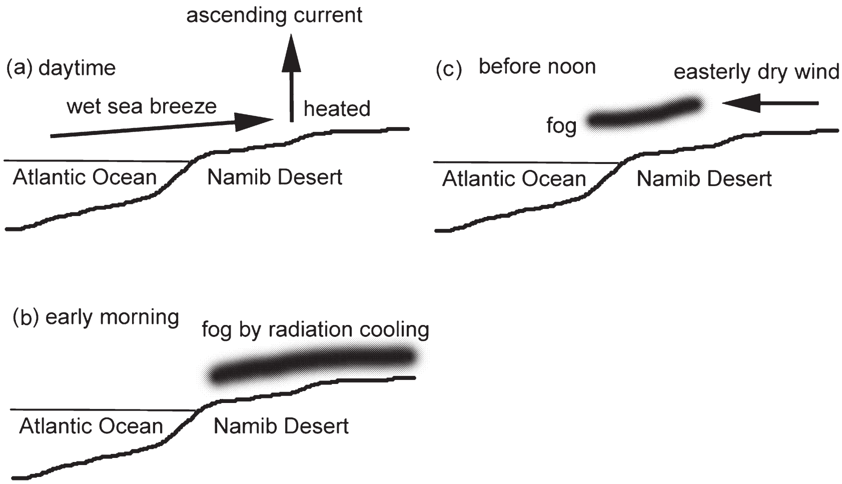


**Fig. 4.** The fog generating model in the Atlantic coast of Namibia in dry season.
(a) Daytime: The sun heated desert and the ascending current arises. The wet sea breeze flows from the west.
(b) Early morning: The radiative cooling occurs over the desert, the water vapor condenses, and then, the radiative fog occurs.
(c) Before noon: The dry land breeze blows from east, and the fog moves westward. The temperature over the inland arises.

## CONCLUSION

The conventional understanding of the fog around the Namib Desert is that it is advection fog which is brought about by the warm westerly wind over the Benguela cold current from south to north. The wind direction and velocity data by the Namibia weather office, our moving observation of temperature and relative humidity by car, and our vertical observation, however, showed that the diurnal fog in dry season in the Namib Desert was radiation fog. Our observation is the result of being based on a field survey in the only dry season of Namibia, and the fog at other seasons has not been considered. Further observation to clarify the mechanism of the fog in Namib Desert at other seasons is required.

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