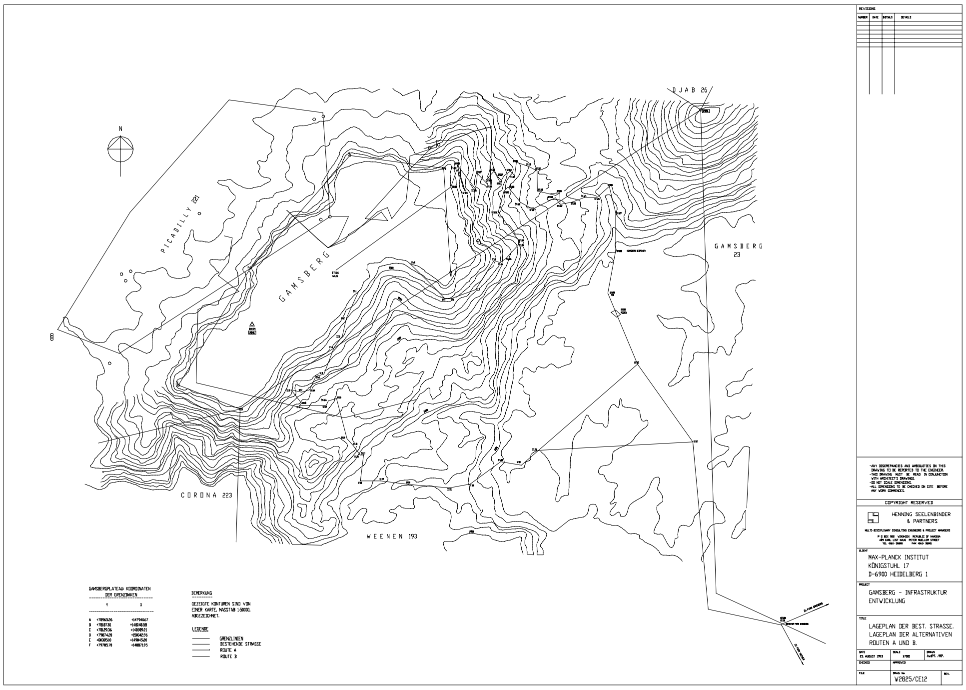

Technical note on Gamsberg Namibian site [1]

Part II: I.R Quality

M. Sarazin, August 3, 1994

[1] Contour level map of the Gamsberg table mountain ([Seelenbinder 93]. As a reference scale, note that the secondary summit at the upper-right corner is the size of Paranal Telescope Area.

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1 Introduction

Part I of the Gamsberg study (April 24, 1994) dealt with the general climatology and described a set of proposed measurements, in particular a study of water vapor content from upper-air soundings, which is developed here. The data base was purchased from the Met Office Defence Services in Bracknell, UK. It consists of 15600 ascents above South America from Lima (WMO 84628), Antofagasta (WMO 85442) and Quintero (WMO 85543) and of 6000 ascents above South-West Africa from Windhoek (WMO 68110/68112) over a nine years period from 1985 to 1993.

The levels are mixed of standards levels, significant temperatures and significant winds. The elements are pressure, geopotential height, temperature, relative humidity, wind direction and speed.

It is shown first that water vapor computed from the Antofagasta ascents (integrating from the altitude of Paranal upwards) is well correlated with in situ measurements obtained with a radiometer monitoring sky emissivity.

Results of cloud free flights above Windhoek (launching site at 180 km North-East of Gamsberg) are then compared to those above Antofagasta (launching site at 150 km North of Paranal) to estimate an upper limit of precipitable water vapor increase from Paranal to Gamsberg.

It is also shown that cloudiness above Gamsberg is well correlated with rain statistics in the area.

2 Calibration of the method: comparison of Antofagasta Upper-Air soundings with Paranal in situ radiometric data

2.1 Paranal Water Vapor Monitor

Bi-hourly measurements of sky emissivity are taken at night from Paranal summit with an I.R. radiometer developed at Tucson (USA) for the NOAO/NNTT site evaluation campaign [Morse 82]. A description of the instrument can be found in [Vlt 90], an excerpt of which follows:

With the sky-radiance monitors, the intensity of the sky radiation is measured in four bands. These bands are centered on 11.1, 14.9, 20.0 and 26.7 micrometre, respectively. The corresponding bandwidths are 0.8, 1.8, 3.6 and 9.0 micrometre.

One of the four measurement bands (11.1 micrometre) is placed in a wavelength region where the atmosphere is very transparent. Thus, in this band, we obtain a measure of sky transparency. Another of the measurement bands (14.9 micrometre) is centered on the fundamental band of CO2, which is highly saturated. With this band, a measure is obtained of the local atmospheric temperature. At the same time, the internal temperature of the monitor is recorded for all sky measurements. Finally, the two principal measurement bands, at 20.0 and 26.7 micrometre, are located in wavelength regions characterized by heavy absorption by water vapor.

In addition to measurements through the passbands described, a series of measures made with a water vapor monitor always includes those made with the light beam blocked. Further, all measurements are made in the form of the recording of the difference in flux between the radiation from the sky and that from an internal reference source. This reference source is a blackbody surface contained in the monitor. With a pyroelectric detector, measurements are made using a chopper, alternating between sky signal and reference signal. The monitor receives sky light over an aperture corresponding to 0.03 steradian. Finally, for all measurement *series, the temperature of the internal blackbody reference is recorded.*

The data reduction is made at Lund Observatory on contract with ESO [Ardeberg 87b] converting emissivity into Water Vapor with a method confirmed by several cross-checks measurements in particular with radiowaves [Schulz 90].

The available data set in computer format consists of 2490 records taken from 0h to 10h UT between June 1992 and December 1993. ESO uses currently three such monitors. The data have been corrected from instrumental factor deduced from regular LN_2 calibration of each monitor as well as from sporadic intercomparison campaign [Lundstrom 94]. The Paranal data set was obtained with monitor #2. Monitor #3 has been sent to Gamsberg for the forthcoming site evaluation campaign (July-August 94) after several weeks of intercomparison with monitor #2 at Paranal.

2.2 Antofagasta Upper-Air subset

Balloons are launched from Antofagasta Airport at 12 h UT each day. 530 of them were successful between June 92 and December 93. After computation of water vapor, only 275 of them fulfilled the following arbitrary conditions for validity (set-up after observing the characteristics of the flights delivering unphysical results):

- No cloud was present during the ascent (cloudiness was arbitrarily assumed when humidity was higher than 70 % at non freezing temperature and higher than 85 % above 200 mb).

-The flight covered at least the range up to 8000 m above sea level (main contributor to the total amount of precipitable H_2O)

-Water vapor was computed by interpolating over at least 4 characteristic levels up to the 200 mb level.

The computation rule for the average water vapor content in an atmospheric slice between altitude h_i and h_{i+1} knowing temperature, humidity and pressure at these levels is the following: let M_i be the mass (in Kg) of water vapor present in a column of 1 m^2 between level i and $i+1$, then :

$$M_i = -\frac{1}{g}\int_{P_i}^{P_{i+1}} w dP \tag{1}$$

in which g is the acceleration due to gravity, w is the mixing ratio in kg/kg, and P the pressure in N/m^2 (1 mB = 100 N/m^2). If the layer is thin enough, w inside the layer can be taken as a constant averaged from the value at the boundaries and:

$$M_i \approx -\frac{1}{g}\frac{w_i + w_{i+1}}{2}(P_{i+1} - P_i) \tag{2}$$

w is a function of vapor pressure e:

$$w_i = \frac{0.622 e_i}{P_i - e_i} \tag{3}$$

which can be estimated from relative humidity R_h along:

$$e = \frac{R_h}{100} e_s \tag{4}$$

where e_s, the saturation vapor pressure, is a function of temperature T (^{o}C) only:

$$e_s = 6.1078 \exp\frac{17.27T}{237.3 + T} \tag{5}$$

An oversized slice thickness is the main cause of error in the case of flights with missing data. In this study however no arbitrary upper limit was set on the thickness but rather a lower limit on the number of slices used for the computation of the integral.

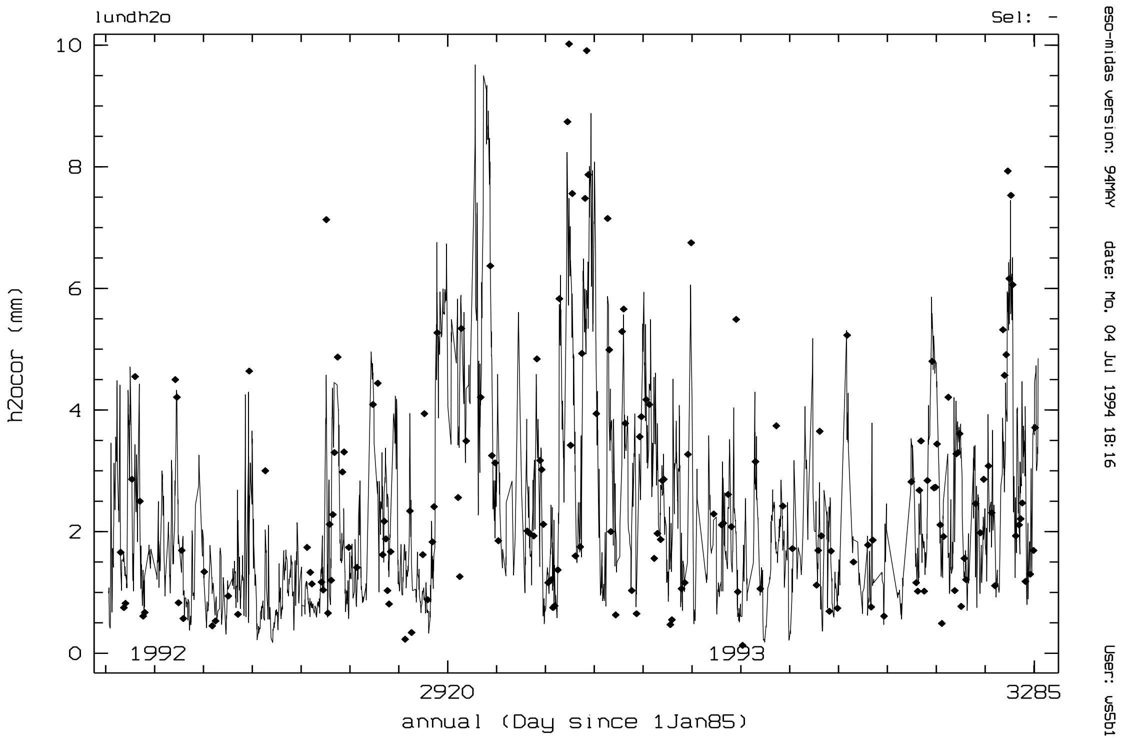

Figure 1: Paranal/Antofagasta H_2O Time Sequence (92-93): the validated Antofagasta Upper-Air data are represented as single events (filled lozenges) over the unbinned in situ Paranal database from June 1992 to December 1993.

2.3 Correlation

The Paranal data set was binned on a six hours basis so as to compare the average water vapor measured at Paranal during the second half of the night (6-10h UT) to the data of the following early morning (12h UT) balloon launch from Antofagasta. Such a binning reduced the Paranal data set to 397 independent samples, 359 of them coincident with a balloon flight out of which 180 water vapor amount could be computed. The corresponding time series are shown on Fig. 1 where the validated balloon data are represented as single events over the initial Paranal database. The average and median values for the subsets at each selection step are given in Table 1 showing that the selection process is not completely neutral since the subset of coincident Paranal data is slightly overestimating the unbinned data.

The statistical distribution of the Paranal and Antofagasta coincident subsets are quite comparable, as shown on Fig. 2, with a tendency of the balloon data to produce more very low or very high values than the radiometer. This particularity is also apparent on the regression plot of Fig. 3. The rms error of 1.3 mm is very comparable to the one obtained when comparing the radiometer data of the first half of the night with those of the second half (1.26 mm) which represent the natural variability of atmospheric water vapor. It is thus concluded that the similarity between the radiometric and Upper-Air data sets is sufficient to consider that the Antofagasta Upper-Air data offers a representative picture of the situation above Paranal.

Type of data	Average/median Water Vapour (mm H_2O)	Number of samples
Unbinned in situ Paranal	2.3/1.8	2490
Binned beg. of night Paranal	2.4/1.9	438
Binned end of night Paranal	2.3/1.7	397
Selected flights Antofagasta	2.9/2.1	275
Selected coincident flights Antofagasta	2.8/2.1	180
Binned coincident end of night Paranal	2.7/2.2	180

Table 1: Paranal/Antofagasta H_2O Statistics according to the data subset considered for comparison purposes.

3 Study of precipitable water vapor from upper-air soundings above Antofagasta (Chile) and Windhoek (Namibia)

3.1 Comparison of Upper-Air soundings above Antofagasta and Windhoek

The 85-93 Upper-Air data sets of Antofagasta and Windhoek have been processed following the method described in the previous section. The only difference is an altitude of 1700 m for the Windhoek launching station while Antofagasta is at sea level. Also the starting altitude for the integration of water vapor was set to 2346 m for Windhoek/Gamsberg against 2636 m for Antofagasta/Paranal.

The assumption that Windhoek results are well correlated with Gamsberg in situ Water Vapour is not as straightforward as for Paranal-Antofagasta and will be reconsidered after the July-August Gamsberg evaluation campaign has provided radiometric data: it is clear that the humidity content in the atmosphere decreases from East to West in Africa at those latitudes. As Windhoek is situated to the East of Gamsberg, the Windhoek estimates must be considered as upper limits of what can be expected at Gamsberg. However the difference Windhoek-Gamsberg is probably much smaller for water vapor statistics than for rainfall statistics ($\approx 25\%$ less rain at Gamsberg) as we are considering only cloud free flights.

The Windhoek data set is larger since balloons are launched from there twice a day (0h and 12h UT) while the Antofagasta 0h UT launches were disrupted in 1987. Because of the longitude difference, 0h UT corresponds to the beginning of the night at Paranal and to the middle of the night at Windhoek. Similarly, 12h UT corresponds respectively to the early morning at Paranal and to the early afternoon at Windhoek. The complete sets are plotted on Fig 4. The statistics are given in Table 2 for specific launch time, the most logical is to compare Antofagasta morning (12h UT) flights and Windhoek night flights (0h UT) when no evaporation effect from the ground can be present.

It is seen in Table 2 that the Windhoek amount is approximately double of the Antofagasta value, with a probability distribution clearly shifted towards high values as shown on Fig. 5. We try in what follows to estimate conditions at Gamsberg and compare it to in situ measurements in Chile.

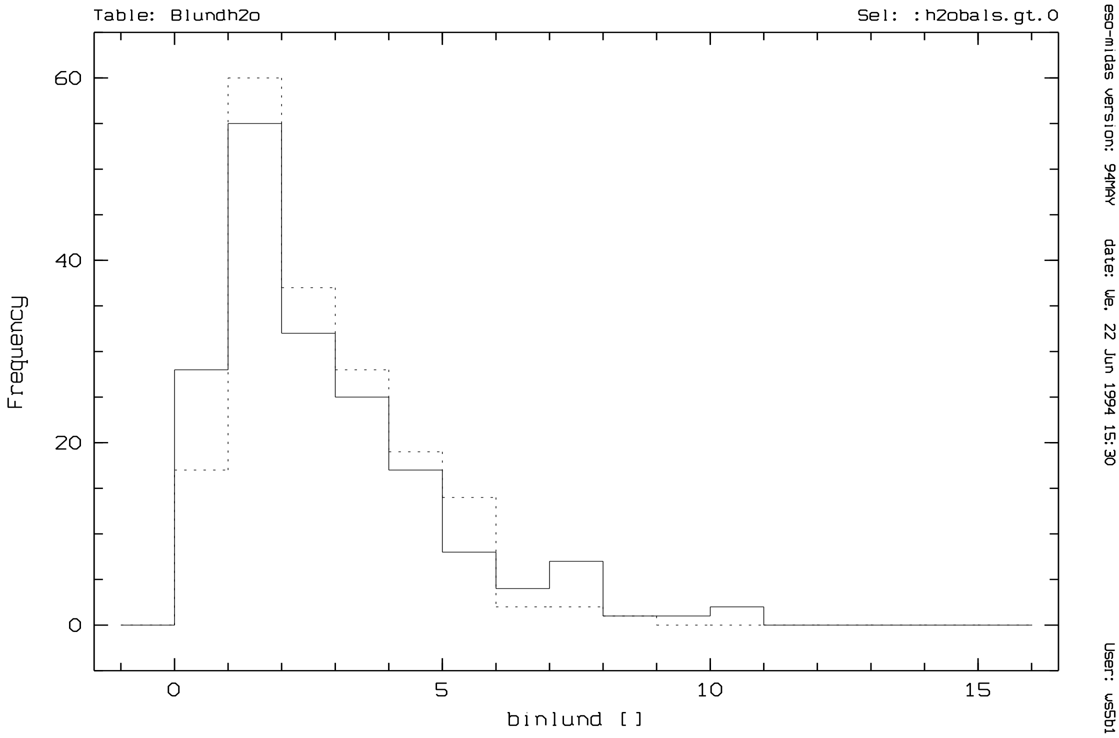

Figure 2: Histogram of H_2O distribution in the comparison subsets of coincident measurements over Antofagasta (full line) and at Paranal (dotted line).

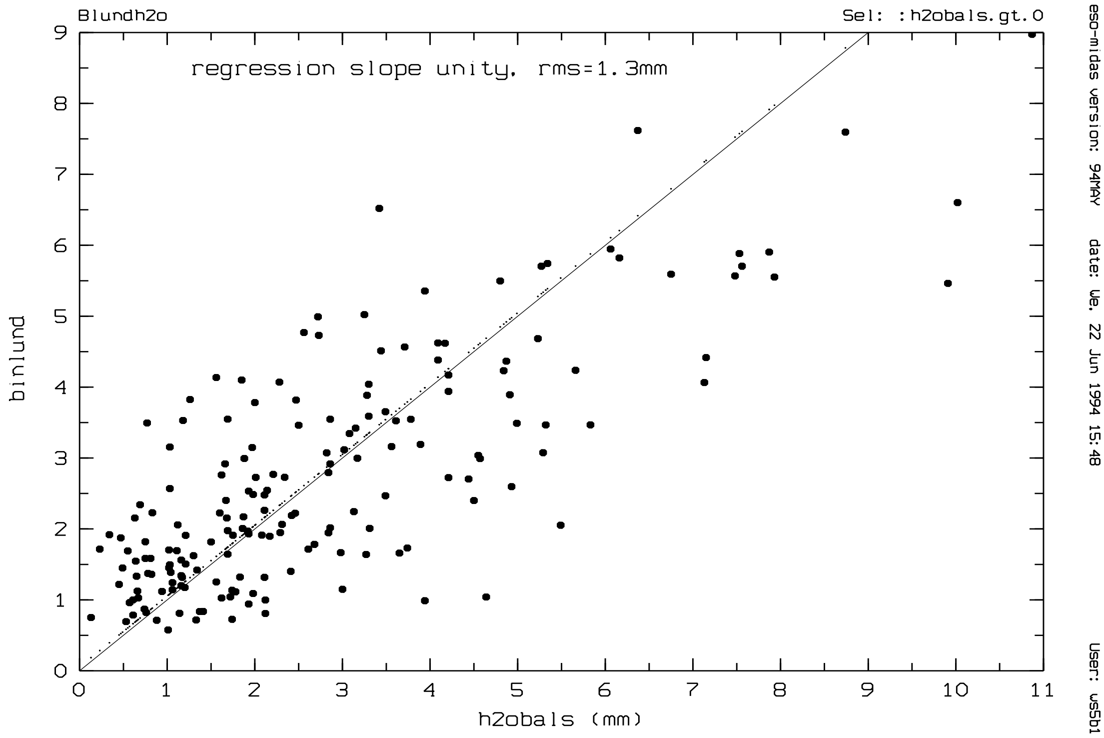

Figure 3: Regression of coincident records of water vapor from Paranal radiometer (vertical axis) and from Antofagasta Upper-Air (horizontal axis) data sets from June 1992 to December 1993.

Type of data	Average/median Water Vapour (mm H_2O)	Number of samples
1985-1987 only		
Selected flights Antofagasta (0h UT)	4.3/3.4	539
Selected flights Antofagasta (12h UT)	3.4/2.7	664
1985-1993		
Selected flights Windhoek (12h UT)	6.4/5.7	1667
Selected flights Windhoek (0h UT)	6.0/5.0	1797
Selected flights Antofagasta (12h UT)	3.2/2.6	1818

Table 2: Windhoek/Antofagasta H_2O Statistics of the raw data set. The Antofagasta 0h UT flights were disrupted in 1987. The last two lines refer to the subsets selected for the comparison.

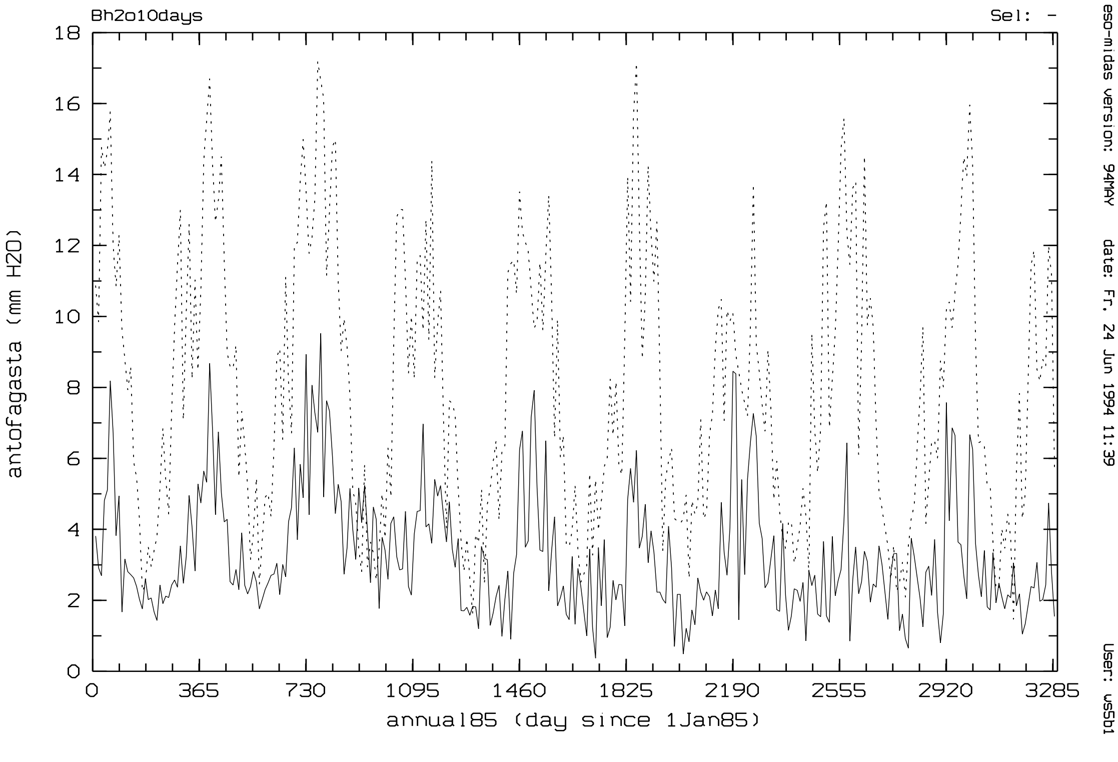

Figure 4: Windhoek (dotted line) and Antofagasta (full line) time sequences (85-93) of precipitable H_2O computed from the altitude of Paranal and Gamsberg respectively and binned over 10 days periods.

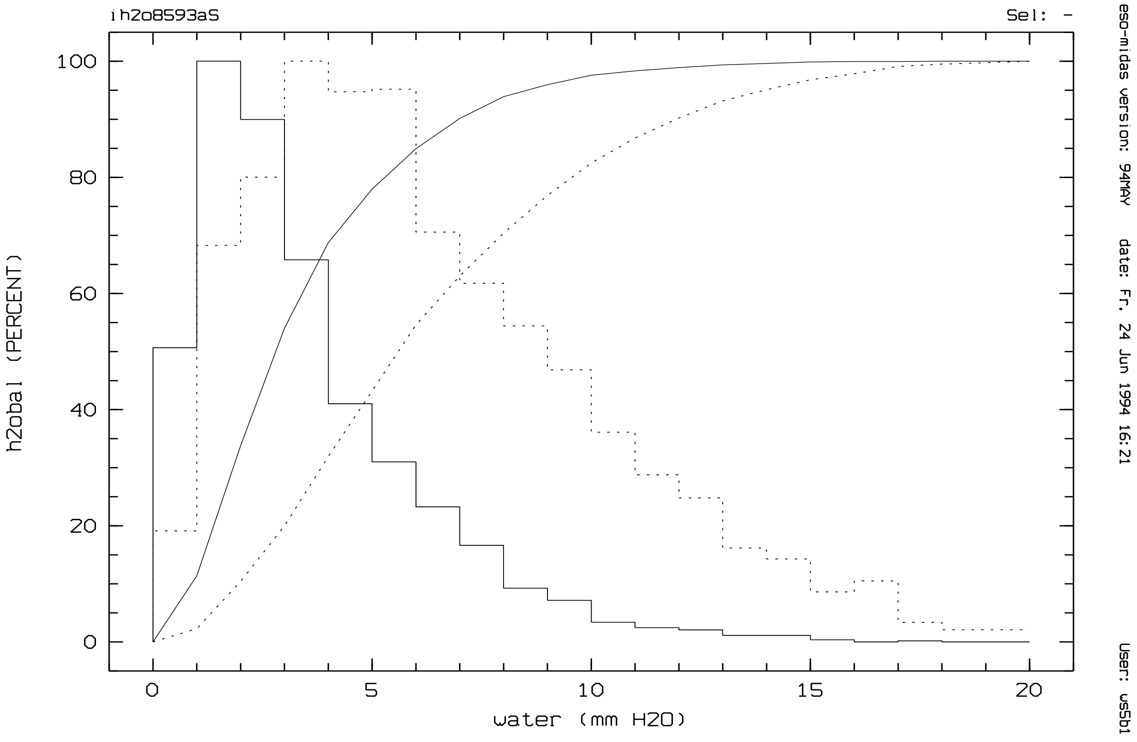

Figure 5: Histogram of H_2O distribution in the (85-93) flights over Antofagasta (full line) and Windhoek (dotted line) computed from the altitude of Paranal and Gamsberg respectively.

3.2 Analysis of Seasonal trends

The statistics of Table 2 take into account the inhomogeneity of the data distribution in time due to cloudiness above Windhoek and to launch failures . It is possible to deconvolve the data base from its local conditions and to transpose these results to Gamsberg, considering that the yearly median is a linear combination of the shorter term (eg: 20 days) medians M_i at Windhoek (Table 3) with a set of normalized coefficients c_i determined by the cloud cover C_i at Gamsberg (extracted from Table 5):

$$M_{gamsberg} = \frac{1}{N}\sum_{1}^{N} M_i c_i;\ with\ c_i = N\frac{C_i}{\sum_1^N C_i} \tag{6}$$

The M_is represent the water vapor content in the atmosphere as a function of the period of the year, they are compared to Antofagasta data in Fig. 6 and to Paranal/La Silla data in Fig. 7.

$M_{gamsberg}$ is the yearly median water vapor content for clear nights astronomical observations. It is compared on the last line of Table 3 to equivalent statistics at Chilean sites given in [Vlt 90]. **According to this study, Gamsberg atmosphere contains at most 2.7 times more water vapor than at Paranal and 1.6 times more than at La Silla**. Because the method is not accurate at both ends of the distribution, it is not possible to compare the 5 and 95 percentiles in the same way. The noticeable increase of yearly median from Windhoek raw results (5.0 mm in Table 2) to Gamsberg estimate (6.1 mm in Table 3) comes from the assumption that water vapor content of clear nights is the same at both locations. The fact that Gamsberg offers considerably more clear nights than Windhoek during the rain season thus inflates the yearly median.

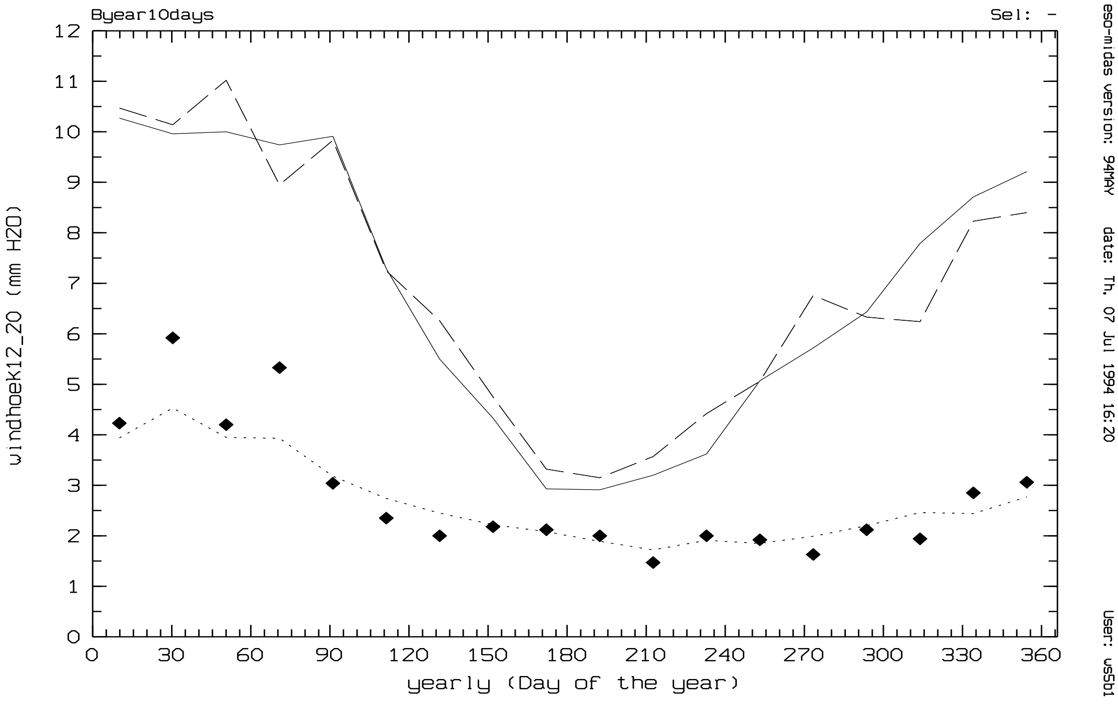

Figure 6: Seasonal variation of precipitable H_2O computed on the basis of 20 days median from 1985-1993 Windhoek night (full line) and day (dashed line) flights and Antofagasta day flights (dotted line) from the altitude of Paranal and Gamsberg respectively. 1983-1989 in situ Paranal nighttime statistics are given for comparison (filled lozenges)

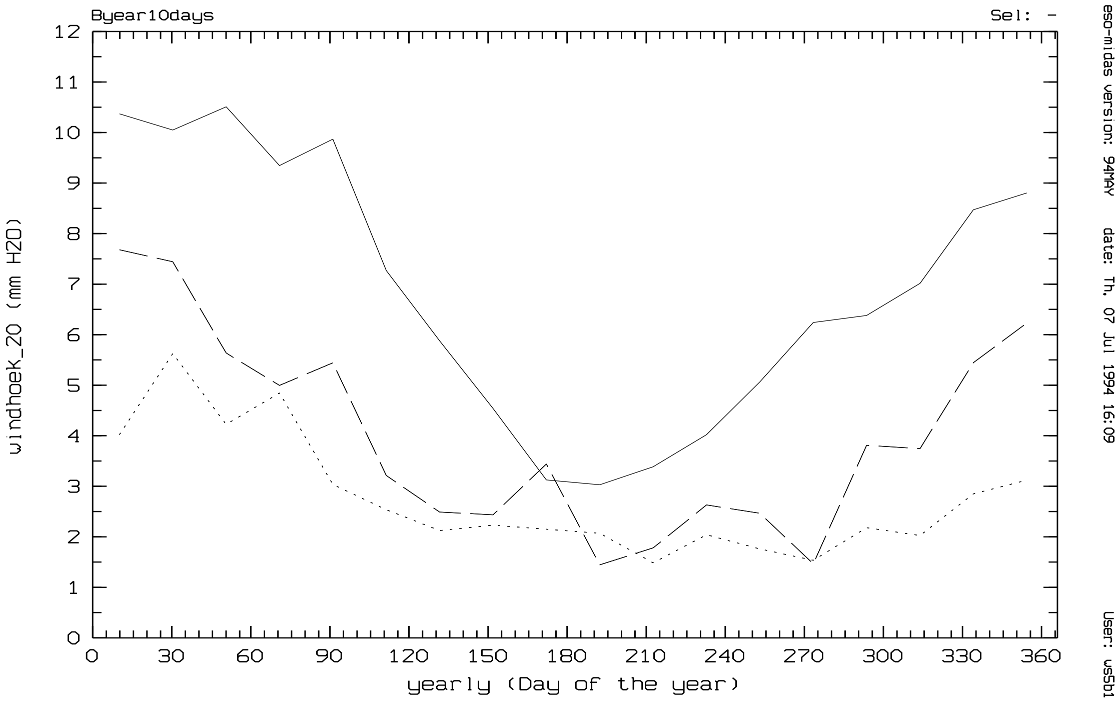

Figure 7: Seasonal variation of precipitable H_2O computed on the basis of 20 days median from 1985-1993 Windhoek night flights (full line) from the altitude of Gamsberg compared to 1983-1989 in situ Paranal (dotted line) and La Silla (dashed line) nighttime statistics.

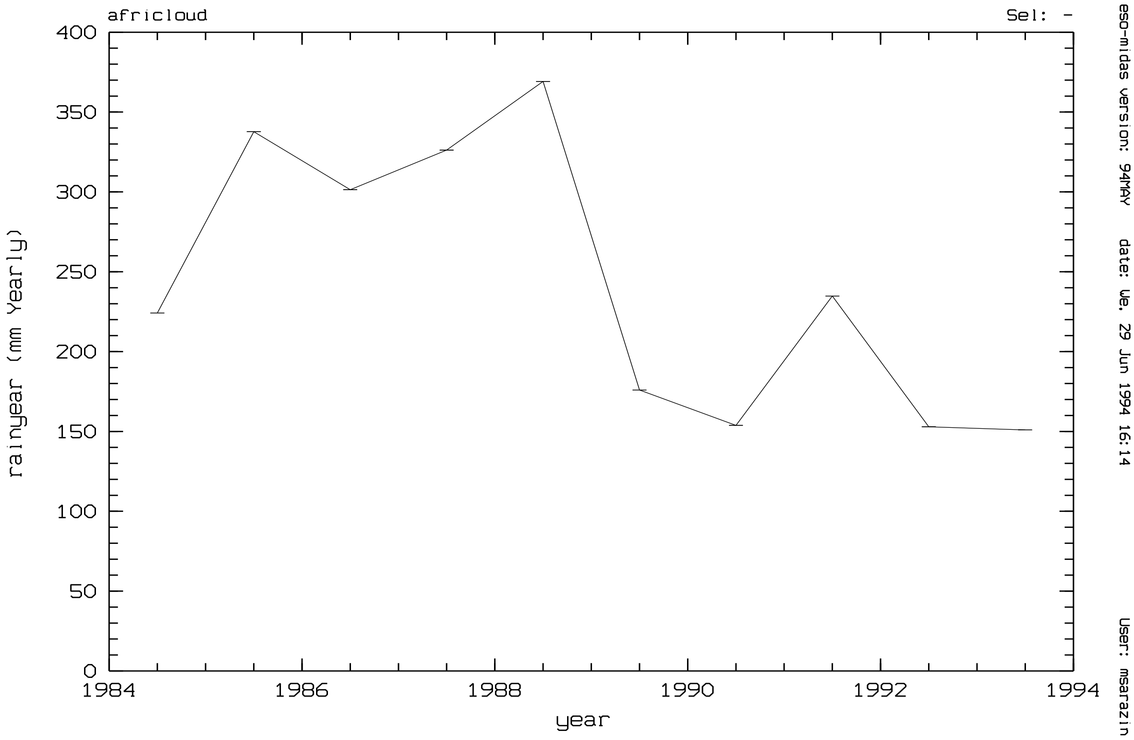

Figure 8: Yearly mean precipitation at Farm Hohenheim between 1984 and 1994.

4 Correlation of cloud cover at Gamsberg with monthly rain records at a nearby farm

4.1 Rain records at farm Hohenheim in the past 10 years

The economy of the farms of the surroundings of Gamsberg is extremely sensitive to climatic variations and cattle is permanently adjusted with pasture availability. The yearly records given in Table 4 and on Fig. 8 show a factor of up to 2.5 between wet and dry years ([Straube 94]). Also note that the seasonal trends shown on Fig. 9 give five absolutely dry months per year (from May to September).

4.2 Correlation of Cloud cover and precipitation

We do not have records of cloudiness above Gamsberg from the same period, but it is possible to compare the seasonal variations of precipitation of Fig. 9 to those of photometric/spectroscopic nights recorded from 1970 to 1975 given in Table 5 ([Neckel 82]).

Fig. 10 show a clear dependency of cloudiness with probability of rain when the latter is lower than 15%. The slope of the regression is the same (-3) for spectroscopic and photometric nights. This shows that the yearly amount of clear nights should be expected to vary in the same proportion as the total amount of rain of Fig. 8.

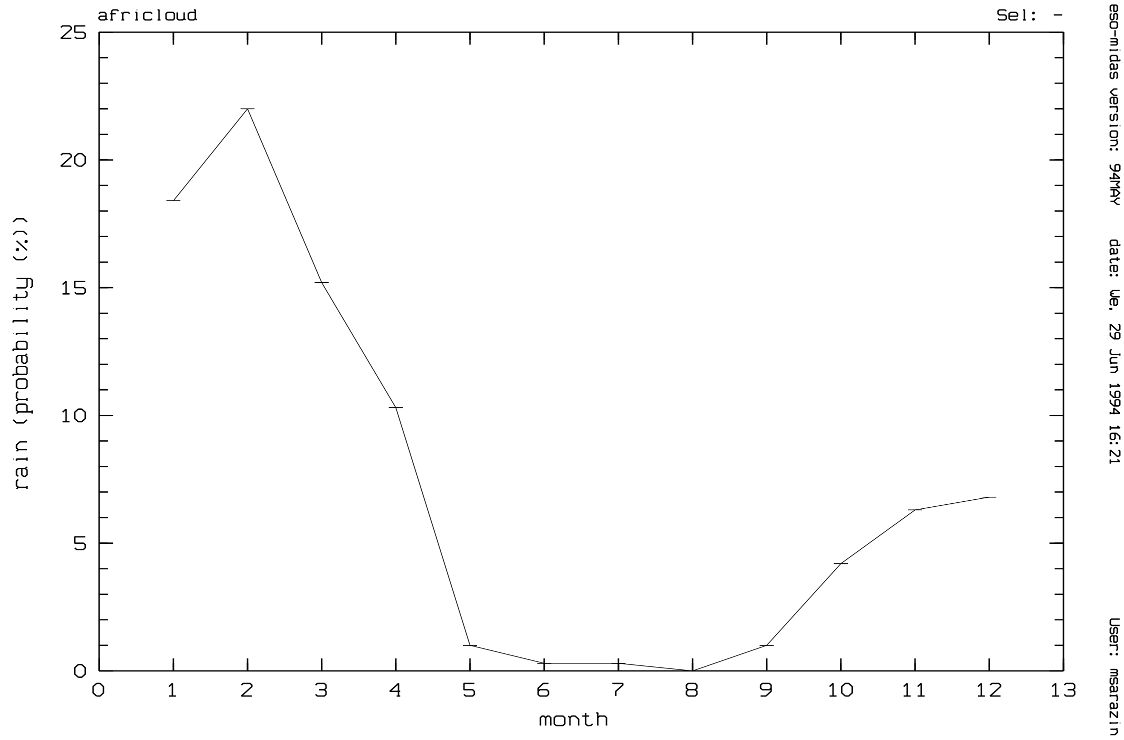

Figure 9: Seasonal rain probability at farm Hohenheim on the basis of monthly records from 1984 to 1994.

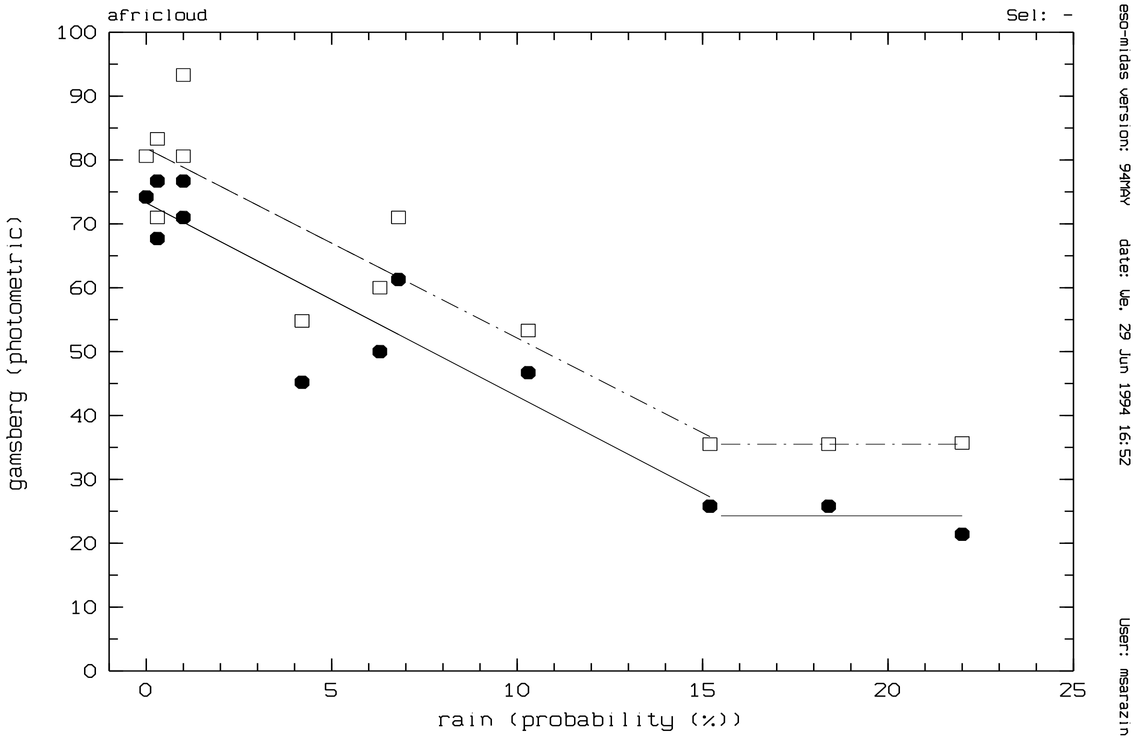

Figure 10: Comparison of the monthly rain probability (84-94) with monthly photometric (filled circles) and spectroscopic (squares) night records (70-75).

Period	1985-1993			1983-1989			
(month and day)	WDH/12	WDH/00	ANF/12	PAR/N	PAR/D	LSI/N	LSI/D
0101-0120	10.3	10.5	3.9	4.2	3.8	6.7	8.4
0121-0210	10.0	10.1	4.5	6.0	5.3	7.4	7.5
0211-0228	10.0	11.0	4.0	4.2	4.3	5.7	5.5
0301-0320	9.7	9.0	3.9	5.3	4.4	5.6	4.4
0321-0410	9.9	9.8	3.2	3.0	3.0	4.7	6.1
0411-0430	7.3	7.3	2.7	2.4	2.7	3.2	3.2
0501-0520	5.5	6.3	2.5	2.0	2.3	2.4	2.6
0521-0610	4.3	4.6	2.2	2.2	2.3	1.8	3.0
0611-0630	2.9	3.3	2.1	2.1	2.2	3.9	2.9
0701-0720	2.9	3.2	1.9	2.0	2.1	1.3	1.6
0721-0810	3.2	3.6	1.7	1.5	1.5	1.7	1.9
0811-0831	3.6	4.4	1.9	2.0	2.1	3.3	2.0
0901-0920	5.1	5.1	1.9	1.9	1.6	1.9	3.0
0921-1010	5.7	6.8	2.0	1.6	1.4	1.3	1.6
1011-1031	6.4	6.3	2.2	2.1	2.2	3.5	4.1
1101-1120	7.8	6.2	2.5	1.9	2.1	4.3	3.2
1121-1210	8.7	8.2	2.4	2.9	2.9	4.1	6.8
1211-1231	9.2	8.4	2.8	3.1	3.2	6.2	6.3
Total (*)		**6.1**		**2.3**		**3.9**	

Table 3: 50 percentile value of water vapor in the atmosphere above the altitude of the sites for periods of 20 days as computed with balloon flights launched from Windhoek (WDH) and Antofagasta (ANF). These data are compared to in situ radiometric measurements made at Paranal (PAR Night and Day) and La Silla (LSI Night and Day) [Vlt 90]. (*) The total is the yearly median H_2O computed for the given photometric night distribution of each site.

Period	Precipitation
1984-1985	224.2 mm
1985-1986	337.7 mm
1986-1987	301.4 mm
1987-1988	326.2 mm
1988-1989	369.2 mm
1989-1990	175.9 mm
1990-1991	153.8 mm
1991-1992	234.8 mm
1992-1993	152.9 mm
1993-1994	150.9 mm

Table 4: Farm Hohenheim rain records ([Straube 94]).

Period	Chance of rain 1984-1994	Photom. nights 1970-1975	Spectr. nights 1970-1975
January	18.4 %	25.8 %	35.5 %
February	22.0 %	21.4 %	35.7 %
March	15.2 %	25.8 %	35.5 %
April	10.3 %	46.7 %	53.3 %
May	1.0 %	71.0 %	80.6 %
June	0.3 %	76.7 %	83.3 %
July	0.3 %	67.7 %	71.0 %
August	0.0 %	74.2 %	80.6 %
September	1.0 %	76.7 %	93.3 %
October	4.2 %	45.2 %	54.8 %
November	6.3 %	50.0 %	60.0 %
December	6.8 %	61.3 %	71.0 %

Table 5: Precipitation and Cloudiness in the Gamsberg area ([Straube 94], [Neckel 82])

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