AIR-SEA INTERACTION OVER WEST AFRICA

SOW C. S. (1), A. Viltard (2), P. de Félice (2)

Abstract

The effects of the sea on West African climate are studied with ERA40 data, Dakar radiosonde and ground level data. Wind, temperature and humidity are used. We find a seasonal variation: during the dry season, winds are northerly or north-easterly over land and sea, however with a southward rotation about 40 ° at the coast. During the rainy season, the wind is north-easterly over the sea but becomes westerly off the coast north of the ITCZ whilst, in the South, the wind is south-easterly, i. e the monsoon circulation.

Dakar temperatures display high correlations with grid-points over the ocean more than 300 km to the West and low correlations with Thies (70 km East of Dakar).

Dakar is a very important station for models data assimilation; the nearest stations with two-daily radiosoundings are Sal, 600 km to the West, and Bamako, more than 1000 km to the East. We suggest that the solitary position of Dakar may influence the prediction quality: Dakar is probably more representative of an oceanic than a continental climate.

1- INTRODUCTION

West African coast is a siege of the confluence of air masses coming from the continent with air masses coming from the ocean. Of this admixture of air of different origin, it results a specific climate characterizing Dakar where the temperature inversions constitute a quasi-permanent phenomenon.

Having only a single radiosonde station in the studied area, we use the ERA40 reanalyze of the temperature and the wind to extend the study on the continent and on the ocean at the neighbourhood of Dakar.

Before beginning the climatic analysis of the temperature data and looking for to connect their variation to those of the wind in the neighbourhood of this station, we compared the ERA40 reanalysed temperature with the observation.

2- DATA AND METHOD

The following data were used:

- the twice-daily data of observation (00 and 12 UTC) of the radiosonde station of Dakar, between the ground and the 850 hPa level for all year 2001;
- the data of ERA40 reanalyzes described by Uppala et al. (2005) at the rate of 4 networks per day (00, 06, 12 and 18 UTC) in a grid surrounding Dakar for the levels 1000, 925 and 850 hPa during year 2001.

The Dakar Yoff station is located at 14,73°N and 17,43°W. The closest grid-point (14,625°N, 18°W) on which the values ERA40 data are computed, was used for the temperature differences calculation between observation and reanalyze data. We have a small number of missing data ; this allows us to validly compare daily data of the European model with observations in altitude available more than 95 times out of 100.

We have also used the average difference between the reanalysis data of 18 UTC and that of 06 UTC of the point close to Dakar to estimate the temperature diurnal variations.

For a given level, we considered the observation data obs_i (i varying from 1 to N) for which we calculate the average *mobs* and the standard deviation $etobs = \sqrt{\frac{1}{N}\sum_{i=1}^{i=N}(obs_i - mobs)^2}$ where N=730.

(1) ASECNA BP 3414 Dakar Sénégal ;

(2) Laboratoire de Météorologie Dynamique du CNRS, Ecole Polytechnique, Palaiseau, France

To evaluate the model quality, the series of the differences $E_i = obs_i - ana_i$ between observation and reanalyzes ana_i are calculated for the grid-point close to Dakar Yoff. The standard deviation of the difference is: $etE = \sqrt{\frac{1}{N}\sum_{i=1}^{i=N} E_i^{\ 2}}$.

Table I shows the reanalyses averages at the reference point, the standard deviation of these reanalyses $etan$, the climatological standard deviation of the observation $etobs$, the difference means E (mean value of the differences E_i) and etE standard deviation of these differences for each of the two studied levels (1000 and 850 hPa). In the line percentage (%) we carried the limits of the reliable interval in 99 % for the difference average between observation and reanalyze with the no hypothesis that this average is invalid. On the last two lines of the table I, we carried the linear correlation between observation and reanalyze at both levels and the correlation inter level between observation series.

Besides the study so led on the series of temperature to the ground and to the level very close to 1000 hPa, we proceeded to a study of the vertical profile of the temperature by using the previous data as well as those of the standard levels 925 and 850 hPa, and the data of temperature at the characteristic levels which correspond to bottoms or summits of inversion. We did not exploit the ERA40 data supplied on motionless isobaric levels 1000, 925, 850 hPa, the data of observations of the radiosonde station of Dakar being more effective to detect the temperature inversions.

In principle the T temperature decreases with height. Exceptionally it happens that T increases with the height in a layer, this is the temperature inversion. This event can take place in the limit between the troposphere and the stratosphere as well as in the low tropospheric layers. The temperature inversions in the tropopause, as global phenomenon of large scale characterizing the separation between two main parts of the atmosphere, are more known than the inversions of low layers which characterize the stability of the air masses in a given place during an observation. For a given sounding where this event is observed, the height Zb where T begins to increase and the height Zs of the end of the growth of T determine altitudes of bottom and the top of the inversion layer.

3- RESULTS

3.1 Temperature time series at the point of reference

Figure 1 shows the temperature time series observed at 00 and 12 UTC at 1000 hPa. Quick variations of great amplitude are observed from January to April while they are relatively small from May to December. Generally, on the various levels studied, behaviours of the time series are very variable from a period to another.

Differences between temperatures observed and temperature provided by ERA40 are established for the level 1000 hPa and shown in Figure 2.

Variations are weak around the average (-0.8°C) from May to December. Important variations are observed from January to May. Because of the evident difference in statistical behavior of the time series, two periods may be distinguished; for each of them the mean value and the standard deviation are computed: for the 271 data (from January 1 to mid-May) the average is –1.81°C and the standard deviation 1.85°C; for the second part of the year the average is 0.06°C and the standard deviation 0.99°C. This difference in pattern is undoubtedly in relation with seasonal effects.

In table I the climatological standard deviations of the observations *etobs* are higher than those of the reanalyzes, this is explained by the smoothing ability of the model. The average difference *E* is always less than one degree Celcius at level 1000 hPa while this difference is small and changes sign at 850 hPa.

By making the null assumption that these samples of 730 differences are all resulting from a population of null average (it means that there is no systematic difference between analysis and observation) a confidence interval around 0 is calculated for each level, from the standard deviation of the differences *etE* between observation and reanalyzes; at the threshold of 99%, the averages have a normal distribution with a null average and a standard deviation close to that of the differences divided by the root of 730. We noticed that the average difference is out of the confidence interval. That means that with a risk of 1%, the null assumption must be rejected and thus we infere that these differences are significant. So, at 1000 hPa, the analysis over-estimates the temperature while it underestimates it at 850 hPa. Table I also contains the linear correlation inter levels of the temperatures observed at Dakar near the ground at 1000 hPa level and at the low layer top at 850 hPa level. The weak value of this coefficient (0.19) suggests that between these two circles, there is a significant difference of behavior for which we try to characterize in the following chapter using reanalyze data.

3.2 Analysis of temperature series in the vicinity of Dakar

A map of the correlation between the observation in Dakar and the reanalyzes at the 42 grid-points close to this station is drawn at 850 and 1000 hPa levels (Figure 3). At 850 hPa the linear correlation is everywhere positive and generally greater than 0.5. The maximum is located on the point immediately at the east of Dakar (0.94) and the area where the coefficient is larger than 0.90 overs the point of reference and extends towards the east up to 200 km from Dakar. At 1000 hPa the correlation is more quickly decreasing when we go from Dakar towards the east (negative values towards south-east at less than 300 km), the maximum does not cover any more Dakar station but an area located open sea, in the west, at more than 200 km.

3.3 Temperature inversion over Dakar

We determined on every radiosounding observation if the phenomenon of temperature inversion was detected. The table 2 presents the monthly rate of appearance of this phenomenon as well as the monthly average thickness of temperature inversion. In 2001, we observed a temperature inversion at 00 and 12UTC except a case in June, 39 cases between July and September and about ten cases during the last quarter; that is with 680 cases of inversion observed on 730 possible, less than 10 % of absence of temperature inversion during this year at these moments of the day at Dakar. As indicated in table 2, the monthly average thickness of temperature inversion is variable.

4- DISCUSSION

The analysis of the statistical results between the observed temperatures and the reanalyzes in 1000 and 850 hPa levels creates peculiarities which it is advisable to underline and to explain:

- the diurnal, not sensitive effect on the observations but restored by the reanalyzes of 06 and 18 UTC at 1000 hPa;

- the weak value of correlation inter-level, in opposition of phase between both studied isobaric surfaces which can explain the geographical situation told below;

- the geographical situation of the radiosounding station situated at the end of a peninsula seems to have an influence more maritime than continental, at least towards the ground where contrary to the level 850 hPa, the temperature in Dakar is very close to that of the ocean, as shown by Figure 3.

The geographical situation of Dakar, evoked in the section 3, shows itself on several timescales; that the diurnal effect is not visible on the observation because of the hours of release of the balloon. However the reanalyze reconstitutes at least partially a visible diurnal effect in 06TU and 18TU doubtless thanks to the observations of surface of the nearby ground station of Dakar. For example on the figure 4 which represents the difference between the average temperatures of 18TU and 06TU from the reanalyzes of 1000 hPa we observe that isolines follow almost perfectly the coast with a diminution of this difference of the continent towards the ocean; in the reading of this, we find that in Dakar, this difference is approximately 4 °C and in Thiès, city situated in 70 km East of Dakar, it would be of 8°C.

Figure 5 shows the maximal and minimal temperatures observed on the ground in both stations of Dakar and Thies in 2001. We so observe the difference, between these two close stations that the diurnal effect which is 2 - 3 times as important on average for Thies than for Dakar.
We also notice that the seasonal variations of the maximal temperature in Thies are much more weaker than those of Dakar but that the fast variations are stronger on the contrary in Thies. For the minimal temperature the seasonal effect is sensitive as much in Thies as in Dakar. The diurnal variation in Thies is very strong in dry season and decreases in rainy season (July-September) while in Dakar it is about constant. In Thies, the monsoon of low layer of southwest which replaces the harmattan during the rainy season brings oceanic wet air less sensitive to the diurnal effect. At Dakar, as we shall specify it farther, the wind blows almost always after a route on the sea and the diurnal effect is thus weaker. Reanalyzes thus seems to reconstitute in a suitable way the diurnal and continental effects.

It would thus seem that reanalyzes gives systematically an overestimation of the temperature when the wind comes from the North and an underestimate when it comes western and when it is very low. It can be due to a systematic error on the vector wind either in an overestimation of the temperature of surface of the sea. The assimilation of the data of temperature in 1000hPa takes into account data of surface which, as we have already said it are numerous on the continent and under-represented on the ocean obviously. When the wind comes from the north sector, Dakar is directly touched thus more refreshed than all the more continental stations. We can explain so the overestimation of reanalyzes. When the wind comes from the West and when it is low, the continental stations and Dakar are subjected to the same influence; however the vegetation, more important on the peninsula, explains why the temperature can be lower than that of the nearby continental stations. This more or less long maritime route of the masses of Saharan air is in agreement with the observation made by Félice et al. (1982) of an increase of the humidity in the low layer in Dakar from May while the monsoon was not yet set in this station.

The maps of streamlines presented in Figure 6 confirm that:

- during the rainy season, the wind is north-easterly over the sea but becomes westerly off the coast in north of ITCZ whilst, in the South, the wind is south-easterly, i. e. the monsoon circulation westward off coast, in the North of the ZCIT while in the South of this zone, we observe a circulation of monsoon.
- during the dry season, on continent as on the ocean, the wind of northly or north-easterly with southward rotation about 40 ° southward, at the coast.

The correlations between the observations in Dakar and the reanalyzes in the nearby points of Figure 6 can then be understood by the fact that in a good part of the year the peninsula of the Cape Verde is under the influence of what takes place on the West and in the North at 1000 hPa level. In 850 hPa level, on the contrary the East wind is always dominant and the correlation shows well that the peninsula of the Cape Verde is then under the influence of what occurs in the East. This wind circulation can explain why temperature inversions are so frequently observed at Dakar with wet bottom and dry top as shown in Figure 7

5- CONCLUSION

ERA40 reanalysis of the temperature in Dakar Yoff restores rather well the temperature observed by radiosounding station of this locality. The significant systematic errors are weak. Quality standards close to those introduced by Kanamitsu (1985) and used by Heckley (1985) in tropical regions, but applied to time series and not to fields in space of table I representing respectively the ratio *etE*/*etobs* and the percentage of occurrences of deviations lower than the climatological standard deviation confirm the good quality of the reanalysis. For all levels of the boundary layer, the temperature reanalysis agrees with the observation; however there appear sometimes important differences between reanalysis and observations

So, in the African west coasts, the diurnal and seasonal variations of temperatures, as well as its vertical variation which engenders the temperature inversions, are very strongly influenced by the wind seasonal, the daily and seasonal behavior of which seems to be the mainspring of these variations. The warmer continental air surmounts the sea air on the African west coasts.

This situation explains that in 1000 hPa, the temperature observed in Dakar is more in agreement with offshore temperature whereas in 850 hPa, the warmer air coming from Sahara, the temperature observed in Dakar is better correlated with the continental temperature. This situation also explains the presence at 00 and 12 UTC of the temperature inversions which by definition are the product of the rise of a warmer air mass.

REFERENCES

- De Félice P., A. Viltard et M. Camara, 1982 : Vapeur d'eau dans la troposphère en Afrique de l'Ouest. *La Météorologie*, **29**, 129 134
- Heckley, W. A., 1985: Systematic errors of the ECMWF operational forecasting model in tropical regions. *Quart. J. Roy. Soc*., **111**, 709 – 738
- Kanamitsu, M., 1985 : A study of the predictability in the tropics based on the ECMWF operational model. *J. Meteor. Soc. Japan II*, **63**, 779 – 804
- Uppala S. M., Kållberg, P.W., Simmons, A.J., Andrae, U., da Costa Bechtold, V., Fiorino, M., Gibson, J.K., Haseler, J., Hernandez, A., Kelly, G.A., Li, X., Onogi, K., Saarinen, S., Sokka, N., Allan, R.P., Andersson, E., Arpe, K., Balmaseda, M.A., Beljaars, A.C.M., van de Berg, L., Bidlot, J., Bormann, N., Caires, S., Chevallier, F., Dethof, A., Dragosavac, M., Fisher, M., Fuentes, M., Hagemann, S., Hólm, E., Hoskins, B.J., Isaksen, L., Janssen, P.A.E.M., Jenne, R., McNally, A.P., Mahfouf, J.-F., Morcrette, J.-J., Rayner, N.A., Saunders, R.W., Simon, P., Sterl, A., Trenberth, K.E., Untch, A., Vasiljevic, D., Viterbo, P., and Woollen, J. 2005: The ERA-40 re-analysis. *Quart. J. R. Meteorol. Soc.*, **131**, 2961-3012.
-

TABLE CAPTION

Table 1 : Mean and standard deviation (*man* and *etan*) of réanalyses ; mean and standard deviation of observations (*mobs* and *etobs*) ; mean distance (*E*) between observations and réanalyses ; standard deviation (*etE*) of this distance ; ratio *etE*/*etobs ;* ; percentage of time when the distance E_i is upper than *etobs ;* linear correlation between the observed temperature and the reanalyzed temperature; linear correlation between the observed temperatures on the two levels.

Table 2: Monthly frequencies of temperature inversions and monthly average of thickness of temperature inversions observed from the ground to the 850 hPa level at Dakar during the year 2001.

FIGURE CAPTION

Figure 1 : Temperature (°C) at 1000 hPa as observed at Dakar in 2001; There are 2 data per day at 00 and 12 UTC. In X-coordinate, number of the observation in the year.

Figure 2 : Difference (°C) between observed temperature at Dakar and reanalyzed temperature at the grid-point 14.63°N/18°W at 1000 hPa level, year 2001. In X-coordinate the number of the measurements in the year.

Figure 3: Linear correlation between observed temperature and reanalyzed temperature at 00 and 12 UTC for the grid-points around Dakar in 2001; a)850 hPa b) 1000 hPa..

Figure 4 : Mean reanalyze temperature difference (°C), between 18 and 06 UTC at Dakar nearest grid-points at 1000 hPa; black triangles, Dakar and Thiès.

Figure 5: Tmax and Tmin surface observed temperature (°C) at Dakar (thick lines) and Thies (thin lines), year 2001. In X-coordinate, dates and in ordinate, temperature in °C.

Figure 6 : Streamlines at the vicinity of Dakar, using ERA40 reanalyzed wind during the rainy season (Fig 6.a) and during the dry season (Fig 6.b).

Figure 7: Monthly mean relative humidity (%) at top (Us) and bottom (Ub)) of inversion layer.

	1000 hPa	850 hPa
Average of obs (*mobs)*	23.86	21.18
Average of Era40 (*man)*	24.53	20.96
Standard dev. of Era40 (*etan)*	2.76	2.11
Standard dev. of obs (*etobs)*	3.23	2.30
Difference means (*E*)	-0.67	0.21
Stand. Dev of diff. mean (*etE*)	1.68	0.80
etE / *etobs*	0.52	0.35
Percentage (%)	91.9	97.4
Correlation Obs/Era	0.86	0.93
Correlation between levels	-0.19	

Table 1

Month	Monthly Frequencies of temperature inversions	Monthly average of thickness of temperature inversions (m)
January	100%	322
Febuary	100%	277
March	100%	374
April	100%	398
May	100%	392
June	98%	320
July	79%	216
August	69%	202
September	80%	167
October	95%	189
November	97%	173
December	92%	249

Table 2

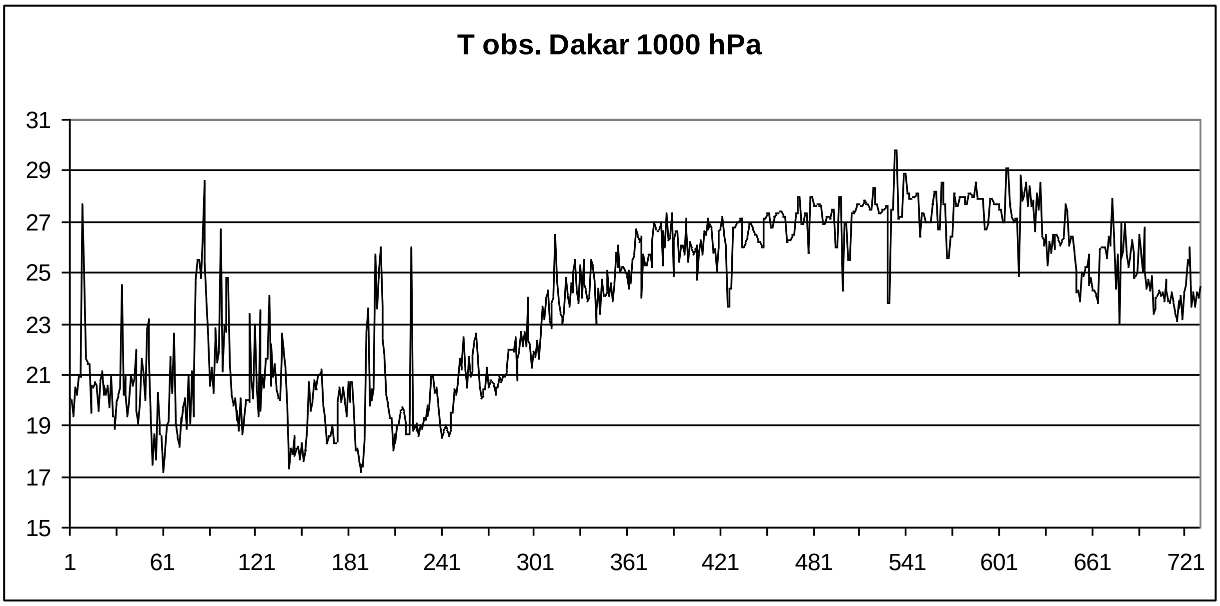

Figure 1

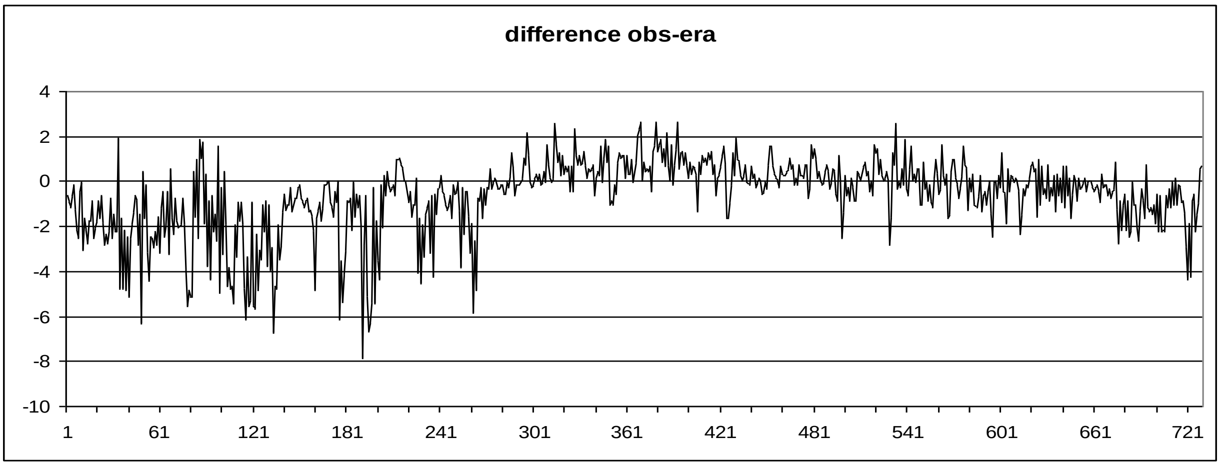

Figure 2

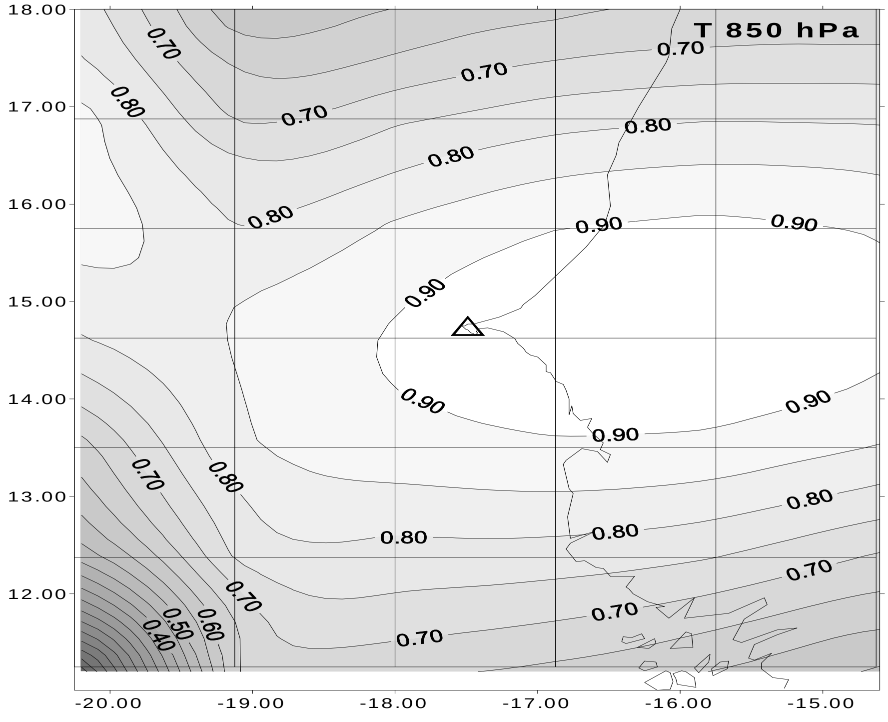
T 850 hPa
18.00
17.00
16.00
15.00
14.00
13.00
12.00
-20.00
-19.00
-18.00
-17.00
-16.00
-15.00
0.70
0.80
0.90
0.40
0.50
0.60

Fig. 3.a

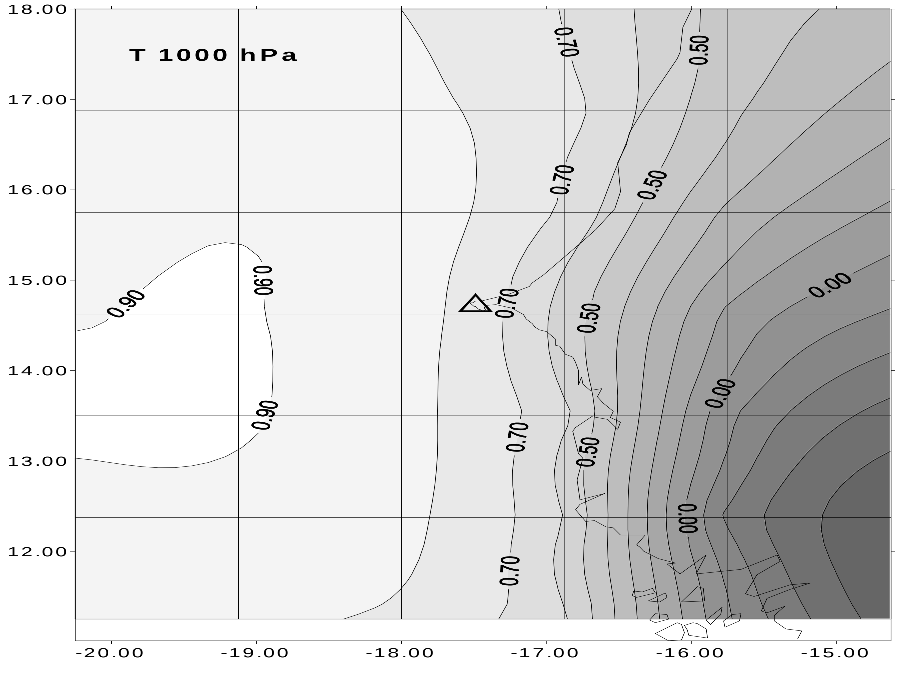
T 1000 hPa
18.00
17.00
16.00
15.00
14.00
13.00
12.00
-20.00
-19.00
-18.00
-17.00
-16.00
-15.00
0.90
0.70
0.50
0.00

Fig. 3.b

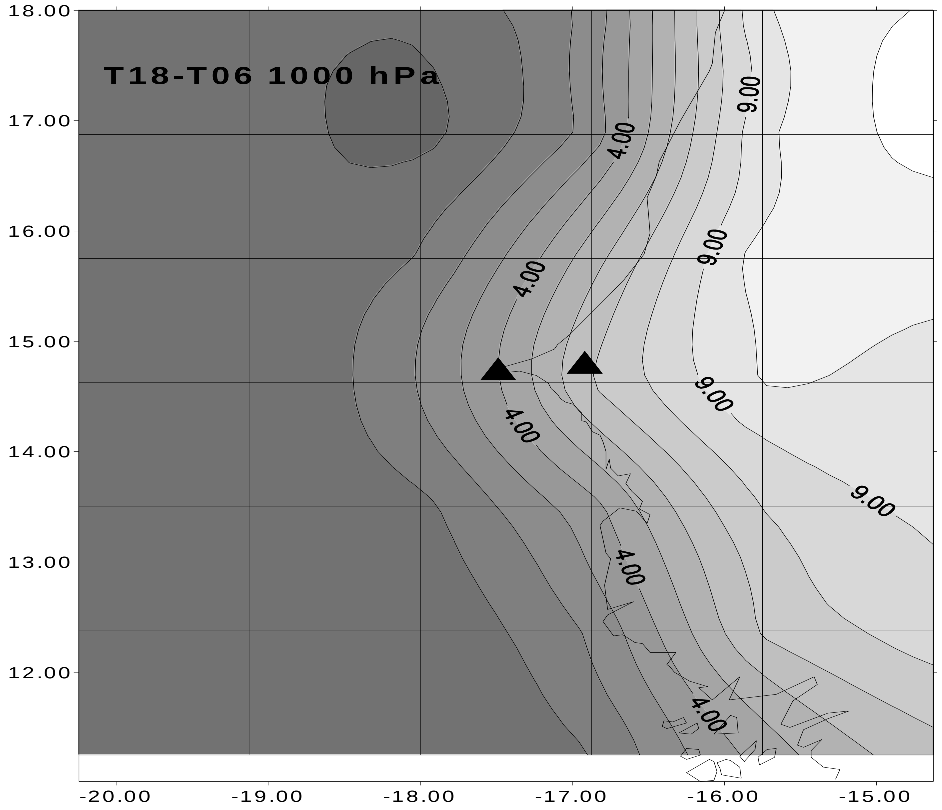

Figure 4

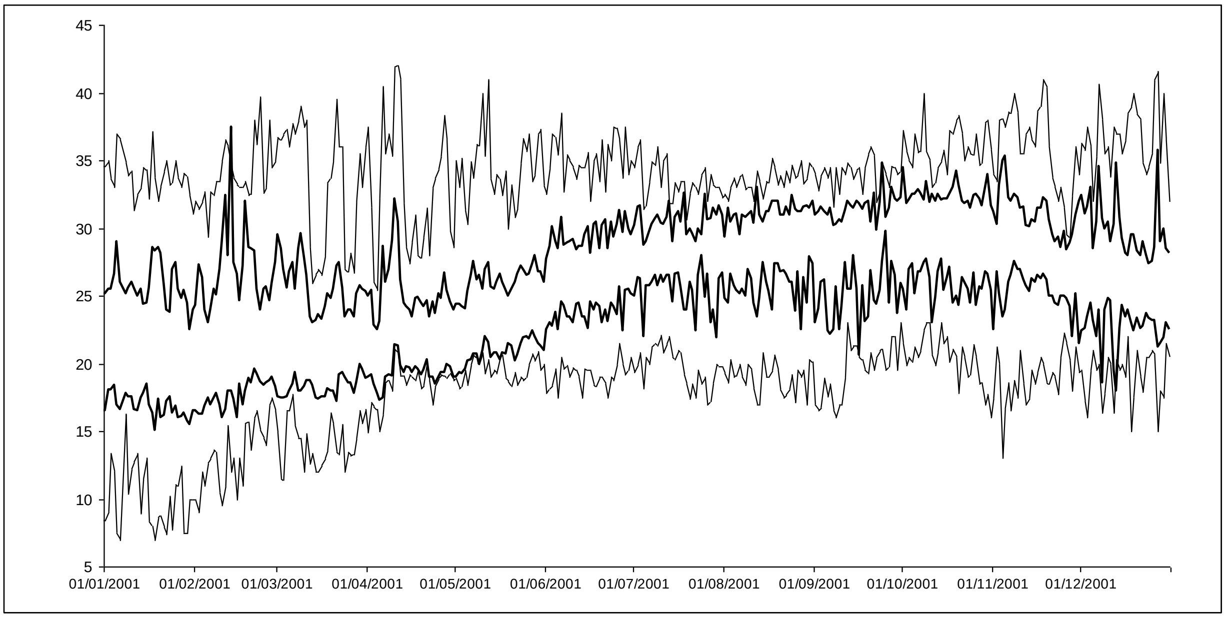

Figure 5

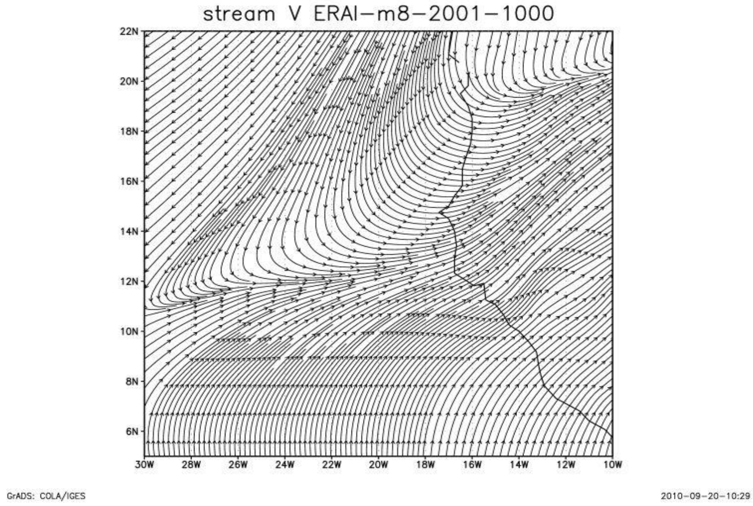

Fig 6.a

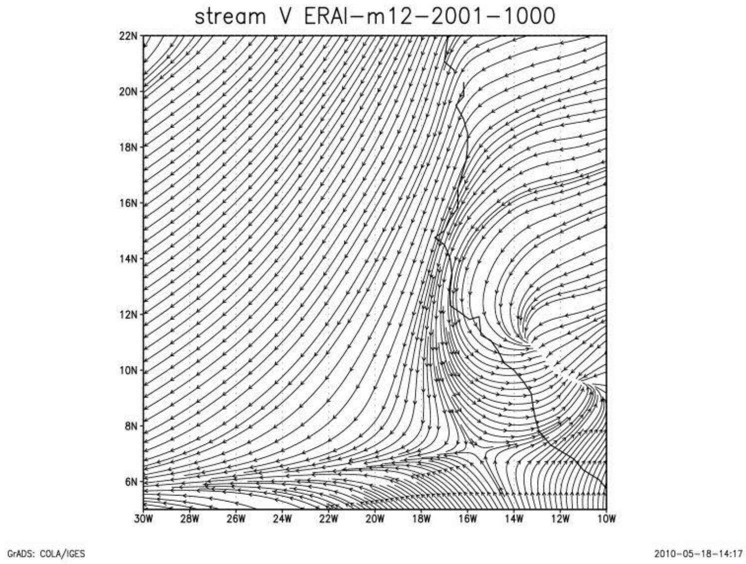

Fig 6.b

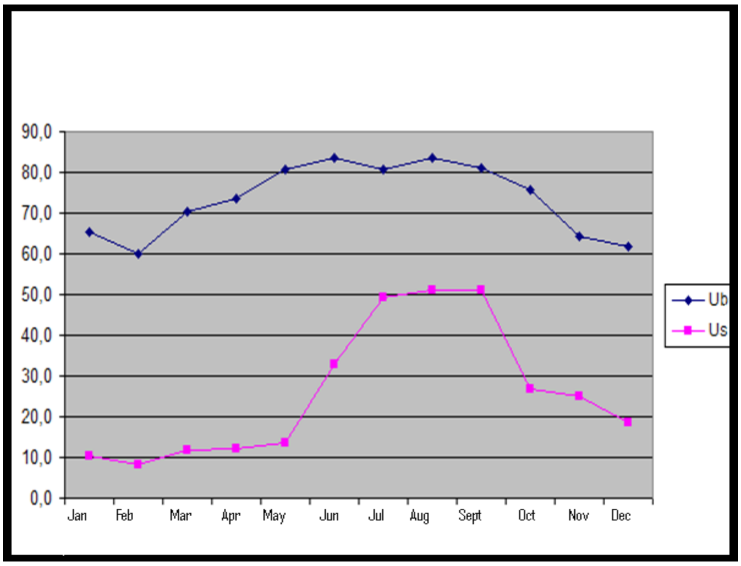

Figure 7