ON THE FORMATION OF LEVANTINE INTERMEDIATE WATER

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ésumé - Abstract

Atmospheric factors favourable to the formation of Levantine inter ediate water are shown to exist within a meso-scale region of the north astern Levant. Evaporation rates are computed and utilized in a simple ox-model. These computations are in agreement with the measured annual rend of salinity until sinking of the surface waters begins in early pring.

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The northeastern Mediterranean region to the south of Asia Minor is wn to be one of the possible sources of the Levantine Intermediate er (LIW); a water mass identified in the whole Mediterranean basin depths of 200-400 m. This distinct water mass is a product of the rmohaline circulation caused by the excessive evaporation in the iterranean (LACOMBE and TCHERNIA,1960, 1974; WÜST,1960; GERGES,1972; COS,1972). The sources and spreading of this water mass have been estigated using the core method of Wüst (1960) and with limited luations of the atmospheric conditions favorable for the formation LIW (MORCOS,1972). According to Lacombe and Tchernia (1960) and t (1960), the primary source region is the area between Rhodes and rus, while Morcos (1972) concludes that there are probably three ferent source regions: around Rhodes, to the north of Cyprus and econdary source region at the Egyptian coast; only after reaching Ionian basin does the LIW become more uniform. The northeastern t of the Levantine Basin (area between Turkey and Cyprus) is wn to contribute large amounts of the LIW by Moskalenko and hinnikov (1965) and has also been claimed to be a possible source even deep water masses (PLAKHIN,1970).

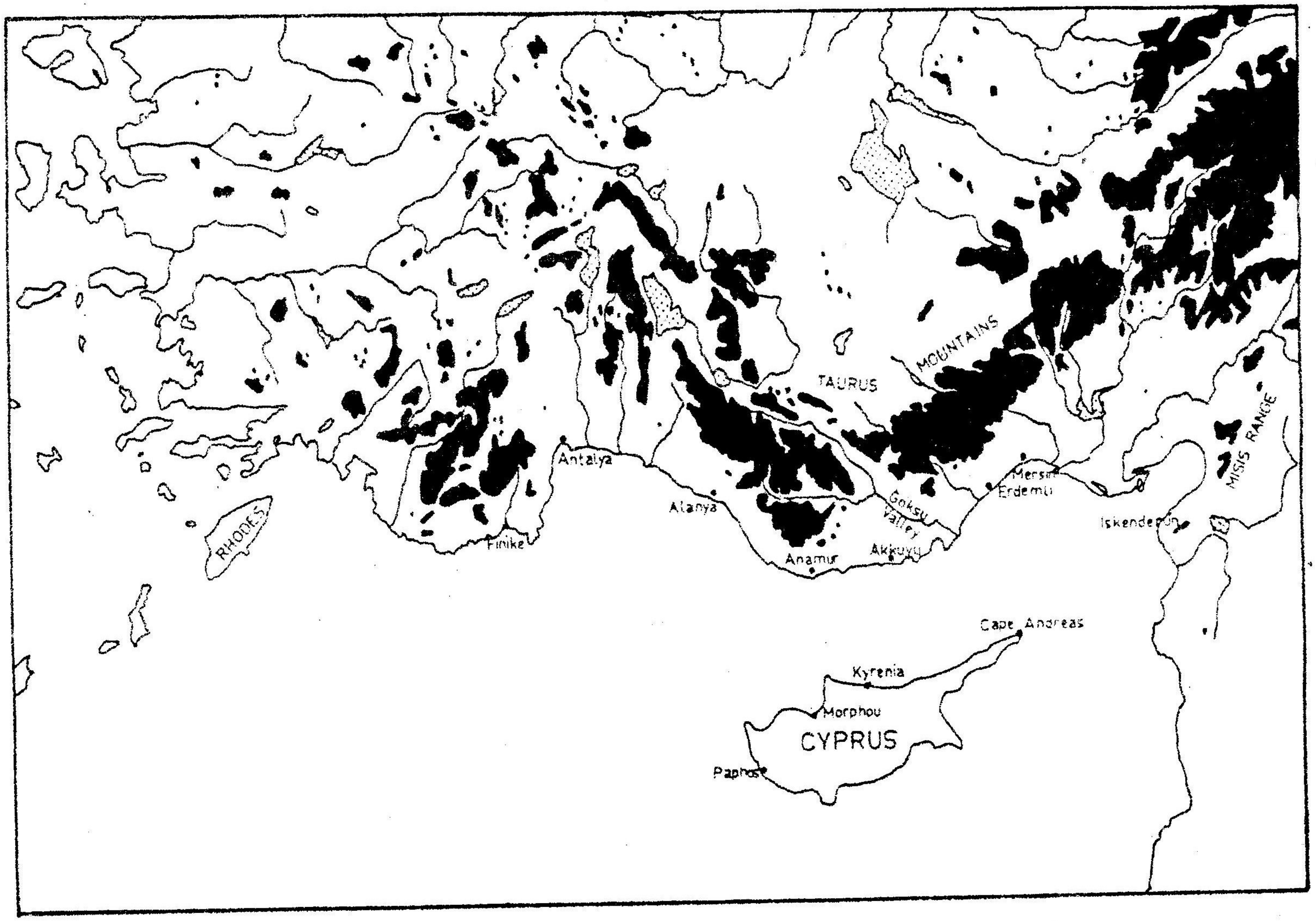

Fig.1: Location of Coastal Stations and Topographic Relief of the Southern Turkish Coast.
(Shaded Areas Represent Elevations Above 1500 m).

An examination of the meteorological factors along the Turkish

oast points to the predominance of evaporation rates at two regions: he Gulf of Antalya and the area between Anamur and Silifke, while the atter is shown to be much more important. Annual variation of salinity, emperature and density obtained in this region show the evidences of IW formation and indicate the time scales of evolution.

vaporation and Rainfall

a. Evaporation: Evaporation rates in units of gm cm^{-2} day^{-2} = cm day^{-1} of sea water) are computed using the following bulk formula BUDYKO, 1963, BUNKER,1972):

$$E = C\ (0.98\ q_w - q_a)\ W \qquad (1)$$

here W is the wind speed in units of cm/sec, q_w the saturation value f specific humidity at the air-sea interface, q_a the specific humidity t a given elevation (10m) above the sea surface, and C is an empirical oefficient. A value of C = 0.216 is adopted when monthly mean values re used in the calculation, and a value of C = 0.194 is taken when sing daily means (BUNKER,1972).

Evaporation has been calculated at the coastal stations Finike, ntalya, Alanya, Anamur, Akkuyu, Mersin and Iskenderun, the locations f which are shown in Fig.1. With the exception of Akkuyu, monthly ean data were obtained from the Turkish Meteorological Office. At kkuyu, where previous measurements were not available, an oceano-raphic measurement programme carried out during August 1977-June 1978 as yielded the meteorological and oceanographical information. In rder to summarize part of the data base used in the evaporation cal-ulations, the annual variations of wind speed, air temperature, and ea surface temperature at the coastal stations are given in Fig.2. he mean sea and air temperatures do not show significant variations rom one station to the other, but the winds are seen to be highest at kkuyu, followed next by Antalya and the other stations.

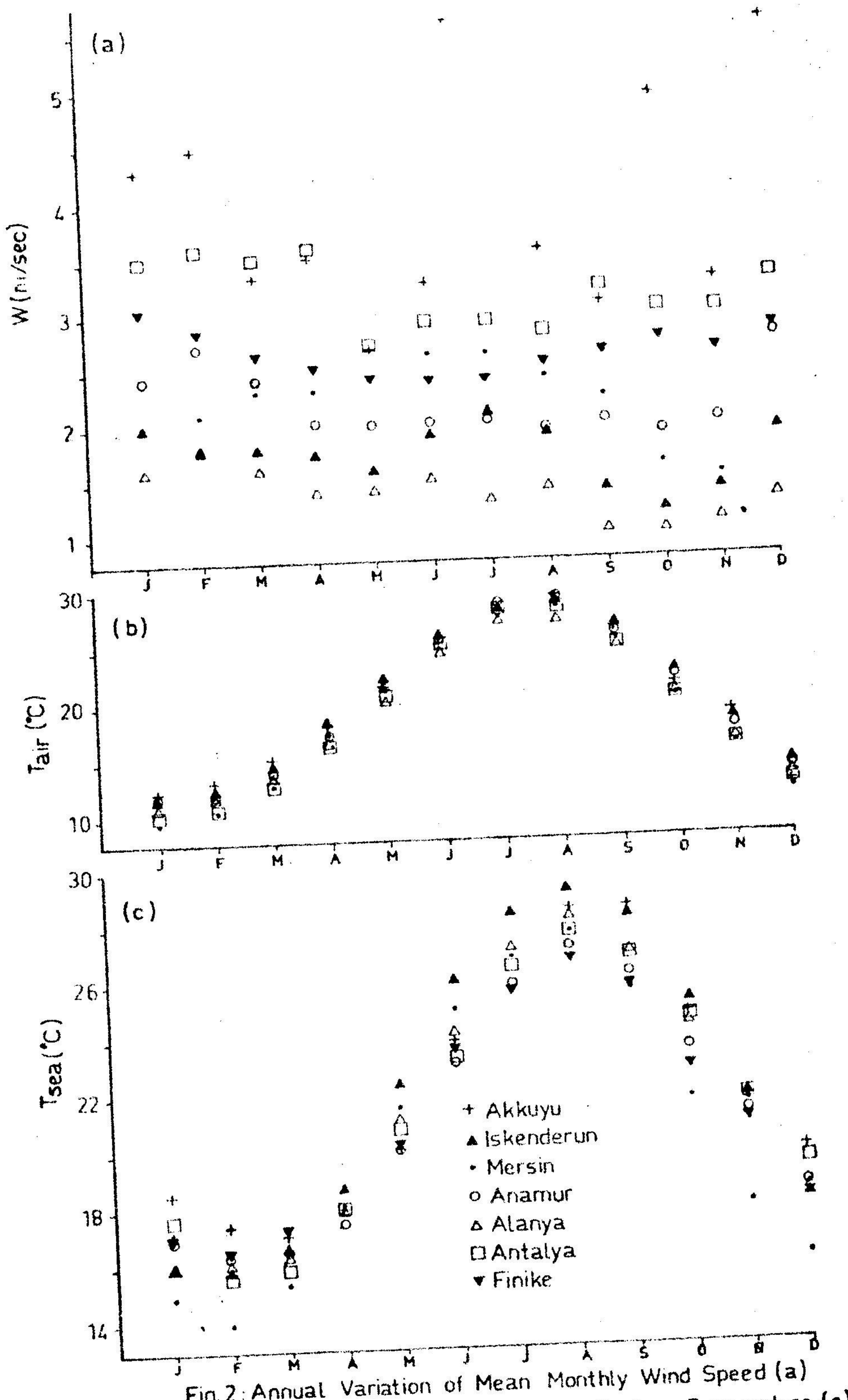

Fig. 2: Annual Variation of Mean Monthly Wind Speed (a) Air Temperature (b) and Sea Surface Temperature (c)

Monthly evaporation values E computed via Eq.(1) and the asured rainfall R are given in Table I. For comparison, pan evaporaon values, when available, are also provided in the same table. It is en in Table I that the annual evaporation in Akkuyu area has the rgest magnitude accompanied by a relatively small rainfall. In fact, ring the cooling period extending from October to February, Akkuyu s the largest evaporation rates among the seven coastal stations. The ly serious competitor to Akkuyu in evaporation is Antalya where the infall is also larger.

The relatively large rate of evaporation in Akkuyu can be attrited to a wind system that is referred to locally as the Poyraz, a rtherly wind that frequently blows through the Göksu Valley, which rms the largest opening in the east-west oriented Taurus mountain ain (Fig.1). The width of the Poyraz wind system is approximately 0 km. In summer (August) the Poyraz is triggered by thermal gradients. cooler months (October-February) the wind system is driven by extraopical cyclones which frequent Anatolia and the eastern Mediterranean ALMEN and NEWTON,1966). The Taurus mountains form an obstruction to e descending motions of the northerly flow behind low pressure areas ALMEN and NEWTON,1966), except in the segment of mountain chain lying tween Silifke and Anamur. The result is locally intensified mesoale northerly flow that often transports the dry air from the upper r layers over central Anatolia as seen from the relative humidity ots in Fig.3.b. The situation is very reminiscent of the Mistral the western Mediterranean (BUNKER, 1972), and the Bora in e Adriatic coast (CROWE, 1971).

Typical Poyraz events have durations of 1-10 days and contain diurnal uctuations due to radiational heating/cooling. Wind speeds may ach up to 35 m/sec (hourly averages) and relative humidity often lls below 10%. These extreme values are not shown in Fig.4 since day averages have been plotted. As a result of the mixing and aporation caused by Poyraz, the water temperature (Fig.3) drops gnificantly during winter months. The variation in water temperares occurs in a series of stepwise drops during Poyraz dates (not

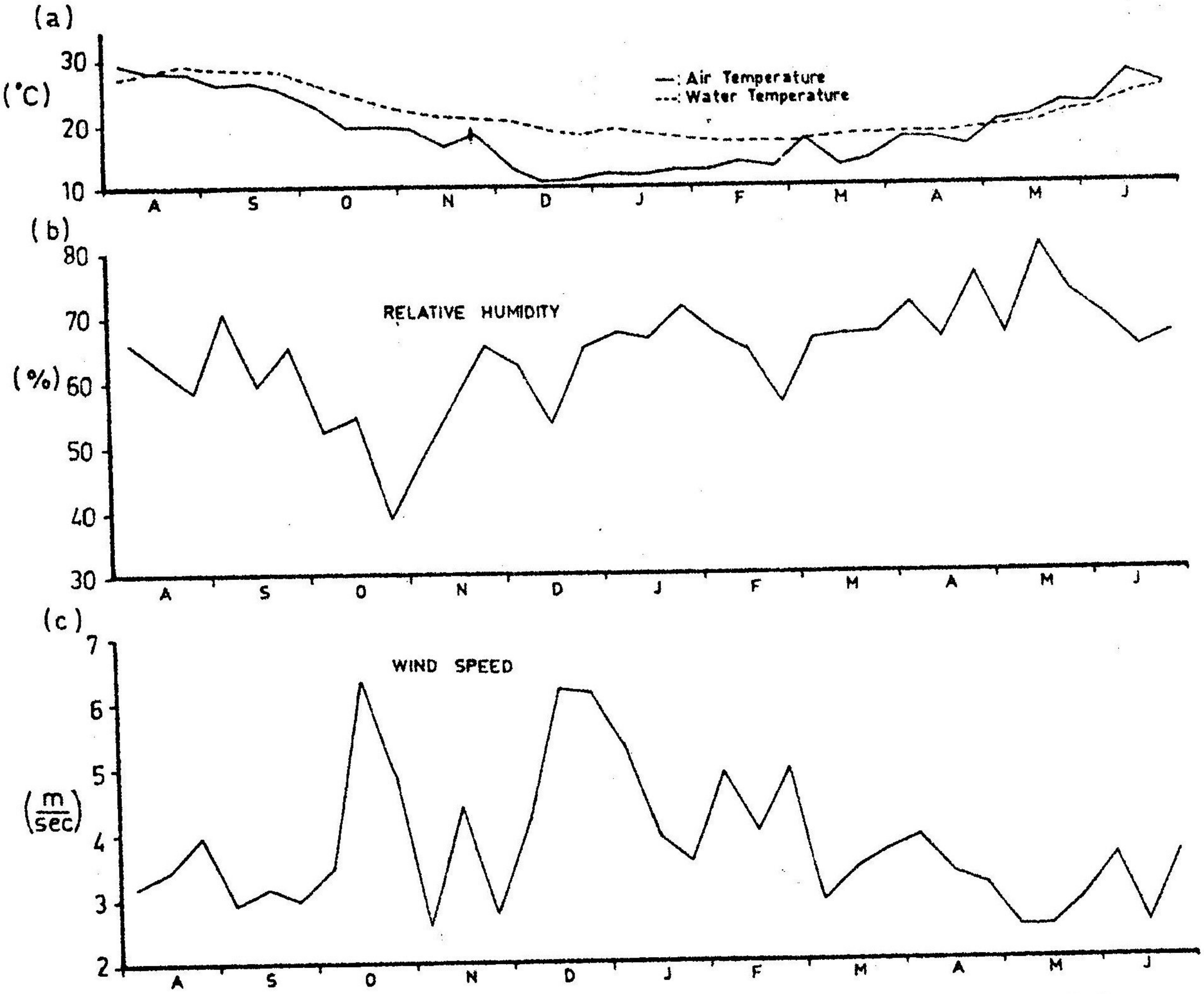

Fig.3: Air Temperature Water Temperature (a) Relative Humidity (b) and Wind Speed (c) Variations at Akkuyu for the Period September 1977–June 1978

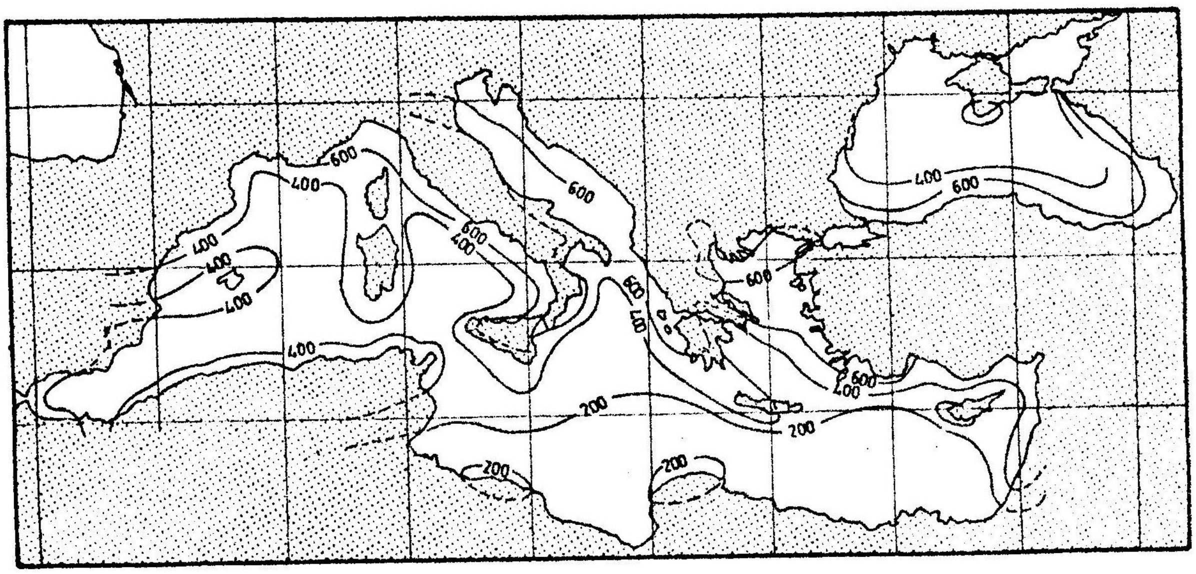

Fig.4: Annual Rainfall Distribution Over the Mediterranean Sea (after Tixeront 1970).

own here due to 10 day averaging). However, the sea water is still out $8^{o}C$ warmer than the air during January, which favors further aporation.

An examination of the topographical features of the Taurus untain chain reveals that there are several narrow valleys which so cause channelization of the northerly winds driven by the large-ale cyclonic disturbances. However, the extent of such a channeli-tion is by no means as large as that found in the Akkuyu area. It pears nonetheless that winds at Antalya are sufficiently high to use considerable evaporation (Table I and Fig.3). It is also worthy note that the relative humidity in Antalya does not show the nima found in Akkuyu (Figure 3). Northerly winds are also found at nike but their intensity is not as high as those found in Antalya. is yields lower evaporation rates in the Finike area.

The rate of evaporation for the eastern Mediterranean during bruary have been computed by Bunker (1972), using SSMO data. The gion of the northern Levant lying between Rhodes and Cyprus is und to have February evaporation rate of 0.52 gm cm^{-2} day^{-1}. The astal stations Finike, Antalya and Alanya are in this region, and t is inferred from Table I that the evaporation rates for these sta-ions are, 0.39, 0.49, and 0.22 gm cm^{-2} day^{-1}, respectively. Conse-uently, our evaporation estimates for Antalya and, to some extent, or Finike is close to Bunker's while the value for Alanya is consid-rably smaller. This is attributed to orography, for Alanya is ell protected from the northerlies. On the other hand, the February vaporation rate calculated by Bunker for the northeastern Levant ying between Turkey and Cyprus is 0.44 gm cm^{-2} day^{-1}. The evapora-ion rates for the stations Anamur, Akkuyu, Mersin, and Iskenderun ocated in this region are 0.31, 0.61, 0.28 and 0.26 gm cm^{-2} day^{-1} espectively.

It is seen that our estimate for Akkuyu exceeds Bunker's, hile the rates for Anamur, Mersin and Iskenderun are underestimated. he average evaporation rate of these four stations is 0.37 gm cm^{-2} ay^{-1}. It is expected that the orographic effects should yield

Table I.

Evaporation E(mm) and Rainfall R(mm). Numbers in parentheses refer to pan evaporation values.

	Finike		Antalya		Alanya		Anamur		Akkuyu		Mersin		Iskenderun	
	E	R	E	R	E	R	E	R	E	R	E	R	E	R
Jan.	114	279	155 (66)	264	63 (116)	244	90 (887)	218	177	137	81 (39)	115	76 (62)	124
Feb.	95	130	141 (70)	156	66 (101)	174	96 (87)	189	164	179	69 (41)	105	62 (70)	99
March	79	92	129 (93)	93	51 (126)	81	81 (107)	110	107	74	78 (60)	50	58 (76)	92
April	76	36	111 (91)	44	45 (107)	34	57 (128)	30	84	38	78 (66)	33	52 (82)	65
May	70	22	85 (107)	31	39 (106)	32	54 (116)	25	42	3	87 (73)	23	57 (99)	53
June	94	6	114 (157)	10	51 (148)	4	63 (152)	5	100	2	102 (87)	11	84 (87)	18
July	109	3	146 (202)	2	63 (148)	2	81 (192)	0	150	0	105 (99)	9	106 (106)	4
Aug.	133	1	166 (196)	3	81 (198)	0	96 (227)	0	213	0	132 (103)	5	107 (104	16
Sept.	156	10	218 (174)	14	63 (132)	24	117 (180)	10	187	1	147 (98)	11	92 (92)	38
Oct.	136	69	189 (137)	58	69 (179)	74	102 (142	77	311	8	99 (89)	41	74 (83)	92
Nov.	123	78	165 (85)	111	54 (104)	131	96 (101)	114	179	14	66 (59)	75	75 (73)	77
Dec.	112	262	162 (68)	284	51 (97)	244	102 (84)	236	305	111	81 (43)	124	84 (92)	107
Total (cm)	130	99	178	107	69	104	104	101	202	57	113	60	93	79
E-R(cm)	31		71		-35		3		145		53		14	

'erent values for these stations. Although the underlying reasons the differences found between Bunker's estimates and those given is difficult to ascertain, the details of the air-land interacs are probably lacking in the SSMO data.

b. Rainfall: The rainfall values given in Table I for various tal stations should be viewed with care when applying these es to the sea, since the measurements at mountainous areas generaleflect the orographic precipitation in the immediate environment. effect of orography is demonstrated by the variation of annual fall recorded over 90 cm. in Finike, Antalya, Alanya and Anamur ower values around 60 cm. towards Akkuyu and Mersin. Large scale urbances moving into the eastern Mediterranean from the Aegean on (Mediterranean Pilot,1976) generally follow the Taurus moun- range. The associated low level fronts are usually intercepted he southwest Anatolian mountains which are aligned in a SW-NE ction (Fig.1), and leave much of their moisture in this region as raphic precipitation. Therefore the cyclones which are rejuven- in the Cyprus area do not bring much rain to the Akkuyu-Mersin tal region, where the Taurus range lies parallel to the coast. A tive increase in rainfall is observed at Iskenderun (80 cm) due he Misis mountain range, which lies in the direction perpendicular he paths of the cyclones.

The orographic influences on precipitation in coastal areas the estimation of rainfall over the northern Levantine sea (area ween Rhodes and Cyprus) a difficult task. Tixeront (1970) has lled the distribution of rainfall over the Mediterranean from ervations at coastal stations on islands and from limited ship obserions. The corresponding distribution of annual rainfall in the west- coastal stations seem to be much in excess, whereas the values r Akkuyu and Mersin seem to be more representative of the rainfall r the sea. In order to obtain corrected rainfall values over the thern Levantine sea, averages of the rainfall recorded at coastal

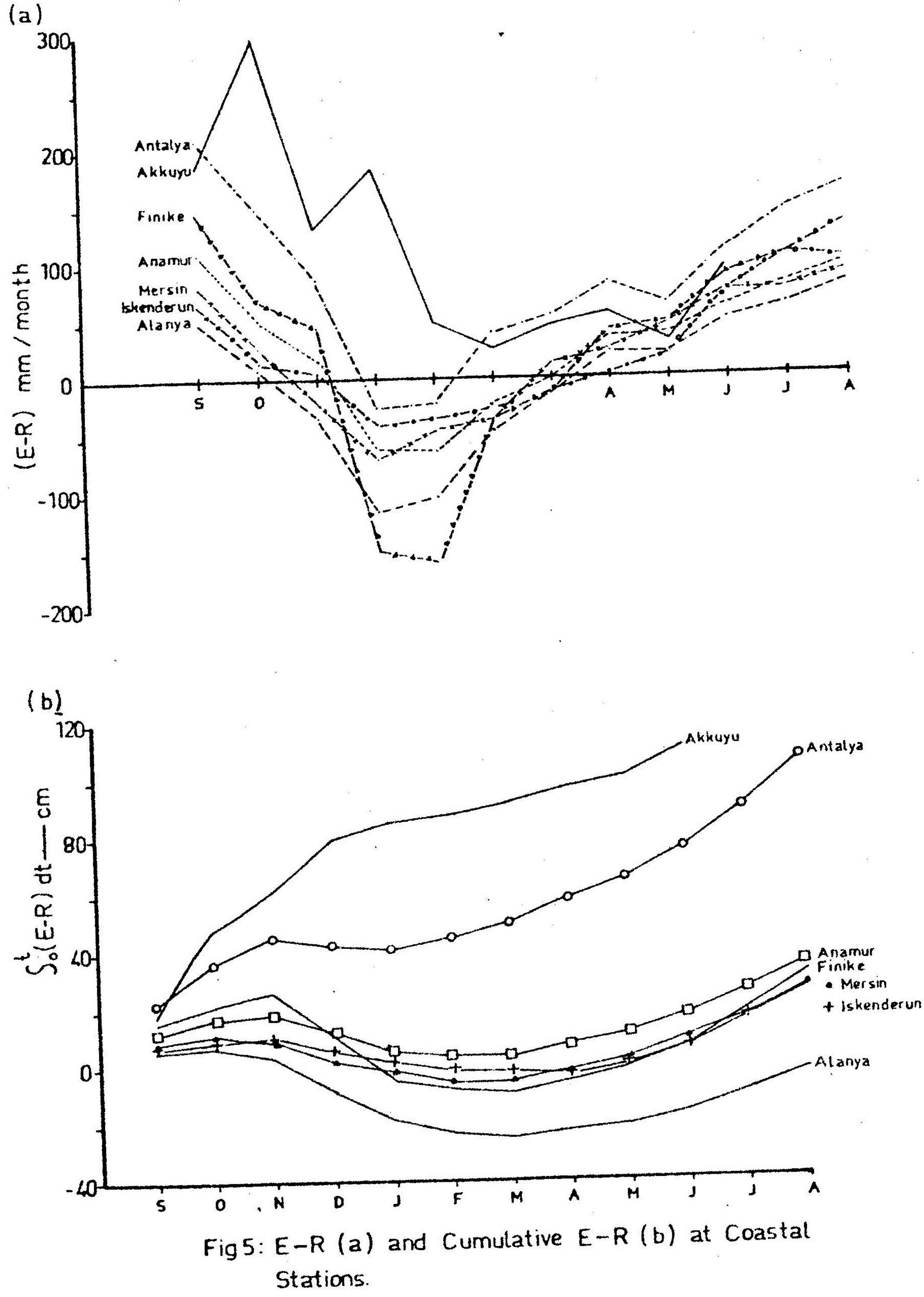

Fig 5: E–R (a) and Cumulative E–R (b) at Coastal Stations.

ations and those across from these stations on Cyprus were formed. The infall was thus estimated by taking the averages Antalya-Paphos nnual average rainfall: 76 cm), Finike-Paphos (78 cm), Anamur-Morphou 9 cm), Akkuyu-Kyrenia (56 cm), Mersin-C.Andreas (56 cm), and kenderun-C.Andreas (65 cm). Cyprus data were obtained from the Mediranean Pilot (1976). The averaged values of annual rainfall compare tter with Tixeront's (1970) estimates (see Fig. 4).

c. (E-R) and Salinity Changes: The values of E-R calculated om the evaporation values in Table I and the corrected rainfall lues described in section 2.b are shown in Fig. 5.a. The highest o peaks occur in Akkuyu during the months of October and December en strong and dry Poyraz winds are effective in the region (see Fig.). The next highest values of E-R are encountered in Antalya, with lues slightly higher than that of Akkuyu during the spring months. owever, the much higher evaporative losses at Akkuyu between Septemr and February are significant in aiding water mass formation. The ther coastal stations display much smaller values of E-R as compared o these two stations.

The salinity of the surface layers of the sea is influenced by he water losses and the mixing of this newly formed water mass over he surface mixed layer. A simple box model accounting for salinity hanges in the mixed layer due to the surface mass flux component is xpressed as (KRAUS, 1977):

$$\frac{dS}{dt} = \frac{1}{h} (E-R) S \qquad (2)$$

here S is the salinity, and h is the mixed layer depth. In the soluion to Eq.(2):

$$S = S_o \exp \int_o^t \left(\frac{E-R}{h} \right) dt, \qquad (3)$$

he salinity evolves from an initial value S_o in proportion to the

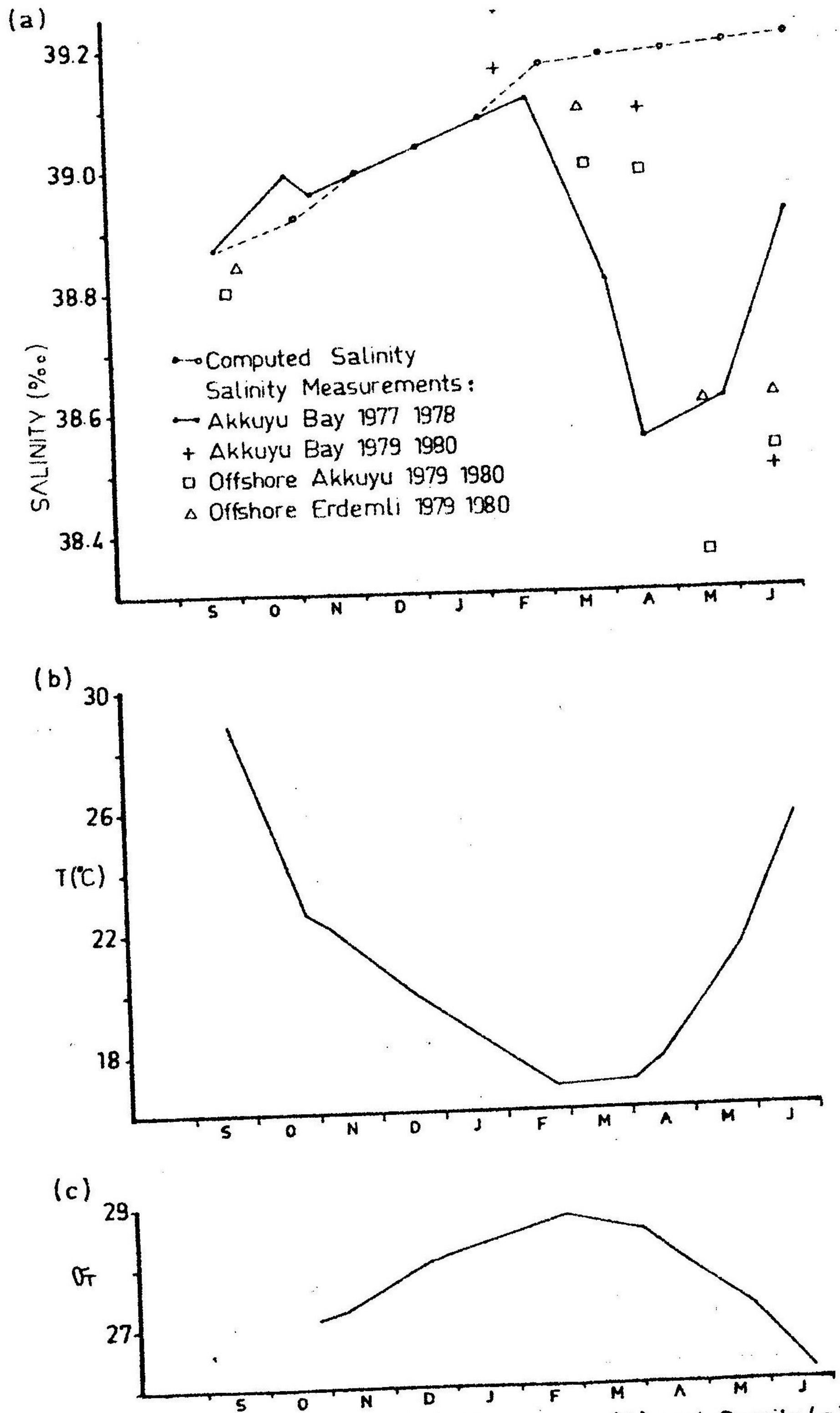

Fig. 6: Salinity (a), Temperature (b) and Density (c) Variations at Akkuyu for the Period September 1977 - June 1978.

ulative values of (E-R)/h. Since accurate information on the annual ch of salinity and mixed layer depth at each station is lacking, a t simple estimation of the cumulative effects of evaporative fluxes been made by assuming the mixed layer depth to be constant and paring the cumulative E-R curves for each station. These curves wn in Fig.5.b indicate the largest contribution to the salinity lution at Akkuyu, followed by Antalya and the other stations.

W Formation

The annual variation of salinity, temperature, and density at kuyu are shown in Fig.6. The measurements have been done in Akkuyu y, where an oceanographic monitoring programme has been carried out a monthly basis. Data from four profiling stations within Akkuyu y have been averaged to obtain the values presented in Fig.6. Akkuyu y is a small (radius=2 km) and deep bay with a continuous connection th the narrow Turkish continental shelf; the depth at the bay en- rance is about 30 m. and it increases linearly further offshore.

The annual march of salinity in Fig.6.a has an absolute maximum f 39.1 $^{o}/oo$ in the month of February, at which time the temperature eaches its mimimum value of 16.8^{o}C and a maximum density value σ_t = 8.7 is observed. During the following months, the salinity first rops to 38.6 $^{o}/oo$, then continues increasing in a new period of volution. The total length of this period is about four months. The alculation of salinity at Akkuyu based on Eq.(3) and a constant ixed layer depth of 150 m. is in agreement with the measurements uring September - February, but fails to produce the sharp drop after ebruary. This remarkable evolutionary phase signifies the period f formation of the Levantine Intermediate Water (LIW).

Continuous monitoring of the annual variability (Fig.6) has not een made available earlier. The surface waters reach salinity sub- axima and temperature maxima during summer. After this pre-trans- ormation phase, the cold and dry outbreaks of continental polar air asses enhance evaporation and the resulting instability mechanisms use water mass formation (LACOMBE and TCHERNIA,1974). The high linity and low temperature waters during winter form the LIW which identified with S = 39.1 °/oo, T = 15.5°C and σ_t = 29.0 (MORCOS, 72). In Fig.6.a. a water mass with values close to these are seen be formed in February. The temperature is slightly higher than at for the core of the LIW, in agreement with Morcos' observations. e dense waters formed at the surface are mixed to much greater depths ter February. In November, there is an Atlantic water of minimum linity (~38.6 °/oo) underlying the seasonal thermocline at 60 - 0 m. and above the intermediate salinity maximum at 250 - 300 m. ob- rved from oceanographic profiles in the northern Levantine region ILLER et al,1970). After the sinking of the dense surface waters d the mixing with this Atlantic water mass, salinity in the region ops considerably during February - April. The uniformity of salinity ofiles up to depths of 300 m. during these months as a result of the oining of surface and intermediate waters has also been reported by acombe and Tchernia (1974) and Morcos (1972). Measurements obtained uring 1979-1980 at Akkuyu and also offshore of Erdemli (Fig.6.a) ndicate a repetition of the sinking process with a delay of about one onth due to the excessive amounts of rainfall (return period 30 years) eceived during this year.

ummary and Discussion

The review of climatological and oceanographic data shows that he northern Levantine is a possible source region for the LIW. In articular, the area between Anamur and Silifke on the Turkish coast hannelizes cold outbreaks reaching the region from the north. ifferent water masses of the Mediterranean are formed at the Gulf f Genoa, the Adriatic Sea and near Cyprus, all of which are regions f cyclogenesis. An analogy also exists between these areas in that ehind the depressions passing from these areas, violent northerly inds (Mistral and Tremontana in the Gulf of Lions, Bora in the north- rn Adriatic coast, and Poyraz on the Turkish coast to the north of yprus) are formed due to channelization of the flow of valleys LACOMBE and TCHERNIA,1974; BUNKER,1972). The Poyraz winds deepen he mixed layer during August-February and cause large evaporation ates as a result of which the pre-sinking transformation of the urface waters takes place. The further mixing of these dense aters through sinking motions contributes to the core of the LIW.

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