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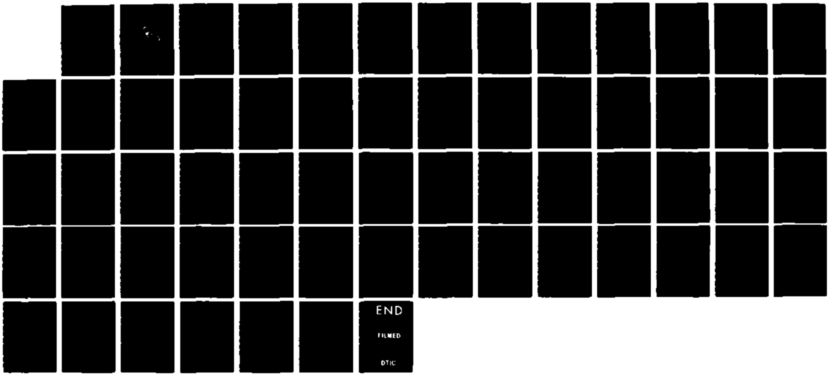

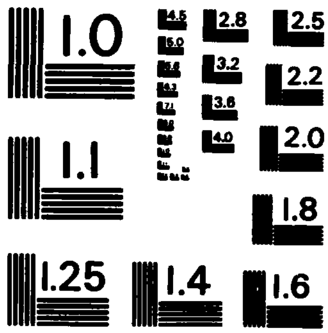

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THESIS

SINGLE STATION ASSESSMENT OF ATMOSPHERIC
BOUNDARY LAYER PROPERTIES IN THE
EASTERN MEDITERRANEAN SEA

by

Charles E. Sellers

June 1985

Thesis Advisor: Kenneth Davidson

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Single Station Assessment of Atmospheric Boundary Layer Properties in the Eastern Mediterranean SEA

by

Charles E. Sellers
Lieutenant Commander, United States Navy
B.S., United States Naval Academy, 1975

Submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY AND OCEANOGRAPHY

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June 1985

Author: Charles E. Sellers
Charles E. Sellers

Approved by: Kenneth L. Davidson
Kenneth L. Davidson, Thesis Advisor

William J. Shaw
William J. Shaw, Second Reader

Robert J. Renard
Robert J. Renard, Chairman,
Department of Meteorology

J N Dyer
John N. Dyer,
Dean of Science and Engineering

ABSTRACT

The marine environment strongly affects the use of naval weapons and sensor systems. The ducting of electromagnetic energy is one of the most important influences on modern systems. The ability to describe the atmosphere is the first step in producing a realistic forecast. This study shows that in the eastern Mediterranean Sea the observed soundings appear to have a systematic error in the lower sections of the mixed layer. This, coupled with the synoptic scale changes in the atmosphere, causes single station forecasting scheme to fail. This thesis emphasizes two points: 1) the need for an accurate description of the atmosphere is paramount to any forecast. 2) the users of any single station forecast must use their knowledge of the models and compare the model results to the other information on hand to determine whether or not the prediction is reliable.

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I. INTRODUCTION

Weapons systems which use Very High Frequency(VHF) and Ultra High Frequency(UHF) electromagnetic radiation are very much affected by the environment in which they operate. Atmospheric refraction causes a condition for EM propagation known as ducting. This occurs most often in the atmospheric boundary layer when a trapping layer causes the energy from a radar to bend toward the earth with a curvature greater than the earth's curvature. This bending can cause the energy to become trapped between layers of different refractivity. This process will be covered in greater detail in section 2A. Another aspect of the energy becoming trapped is that the area just above the trapping layer does not receive enough energy for detection. This is known as a "radar hole". The major variables which determine ducting are the vertical gradients in temperature and humidity (Kerr,1951). These parameters can cause extended ranges due to trapping layers as well as holes in the radar or radio's coverage.

The advantages to be gained with the ability to predict the ducting conditions are quite important. Military commanders would be able to use the predicted EM propagation patterns to establish the counter-detection and Electronic Support Measures(ESM) detection ranges. Also they would be able to formulate the most effective Emission Control(EMCON) policy. The greatest advantage could be in the positioning of air and sea surveillance assets and directing the altitude and flight profiles for strike aircraft to minimize their detection.

The Navy employs a microcomputer-based system, the Integrated Refractive Effects Prediction System(IREPS)

(Hitney,1979), to identify the ducting conditions. IREPS also assesses the effects of the refraction on various EM systems. Currently, IREPS is being employed on all of the Navy's aircraft carriers and at some of the Navy's oceanography centers. The IREPS program is initialized with the vertical distribution of the temperature and humidity from a radiosonde launch. The model's most important assumption is that the atmosphere is horizontally homogeneous.

Given an accurate sounding, IREPS is effective for identifying the layers present at the radiosonde launch site for the time at which the launch took place. It does not predict how the conditions will change with time and space. Another area of concern which causes problems is the assumption that the vertical structure of the temperature and specific humidity will remain the same between launches. There are two methods to solve this problem. The first would be to make more frequent launches. The second is to develop a model to forecast the changes in the refractivity conditions. A model to forecast the changes in ducting has been developed and will be discussed in the next section.

A. SINGLE STATION FORECASTING

A ship at sea attempts to have available a forecast for the area in which she is operating by using only the observations from that ship. This forecast is known as a single station forecast. The advantage of a single station forecast approach is that the ship is not dependent on an outside source for information. This permits the ship to act independently of the environmental products, such as a surface analysis or a 500mb isotach, which are produced at remote stations. Also, the meteorologist can determine whether recent data supports the prediction or are inconsistent with it. Another advantage of a single station forecast is the ability to make predictions when the information is needed rather than according to an established time schedule.

The forecast is limited by the assumption of a horizontally homogeneous atmosphere. This is a particular problem in any area which has varying characteristics due to the different solar effects such as a land mass versus an oceanic area. This is a problem in the eastern Mediterranean Sea due to the area having hot dry land on three sides and a large island in the center.

For subsynoptic conditions a single station forecasting system is ideal due to the major effect of local conditions. The effect of squall lines moving through the area or the effect of the large scale land/sea radiational differences can be taken into account as the ship moves away from the affected area by taking another sounding as the local effects stabilize. A single station forecasting model has been developed for the marine atmospheric mixed layer, which typically is found below 1000m. The microcomputer-based marine boundary layer model, which is described in Section 2B, was developed by the Environmental Physics Group at the Naval Postgraduate School(Davidson,et al. 1984).

The data used for this examination of the forecasting model were those from radiosonde launches made by the USS Eisenhower during a Mediterranean deployment in September 1983. The Mediterranean Sea was selected for study because it is the area in which the U.S. Navy is most likely to deploy the largest number of ships. The eastern Mediterranean Sea is the most volatile region in the area and, hence, the most likely to require the U. S. Navy's presence. This is easily seen during the Eisenhower's deployment in the falll of 1983 when her presence was required to support the Marines ashore in Lebanon.

The Eisenhower was operating in a localized area for the period mentioned above. This is unique in most Navy operations due to the tactical advantage gained by a task force continuously shifting its position. In this instance the ship was required to remain on station in a relatively confined area because she had to be able to quickly provide support to the Marines. In the open ocean this is usually not a problem, but in the Mediterranean the land surrounds the task force on three sides and restricts the force's ability to use its mobility.

The purpose of this thesis is to evaluate the application of the atmospheric mixed layer model to current fleet tactics in the eastern Mediterranean. The data considered were from radiosondes taken from the USS Eisenhower in the eastern Mediterranean during February 1983 as shown in Fig. 1.1 This area is of vital interest since it is a primary operating area.

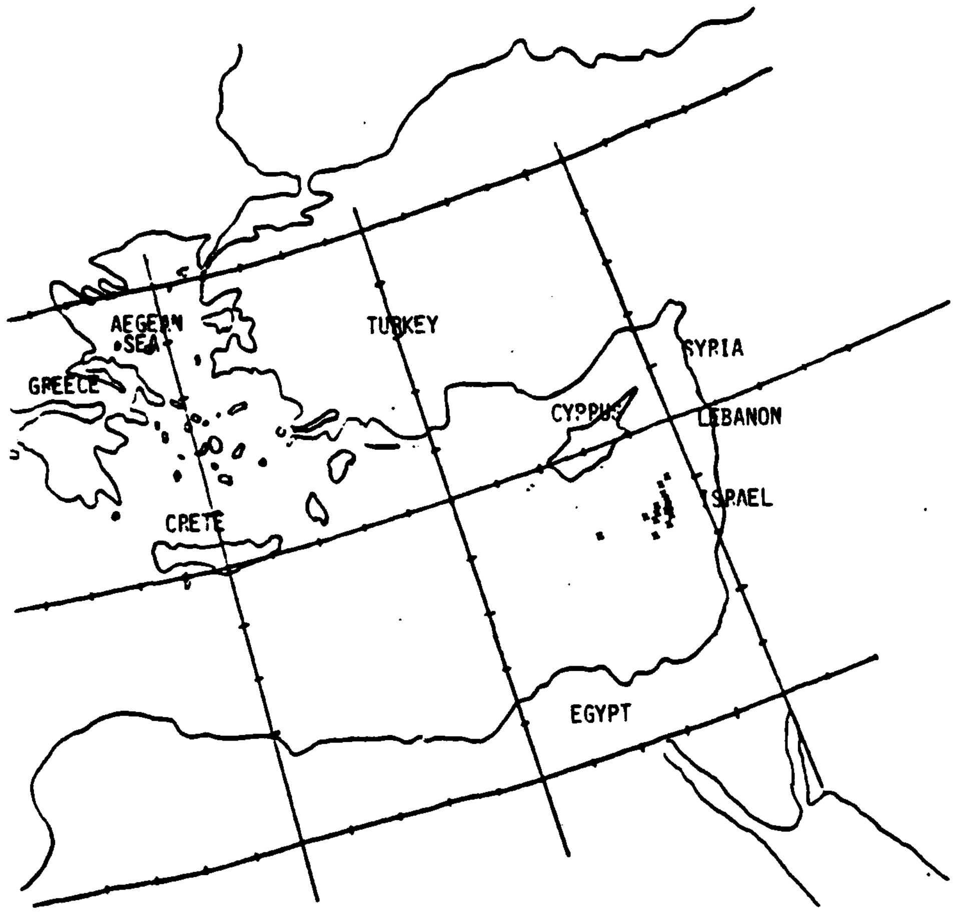

Figure 1.1 Radiosonde Launch Positions

II. DUCTING PHENOMENA AND MODEL DESCRIPTION

A. DUCT FORMATION

EM wave ducting is associated with thermal inversions which act as trapping layers that refract, or bend, EM energy toward the earth. Inversions which occur on top of the well-mixed boundary layer are associated with large changes in the potential temperature. However, in this thesis the specific humidity jump(decrease) within the inversion is also addressed because of its importance. Strong inversions are typically found in marine regions when a surface high pressure system is present. They are found in areas of either extensive low-level stratus clouds or clear sky conditions. Conversely, ducting is minimal near fronts and in areas of convective activity. The vertical motion which occurs near fronts removes the inversions as the air column becomes mixed.

As is illustrated in Fig. 2.1 warm dry air over the hot land regions rises and sinks over the cool moist air over adjacent bodies of water (Wallace and Hobbs, 1977). This can occur on a subsynoptic scale up to 70km from the coast if the heating over land is significant, as it is in the eastern Mediterranean Sea in September. This can also be capped by a subsidence inversion. This condition is the most favorable one for duct formation.

Ducting conditions are normally identified with plots of the modified refractivity(M) versus height. M and N(refractivity) are related to the distribution of temperature and humidity (Kerr,1951). M and N are related as follows:

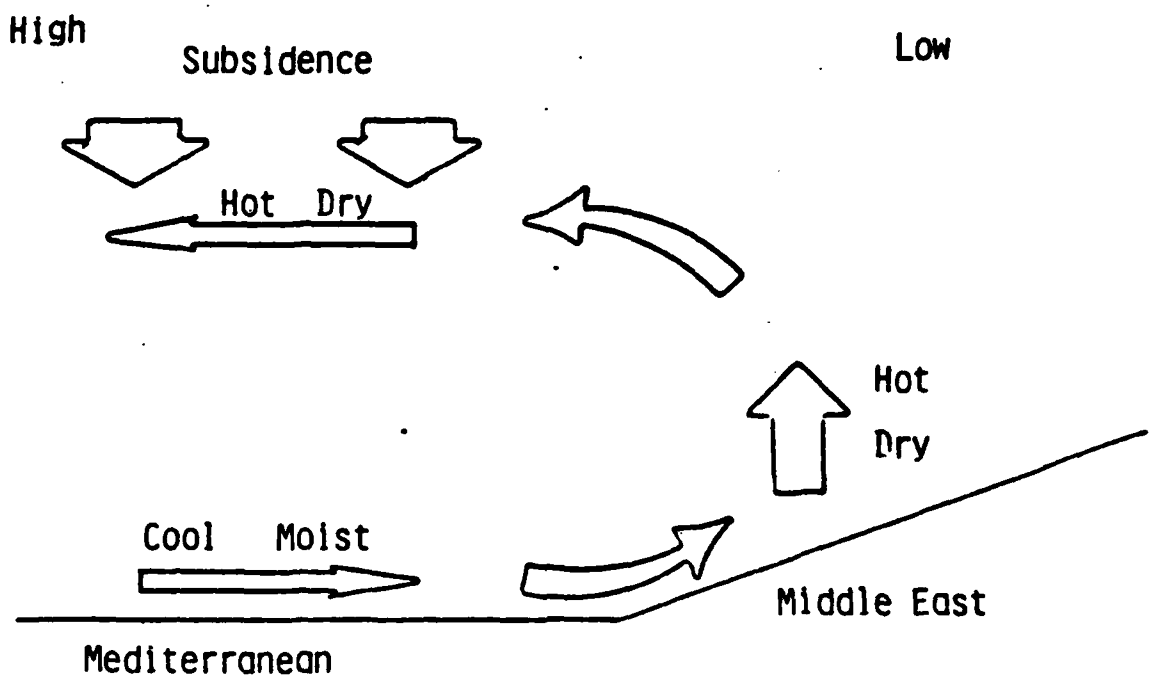

Figure 2.1 Optimum Conditions for Duct Formation

$$M = N + .157h \qquad \text{(eqn 2.1)}$$

where h=height in meters. As can be seen in Equation 2.2, N is directly related to temperature(T) and indirectly to specific humidity(q).

$$N = 77.6(P/T) + 3.73\times10^5(q/T^2) \qquad \text{(eqn 2.2)}$$

On the basis of near surface values of P, T and q, the N gradients are related to the P, T and q gradients as:

$$dN/dZ = .3(dP/dZ) + 7(dq/dZ) - 1.3(dT/dZ) \qquad \text{(eqn 2.3)}$$

Figure 2.2 is an example of the vertical distribution of the potential temperature and the specific humidity with the corresponding M profile and duct indicated.

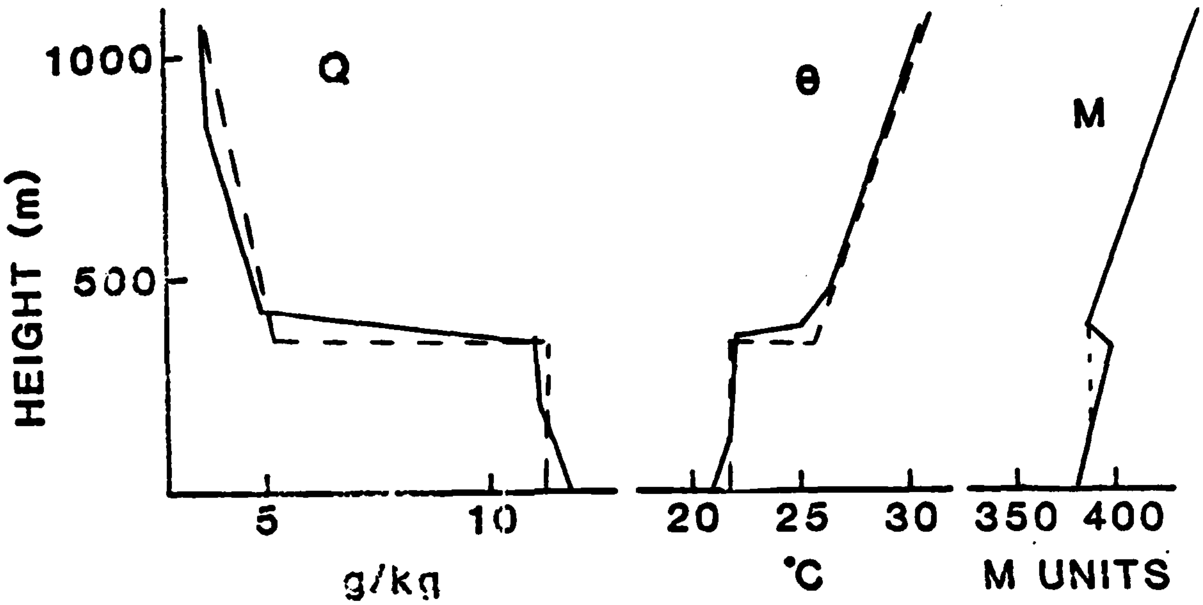

Figure 2.2 Vertical Structure of θ, q and M Profile for a Typical Inversion

The M profile is used instead of the N profile because of the ease with which ducting information can be extracted from it. The top of a duct corresponds to the height above the surface where the M value is a minimum. The duct base corresponds to the height at which a vertical line drawn downward from the point of minimum M value first intersects the profile (Beach, 1980).

B. MODEL OVERVIEW

The Naval Postgraduate School(NPS) Mixed Layer Model is an integrated, two layer, zero-order model which predicts changes in the Marine Atmospheric Layer Boundary Layer(MABL). The model will be referred to as the NPS model. The upper layer is nonturbulent while the lower layer is turbulent and bounded by the sea surface and the inversion. The lower layer is assumed to be well-mixed because of its turbulent nature. The inversion is assumed to have zero thickness.

The inputs required for model predictions are:

(1) vertical distribution of temperature
(2) vertical distribution of moisture
(3) sea-surface temperature
(4) surface wind speed
(5) subsidence
(6) latitude
(7) Julian date
(8) local time of sounding

Subsidence rates are estimated from previous sequential radiosonde launches using the procedures described by Lenschow(1973). This method vertically integrates the moisture budget and assumes the specific humidity is well-mixed in the boundary layer. Also, it assumes the changes in the specific humidity occur due to fluxes at the sea surface and inversion only. The latitude, Julian date and local time are required to estimate incident solar radiation. The NPS model also predicts, in addition to the refractivity profile, the following:

(1) height of the inversion
(2) values of the well-mixed properties (temperature and moisture)
(3) the strength of the temperature and moisture jumps at the inversion

The parameters of the model have been discussed in a series of reports and journal articles prepared by the Environmental Physics Group at the Naval Postgraduate School (Davidson, et al.1984; Boyle, et al.1984; and Schacher, et al.1981.). Graves(1982) describes how calculations are made in the model and the methods used to arrive at a duct altitude and depth.

The general predictive equations of the model for the clear sky conditions are:

$$\frac{\partial h}{\partial t} = C\,\frac{\overline{W\theta}_{vo}}{\theta_v} + W_s \qquad \text{(eqn 2.4)}$$

$$\frac{dX_m}{dt} = (\overline{WX}_o - \overline{WX}_i)/h \qquad \text{(eqn 2.5)}$$

$$\frac{d\Delta X_m}{dt} = \gamma_x\,\frac{dh}{dt} - W_s - \frac{(\overline{WX}_o - \overline{WX}_i)}{h} \qquad \text{(eqn 2.6)}$$

where:

X =Any conservative property

h =Depth of the well mixed layer

$\overline{W\theta}_{vo}$=Surface buoyancy flux

θ_v =Virtual potential temperature

W =Subsidence rate

$\overline{WX}$=Flux of quantity X at the surface (o) and inversion(i)

γ_x =Gradient of X above the inversion

The model was adapted by Brower(1982) for use with the HP-9845 micro-computer. The model was evaluated on the basis of synoptic data in different regimes and geographic areas (Boyle, et al.,1984; Graves,1982; and Gleason,1982). The model has been coupled to an upper-ocean model (Davidson and Garwood,1984). For this thesis the uncoupled model was used because simultaneous ocean data were not available.

C. METHODOLOGY

An important model feature is the simplified initialization, as was shown in Fig. 2.2, to describe the potential temperature(θ) and the specific humidity(q) in the MABL and the inversion above it. The model requires an assumption of a well mixed layer which means θ and q must remain constant with height in the layer. Also, the subsidence rate is constant at a given height throughout the forecast period.

The initial profile and the subsidence are difficult to parameterize if the inversion is weak or if the sounding has multiple inversions. At the present stage the initialization is established subjectively by the user. This has been found to be the only method to remove the inaccurate data points.

Another cause of problems is calculating the subsidence. This is a difficult parameter to determine because there is no method to directly measure it. The subsidence is calculated using data from 12 hours preceding the forecast initializing sounding. Therefore, subsidence values represent average values over the 12 hours preceding the forecast period.

The final area of concern is that there is no "ground truth" for verifying ducting conditions. In this study the NPS model forecasts are compared to the observed sounding. This is possible because radiosonde launches were approximately 12 hours apart. The launches every 12 hours permitted a direct comparison between both the NPS model's 12 and 24 hour forecasts with the observed sounding at the verification time.

III. ATMOSPHERIC CONDITIONS

A. DATA SOURCE

The purpose of this thesis is to evaluate the application of the atmospheric mixed layer model to current fleet tactics in the eastern Mediterranean Sea. The data considered were from radiosonde launches taken from the USS Eisenhower in the eastern Mediterranean Sea during September 1983, as was shown in Fig. 1.1.

The radiosonde launches from 4 to 11 September 1983 provided an excellent example of varying ducting conditions. The M profiles for this period always showed one or two trapping layers for the first few days. As time progressed the synoptic situation changed, causing the ducts to weaken and to disappear near the end of the period. This evolution of ducting conditions provided an excellent opportunity to view the model under operational conditions. These conditions did not meet the optimum conditions for model performance. However, the area in which the Eisenhower was located is in an area in which our ships must spend a large amount of their time.

The data from the Eisenhower also included a refractivity forecast, which was locally prepared using synoptic scale weather information and sounding information available to the ship. It was considered in this study because it takes into account effects of synoptic- scale events on the refractivity. The forecast was based on procedures developed by the Geophisics Division at the Pacific Missile Test Center(PMTC), Point Mugu, Ca.(Rosenthal,1976). Given the limitations of synoptic scale forecasting of refractive conditions, this product proved to be relatively accurate.

B. SYNOPTIC SITUATION (4-11 SEPTEMBER 1983)

Atmospheric boundary layer conditions in the eastern Mediterranean Sea are very dependent on the season and the adjacent topography. The area of interest in this thesis is east of Cyprus where topography is dominated on the north by the Bey Daglari and and Taurus mountains in southern Turkey. There are major gaps in this barrier. To the east, the Lebanon mountains form a low barrier which will permit warm dry air to flow eastward under some synoptic situations.

Conditions for the area during September are dominated by an intense heat trough over southern Asia which extends westward over Turkey. This permits a ridge to form over the eastern Mediterranean Sea (Brody, 1980) The ridge will cause subsidence over the eastern Mediterranean Sea.

The synoptic situation during this period was dominated by a ridge in the central Mediterranean and a thermally induced low pressure system in the Middle East. The strength of these varied during the period. This ridge influenced two cold fronts, which came through the central Mediterranean Sea on the fourth and seventh of September, to pass to the north of the region. The absence of frontal passages permitted a well-defined marine atmospheric boundary layer to remain in the region around Cyprus for much of the period of interest. The thermal low pressure system formed over Lebanon and Syria which are east of the region of interest. Also a trough on the southern coast of Turkey extended toward Cyprus on two occasions.

C. DAILY SYNOPTIC AND REFRACTIVITY CONDITIONS

The following description of day-to-day weather and refractivity conditions for the study period are presented because they represent the information normally available to the single station forecaster. These effects should be taken into account when a forecast is made.

1. 4 September 1983

The 0000GMT Surface Analysis, Fig. 3.1, shows a high pressure system situated over southern Greece and a low pressure system over southeastern Turkey. This synoptic situation caused a general subsidence over the entire eastern Mediterranean Sea. A mid-level trough was located over the Aegean Sea. The 0205GMT radiosonde launch shows two elevated ducts with a top height of 1200m. The IREPS propagation assessment identified possible holes in the EM coverage between the layers and above the higher duct.

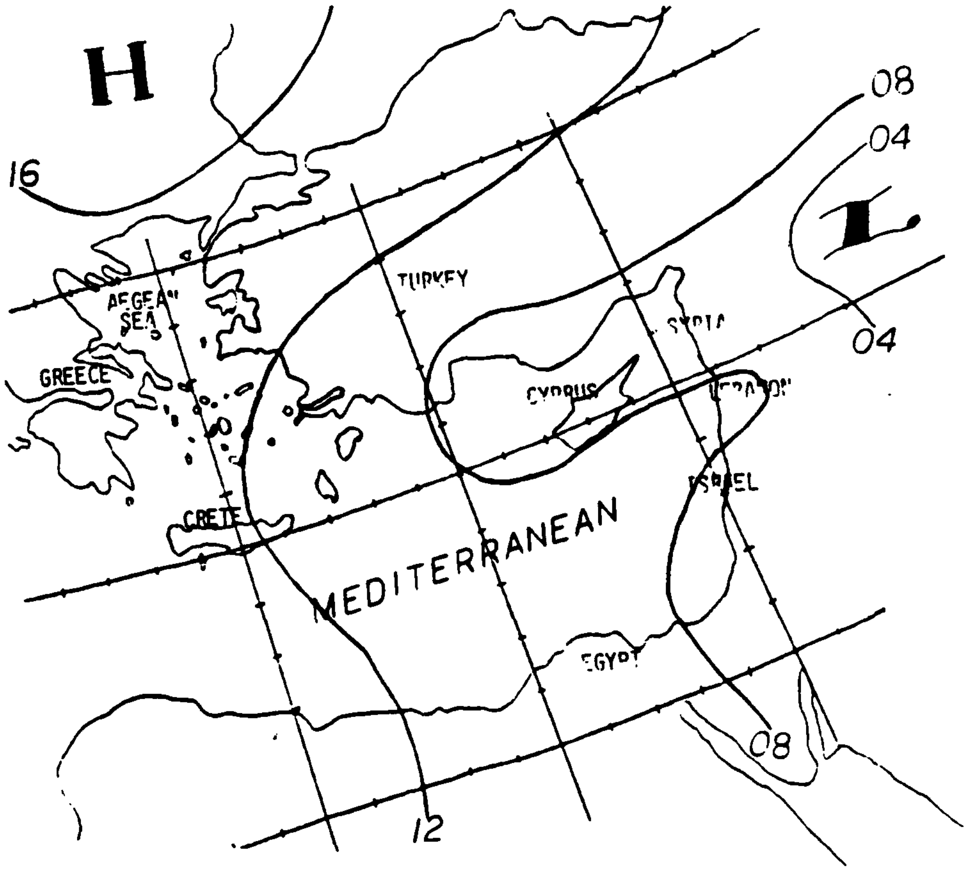

Figure 3.1 0000GMT 4 September 1983 Surface Analysis

The 1235GMT sounding had a surface duct and an elevated duct with a top of 700m. Again holes were possible between the layers and above the highest duct. A super-refractive layer was possible above 1000m with radar holes above it.

2. 5 September 1983

The 0000GMT Surface Analysis, Fig. 3.2, shows that the high pressure system which was located over Greece had weakened and a weak trough is moving into the western side of Greece. The strong low in Syria remained in the same position and the wind continued to blow from the west in the area around Cyprus. There was a mid-level low over southern Turkey and in the northern sections of the eastern Mediterranean Sea. A mid-level low in this position caused warm air to flow from the hot inland areas of Turkey, Syria, and Lebanon at the mid-level heights toward Cyprus. This provided a cap to the inversion at the top of the MABL and good conditions for ducting in the Eisenhower's vicinity.

The 1800GMT refractivity forecast shows surface trapping in the area east and south of Cyprus. This is verified by the 0100GMT radiosonde launch which had a surface duct and an elevated duct with a top of 950m. The IREPS assessment indicated possible EM holes between the ducts and just above the upper ducts. The 1215GMT launch showed a thicker surface trapping layer and an upper layer of super refractivity between 550m and 800m.

3. 6 September 1983

The 0000GMT Surface Analysis, Fig. 3.3, shows a strong low in southwestern Turkey and Syria with an associated trough extending across the southern coast of Turkey. The weak trough located west of Greece on the 5 September 0000GMT analysis had dissipated. This combination of meteorological systems caused a flow in the eastern Mediterranean Sea which was from southern Turkey across the area around Cyprus to Lebanon. This provided hot dry air to the

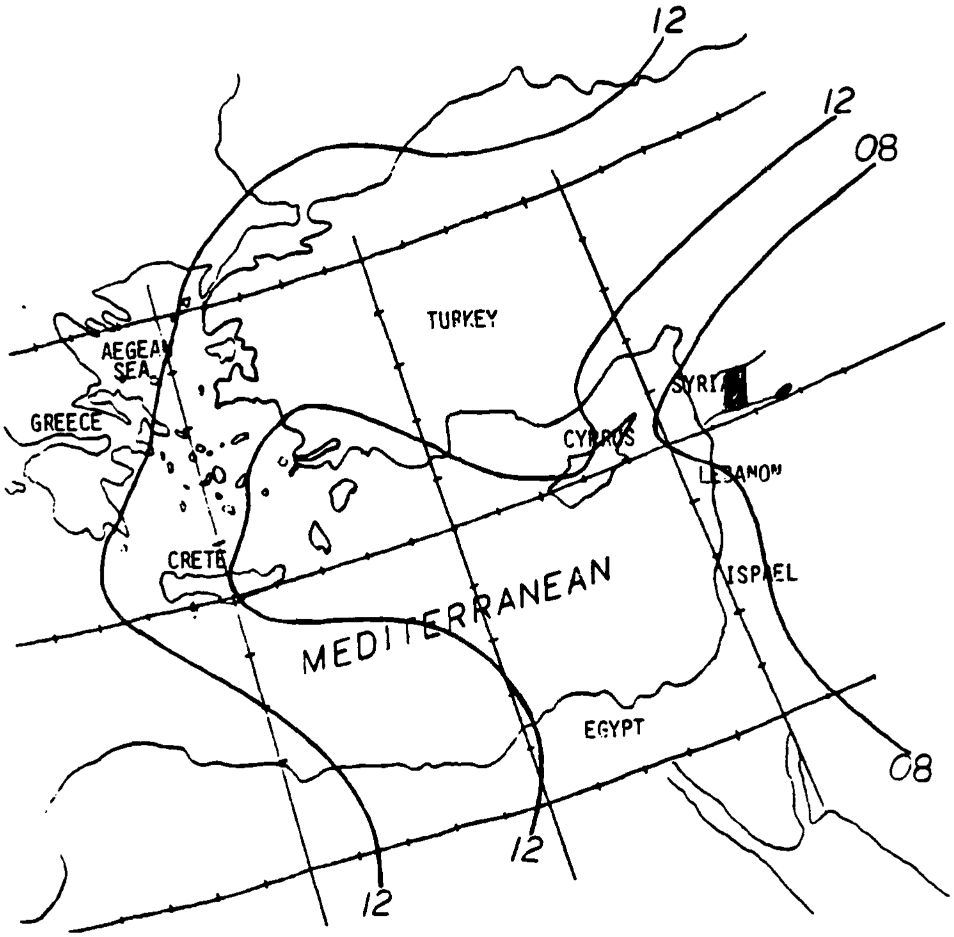

Figure 3.2 0000GMT 5 September 1983 Surface Analysis

mid-levels which would produce a well defined inversion. A small mid-level developed over Cyprus which tended to weaken the inversion due to convective activity and cause the ducting conditions to weaken and a thicker inversion to form.

The 1800GMT refractivity forecast showed the maritime area to the east and south of Cyprus to be super refractive between 750 and 1200 m. The immediate area around Cyprus and to the north and west were predicted to have normal refractivity on the surface with a possibility of elevated trapping layers. The 0030GMT radiosonde showed an elevated duct with a top at 1100m. The 1155GMT launch also shows an elevated duct with a top at 1150m. An IREPS

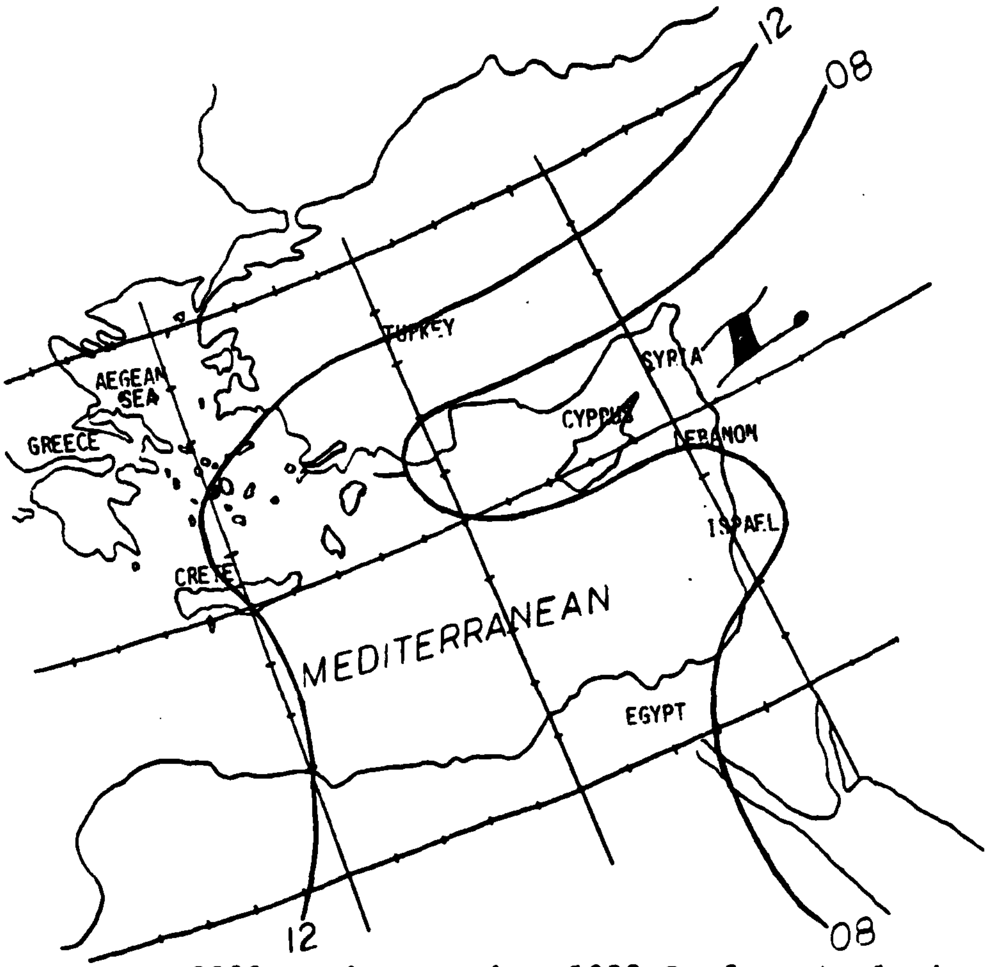

Figure 3.3 0000GMT 6 September 1983 Surface Analysis

analysis indicates that radar holes were possible above these ducts. These confirm the refractivity forecast from the launch location to the southeast of Cyprus.

4. 7 September 1983

The 0000GMT Surface Analysis, Fig. 3.4, shows a strong low centered in Syria and a high located over Yugoslavia. The trough along the southern coast of Turkey remained in place. This synoptic pattern caused a weak flow from west to east across the area around Cyprus. The mid-level charts show a weak trough over the Cyprus area. This provided a weak cap over the inversion and relatively poor ducting conditions.

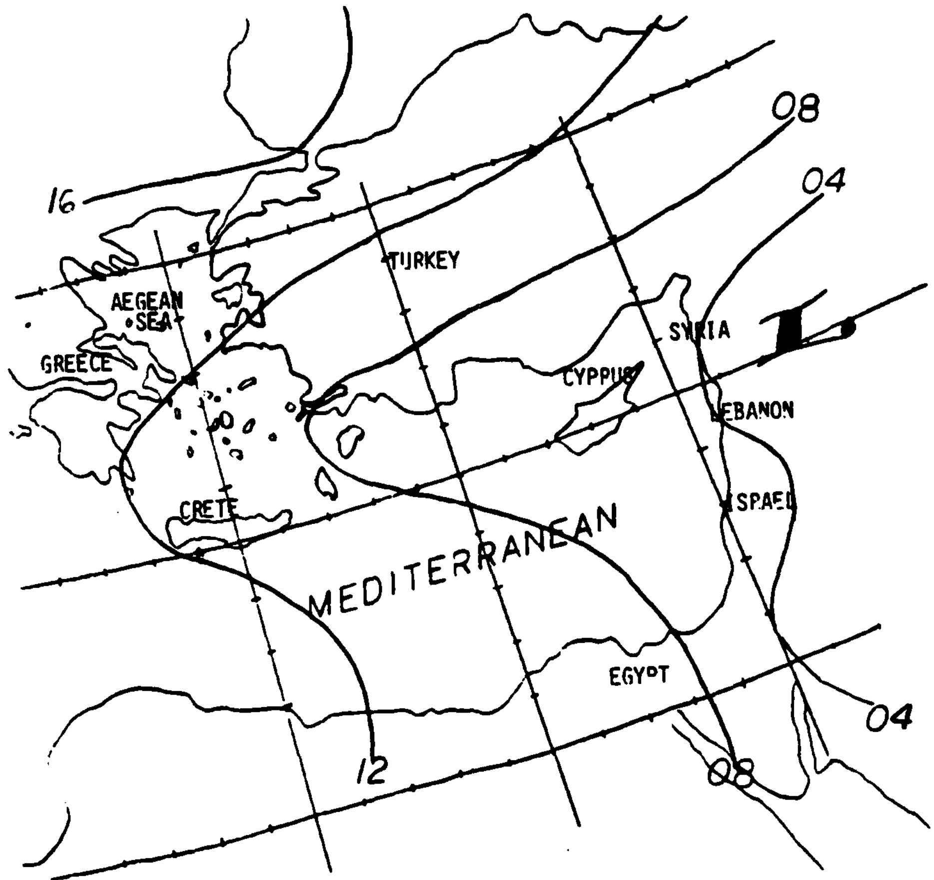

Figure 3.4   0000GMT 7 September 1983 Surface Analysis

The 1800GMT refractivity forecast showed the area surrounding Cypress to have normal refractivity with a possibility of an elevated duct between 600 and 1850m. The 0100GMT radiosonde showed a small duct with a top of 1550m. A small high duct is consistent with a weak elevated trapping layer.

5. <u>8 September 1983</u>

The 0000GMT Surface Analysis, Fig 3.5, indicates a semi-permanent low in northern Syria and a trough along the southern coast of Turkey. There was a high over western Egypt and another over Hungary. A ridge over the central Mediterranean Sea connected the two highs. The mid-level charts showed a weak ridge over the southwestern coast of Turkey. This weather pattern will cause an eastward surface flow in the vicinity of Cyprus with subsidence taking place aloft. This is the ideal situation for ducting conditions to develop. As the day progressed, the inversion should have strengthened and the MABL should have become well-

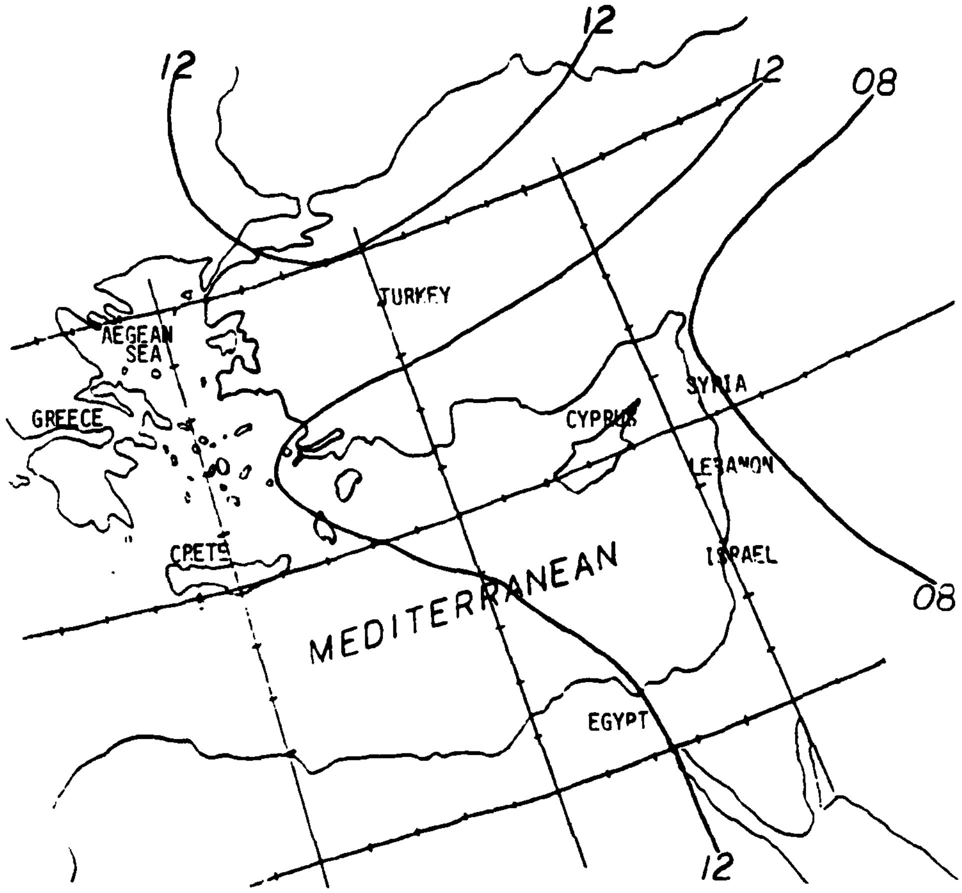

Figure 3.5 0000GMT 8 September 1983 Surface Analysis

The 1800GMT refractivity forecast showed surface super refractivity and possible elevated layers between 450 and 750m. The 0052GMT radiosonde showed a surface duct. This is consistent with the situation on 7 September which had a weak high inversion and no surface trapping. The 1430GMT sounding showed an elevated duct with a top of 800m with a possibility of radar holes above this layer. This elevated duct verifies the forecast of developing elevated ducts.

6. 9 September 1983

The 0000GMT Surface Analysis, Fig 3.6, showed a strong low in Syria and a trough over the southern coast of Turkey. A high was over Bulgaria with a ridge across the central Mediterranean Sea. This synoptic pattern will cause a strong eastward flow over the water surrounding Cyprus. The mid-level charts supported this synoptic pattern of eastward flow with an additional southern component. This weather pattern promotes the development of a well-mixed MABL in the vicinity of Cyprus. Good ducting conditions should continue through the day.

The 1800GMT refractivity forecast showed surface trapping with elevated layers between 450 and 900m in the area southeast of Cypress. The 0100GMT observed sounding showed a surface duct and an elevated duct with a top of 500m. The sounding showed possible a radar hole above 500M. The 1400GMT radiosonde launch identified a surface duct and an elevated duct with a top of 600m. This refractivity condition is consistent with the synoptic weather pattern and the refractivity forecast.

7. 10 September 1983

The 0000GMT Surface Analysis, Fig. 3.7, shows that the low pressure system over northern Syria has weakened slightly and the ridge in the central Mediterranean has moved northeast slowly. The mid-level charts showed a ridge over Greece and a weak trough over Lebanon. This synoptic pattern caused a strong eastward wind near the surface and weak subsidence in the mid-levels of the atmosphere. This should cause the inversion and the ducting conditions to weaken.

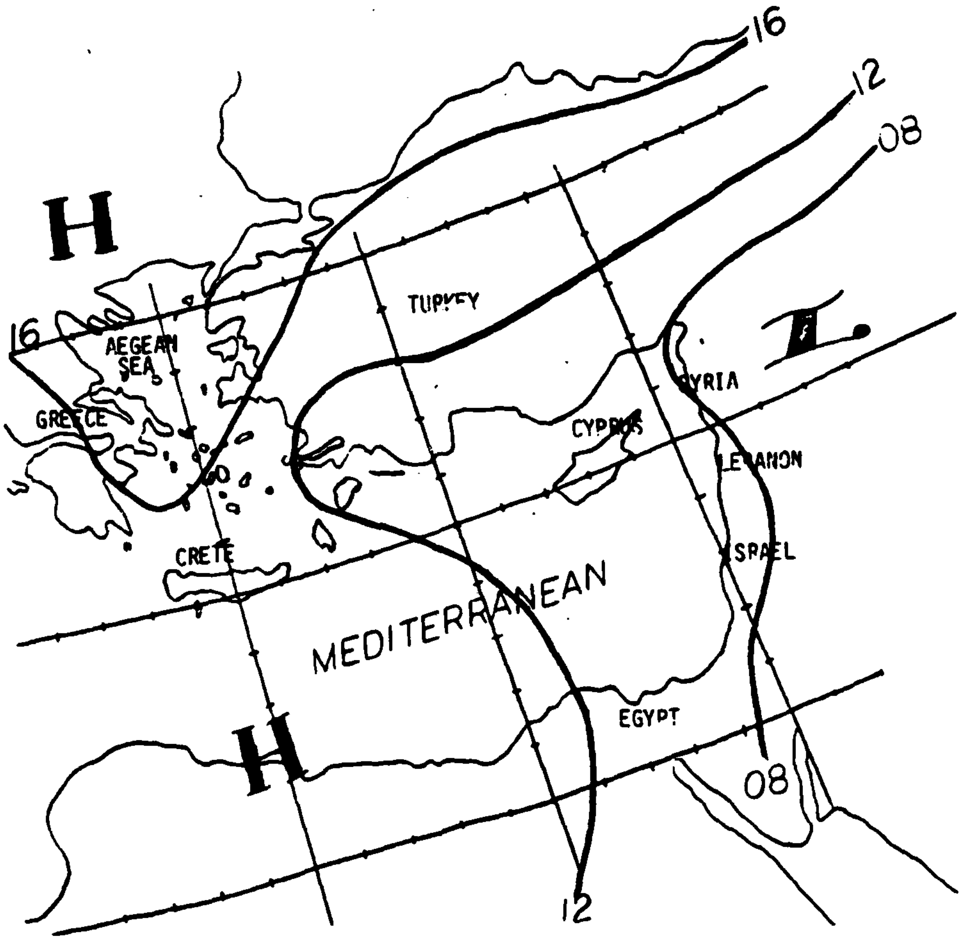

Figure 3.6   0000GMT 9 September 1983 Surface Analysis

The 1800GMT refractivity forecast predicted a super refractive layer on the surface with ducts possible between 304 and 1850m. The 0116GMT radiosonde showed a large surface duct up to 450m. The sounding indicates possible radar holes above the duct. The 1215GMT radiosonde identified an elevated super refractivity layer. This is due to the weak pressure gradient which leads to the weak subsidence over the launch point.

8. 11 September 1983

The 0000GMT Surface Analysis, Fig.3.8, shows that the semi-permanent low pressure system in northern Syria has re-established itself and the trough off the southern Turkey

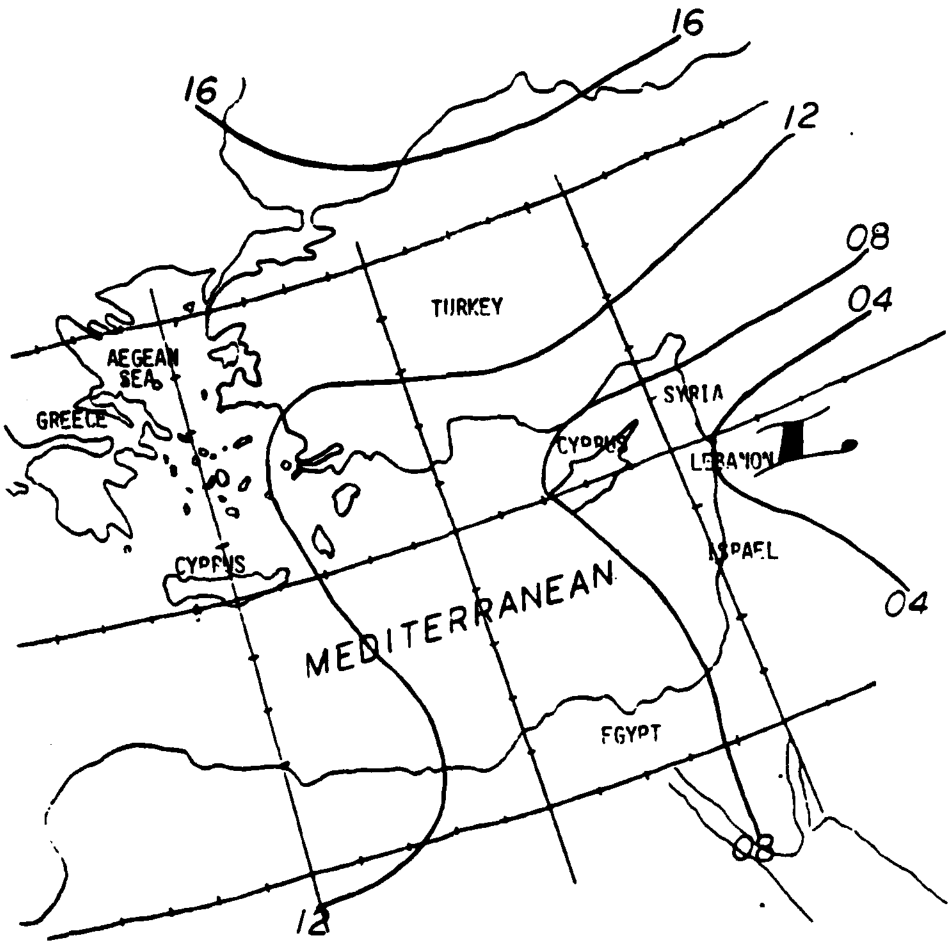

Figure 3.7 0000GMT 10 September 1983 Surface Analysis

coast has shifted south to the northern coast of Cyprus. The mid-level charts showed a weak trough from Isreal to the southern Cyprus coast. This weather pattern should cause a further weakening of ducting conditions.

The refractivity forecast of 1800GMT showed the area surrounding Cyprus to be normal while further south the prediction was for super-refractivity on the surface. The 0100GMT radiosonde showed a surface duct. The sounding indicates EM holes above the duct. The 1206GMT radiosonde showed a weak super- refractivity layer on the surface. This pattern indicates the inversion is weak and the ducts are breaking down.

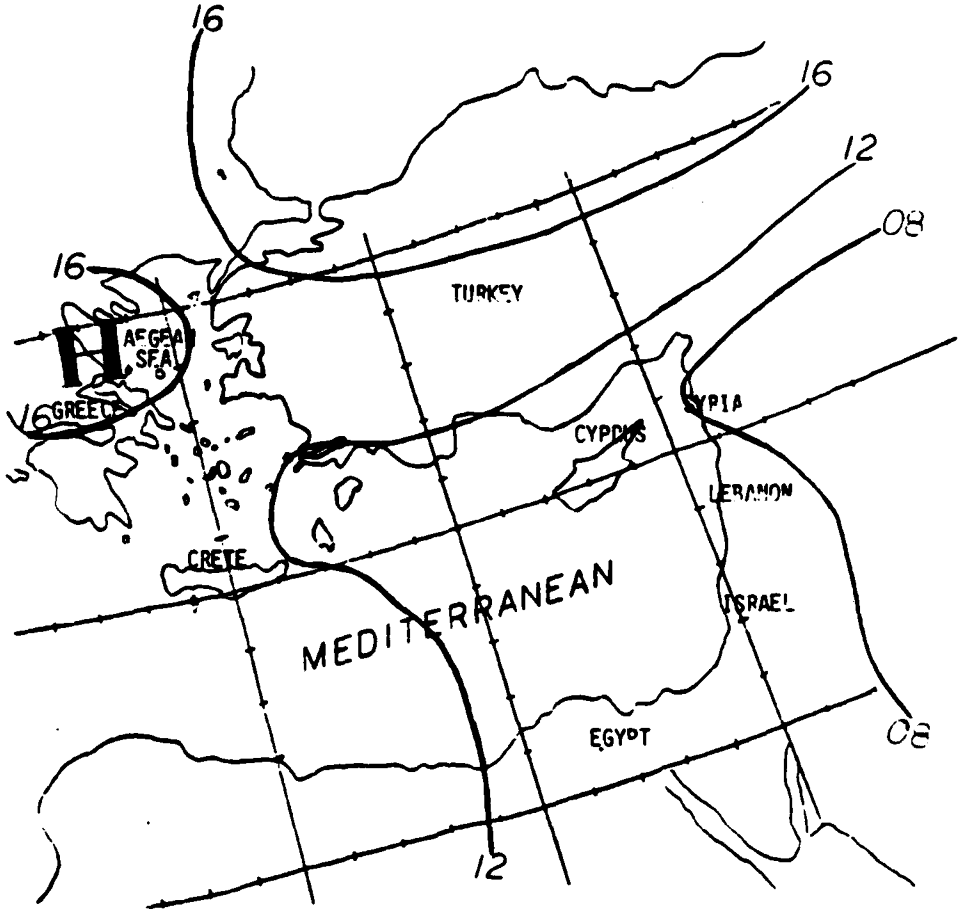

Figure 3.8 0000GMT 11 September 1983 Surface Analysis

9. Synoptic Situation Summary

As the descriptions in the previous section suggest, the changing synoptic scale weather patterns had a great effect on ducting conditions in the eastern Mediterranean Sea. During the 4-11 September 1983 period, two mid level lows developed in the Eisenhower's vicinity. Both of these weakened the inversion and caused the ducts to rise and/or dissipate. As the mid level lows shifted away from the Cyprus, the inversions strengthened and the ducts reestablished themselves.

In view of the synoptic scale changes the refractivity forecast appeared to be satisfactory. Normally, they accounted for the relevant synoptic scale factors. However, the refractivity forecast's were for deeper ducts than were normally present. This type of forecast combined with a single station forecast, if properly verified, should yield useful results. The following chapter describes the results from an analysis of a single station forecast model.

IV. MODEL RESULTS

The purpose of this section is to examine a single station model for predicting EM ducts in the eastern Mediterranean Sea. A direct comparison of radiosonde soundings and the NPS model output will not necessarily verify the model because of the model's simplified structure. An additional factor is that the launching platform is not in precisely the same location for sequential launches. Both of these influences hinder a direct verification of the 12-hour(h) and the 24-h duct forecasts for the NPS model. The method used in evaluating the model is to consider the tendencies of rising and falling ducts.

The launching platform, the USS Eisenhower, is a large aircraft carrier(98,000 tons) which is both a heat source and a wind deflector. This can cause several problems in the initialization and verification soundings due to errors in the first few data points of the sounding. The latter problem occurs because the first few readings are taken when the radiosonde is not stabilized with respect to the environment, and the launching platform can affect the wind and temperature for the initial data points. Some of the errors can be minimized by launching the radiosonde from as far as possible above the main deck. This is partially successful but the first few readings are still affected by the launch platform as seen in data to be presented.

Significant problems associated with the NPS model are due to the method of initializing the sounding data. A simplified analysis of the MABL is used to initialize the model to start the calculations for the refractivity. It is based on average values below the inversion and only allows for one duct to be forecast in the MABL for each sounding.

This eliminates the possibility of both a surface duct and an elevated duct being forecast together.

Further effects on the forecasting of the ducting conditions are the effects of the synoptic-scale weather conditions. The user of this type of model will have to evaluate the results of the single station model with the changes that are forecast in the large- scale weather patterns rather than depend solely on this forecast.

The prediction for each sounding is shown in Table I for the NPS model and is compared with results of observed soundings. The initial observed sounding ducts were approximated for the NPS model simplified initialization in eleven out of thirteen radiosonde launches. This agreement existed because part or all of the NPS model's initial profile had a duct between the bottom of the lowest duct and the top of the highest layer of the observed sounding.

The trend of the duct height changes for the 12-h forecast was correct seventy percent of the time. The trend of the height changes for the 24-h forecast was correct only fifty-three percent of the time. Persistence was correct for the 12-h forecasts in nine of thirteen cases and for the 24-h forecasts in eight out of thirteen. For this limited sample in the eastern Mediterranean Sea, this shows that the NPS model, if used alone, is not much better than persistence. The specific causes for these inconsistencies will be discussed later in this chapter.

A. DAILY NPS MODEL PREDICTION RESULTS

1. 4 September 1983

The synoptic-scale conditions in the launch area, as discussed in Section 3C, indicated there could be a strong inversion layer due to the subsidence occurring in conjunction with the high to the east. The 0205GMT observed

TABLE I

NPS Model and Observed Sounding Ducts

Model	Date (1983)	Time (GMT)	Duct Height Forcast (m) 0H	12H	24H
NPS	4 Sep	0205	502-958	861-1274	1113-1507
Observed			167-722 915-1183	0-57 573-707	0-58 467-938
NPS		1235	0-634	7-700	167-809
Observed			0-57 573-707	0-58 467-938	0-94 536-819
NPS	5 Sep	0100	50-617	0-585	0-568
Observed			0-58 467-938	0-94 536-819	695-1093
NPS		1215	263-613	179-577	156-529
Observed			0-94 536-819	695-1093	592-1158
NPS	6 Sep	0030	104-610	0-555	0-546
Observed			695-1093	592-1158	1453-1557
NPS		1155	309-944	468-1044	607-1148
Observed			592-1158	1453-1557	no launch
NPS	7 Sep	0100	0-280	0-280	0-278
Observed			1453-1557	no launch	0-82
NPS	8 Sep	0052	7-400	0-386	0-396
Observed			0-82	371-801	0-81 95-511
NPS		1430	551-988	942-1390	1317-1781
Observed			371-801	0-81 95-511	0-84 271-596
NPS	9 Sep	0100	0-259	0-267	0-272
Observed			0-81 95-511	0-84 271-596	0-466
NPS		1400	0-227	0-185	0-146
Observed			0-84 271-596	0-466	no layer
NPS	10 Sep	0116	0-109	0-47	0-21
Observed			0-466	no layer	0-234
NPS		1215	0-332	0-332	0-343
Observed			no layer	0-234	no layer

sounding (solid line), Fig. 4.1, indicates ducts between 150m and 700m between 900m and 1200m. This radiosonde profile seems to have two errors. The first is in the lower section of the sounding which shows an unreasonable minimum of 5g/kg in the specific humidity at 75m. This data point is questionable due to the proximity to the ocean. This would make a large loss of moisture inconsistent with the rest of the sounding which indicates the average for the MABL is 14g/kg. The second error occurs where the sounding shows a minimum in the specific humidity at 700m. For this error the sounding probably overestimated the decrease in the specific humidity. The NPS model's simplified initialization indicates a duct from 500m to 950m. The discrepancy between the top of the upper duct of the observed sounding and the initializing profile is believed to be caused by the overshoot of the decrease in the specific humidity. This caused the observed sounding to indicate two elevated ducts.

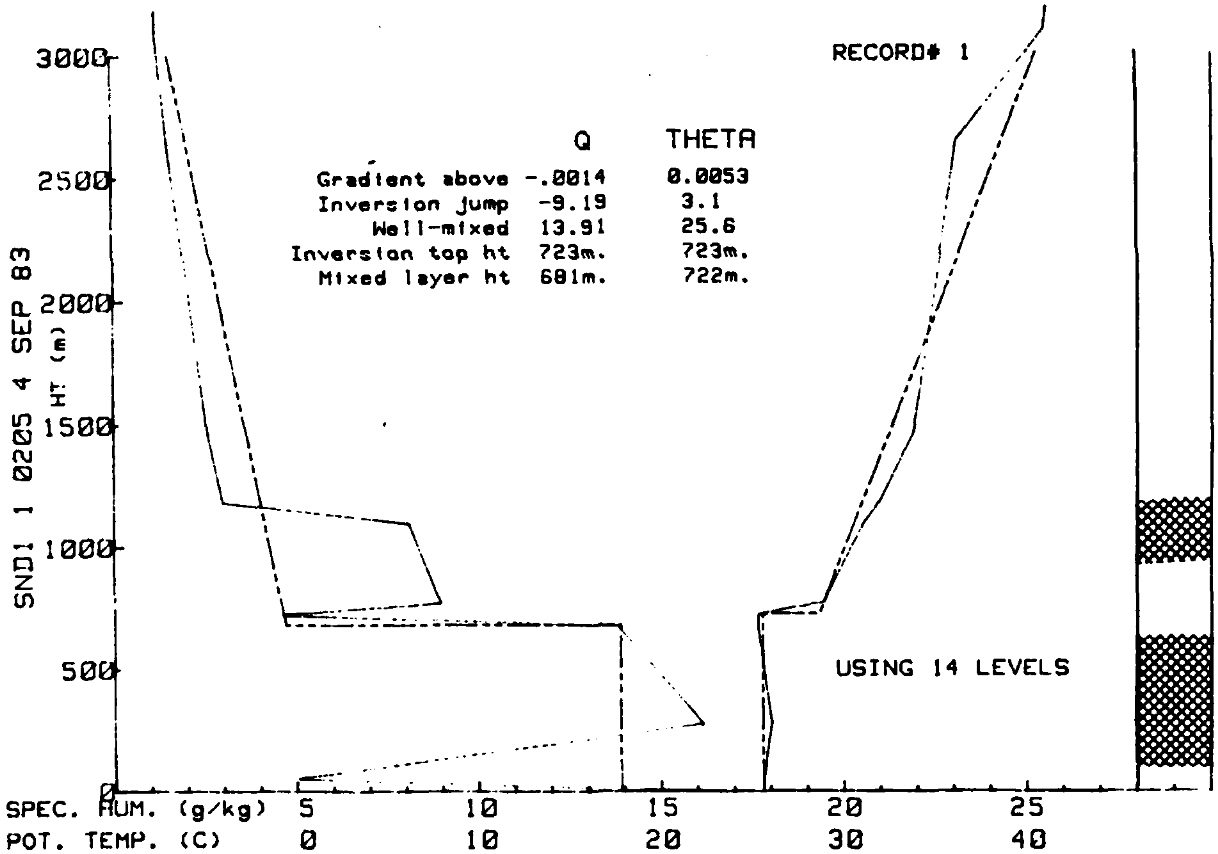

Figure 4.1 0205GMT 4 Sep 1983 Sounding(Solid), Initializing Profile(Dashed) and Observed Ducts(Hashed)

The NPS model was used to obtain 12 and 24-h predictions. The predicted ducts for this sounding are from 850m to 1250m at 12-h and from 1100m to 1500m at 24-h The duct is probably rising due to the entrainment and the low value of subsidence which was calculated using data from the 12-h preceding the initializing radiosonde. The observed profile valid for the 12-h forecast yielded two layers from 0 to 50m and from 550m to 700m. Both layers were lower than those in the initial sounding. The verifying sounding for the 24-h forecast has two layers from 0 to 50m and from 400m to 950m. This is higher than that observed at 12-h but lower than the original conditions at 0205GMT. In both of these verifications, the existence of the lower duct is uncertain due to the rapid decrease of the specific humidity in the lower sections of the soundings.

The 1235GMT initializing radiosonde, Fig 4.2, shows two ducts. The first is from the surface to 50m with the second from 550m to 700m. Again, the lower duct is believed to be due to the errors in the sounding data. The top of the upper duct is significantly below that of 10 hours before. The NPS model's initial profile has a duct from the surface to 650m which agrees with the observed conditions.

The 12-h forecast had a duct from 7 to 700m. The verifying sounding, Fig. 4.3, shows a surface duct up to 50m and an elevated duct between 450m and 950m. Again the existence of the lower duct is uncertain due to problems stated above. The verifying sounding indicates that the inversion above the MABL is not a thin layer which is required for the simplified initialization of the NPS model. This causes the upper duct to have a higher top than was forecast. The 24-h forecast for a duct from 150m to 800m is verified by the 1215GMT radiosonde of 5 September 1983 which showed ducts from 0 to 100m and from 550m to 800m. The lower duct is believed to be inaccurate due to the unrepresentative

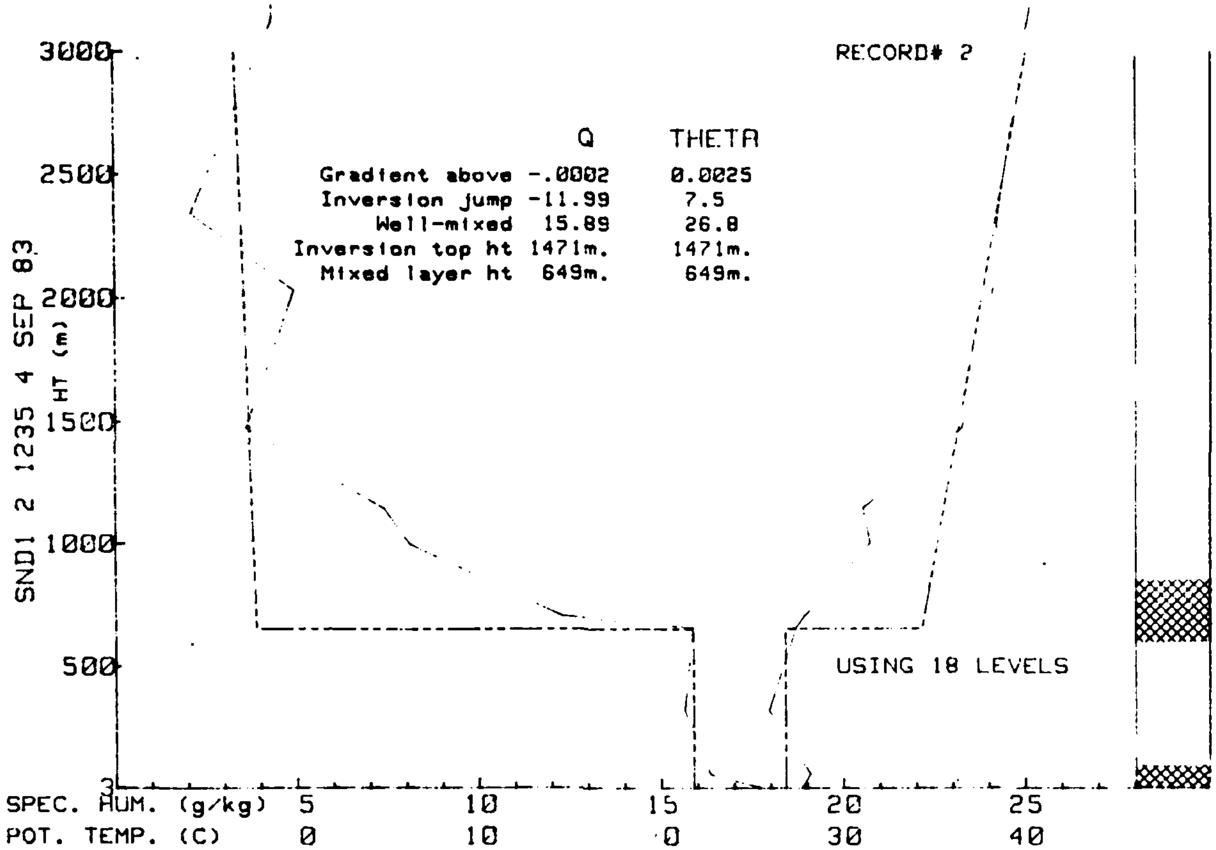

Figure 4.2 1235GMT 4 September 1983 Sounding and Initializing Profile

specific humidity and the potential temperature in the lower part of the sounding. The higher duct's top verifies with the forecast.

In summary, as the day progressed the observed specific humidity and potential temperature profiles became much less complicated. The observed soundings which showed surface ducts are believed to be inaccurate at lower levels due to the rapid decrease of the specific humidity in the section of the atmosphere which is in close proximity to the ocean surface. Therefore the simplified model is a fair representation of the observed MABL properties.

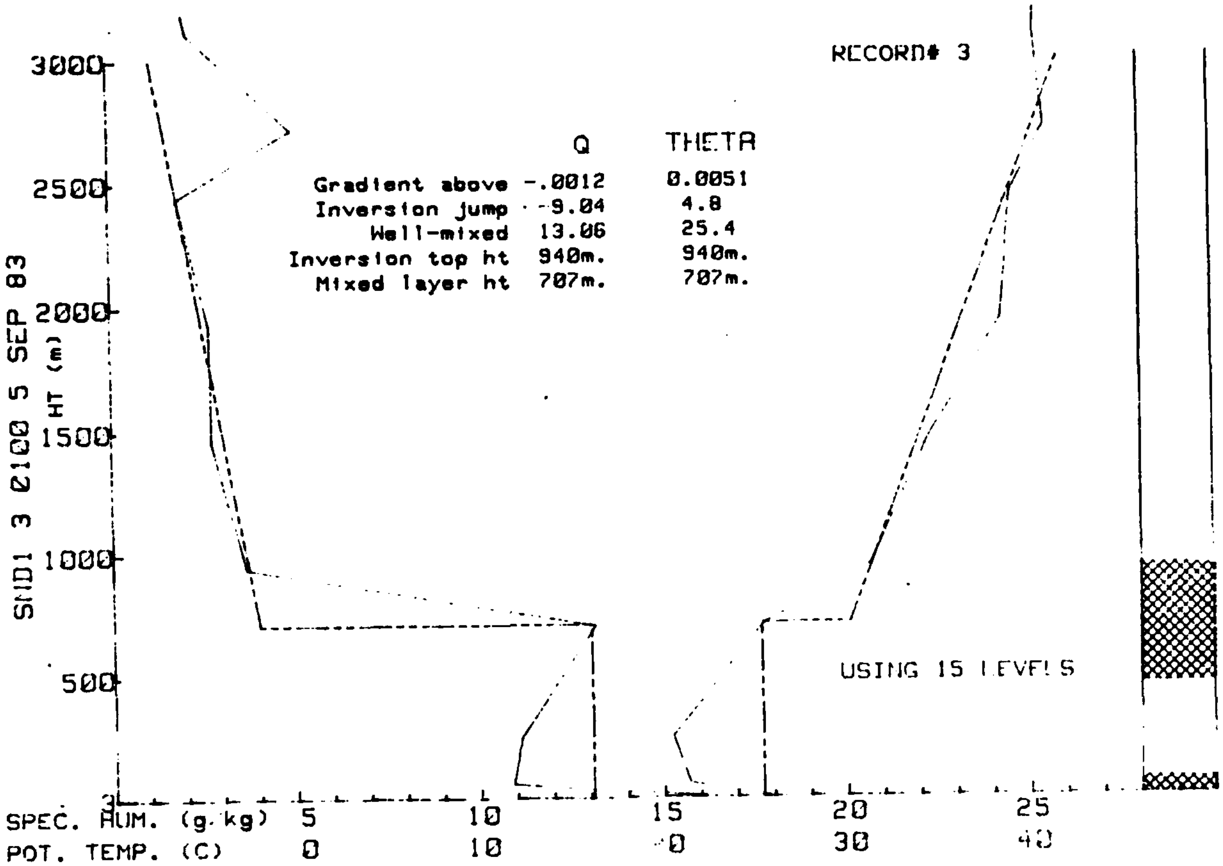

Figure 4.3 0100GMT 5 September 1983 Sounding and Initializing Profile

2. <u>5 September 1983</u>

The synoptic scale conditions for this day, described in Section 3C, could cause a strong inversion. The trough in southern Turkey and the mid-level low over the coast of Turkey coupled with the ridge to the west of Cyprus could have resulted in strong subsidence occurring over a well established inversion. This would contribute to duct development. The 0100GMT sounding shows two layers from 0 to 50m and from 450m to 950m. The lower duct is probably incorrect due to the rapid decrease of the specific humidity between the surface and 50m. This large decrease shown in Fig 4.3 is inconsistent with a well-mixed MABL. The NPS model's simplified initial analysis indicates a duct between 50m and 617m. The observed sounding shown in Fig. 4.3 shows the inversion to be about 300m thick. By using the well-defined height of the bottom of the layer in the simplified initial analysis, the NPS model calculates a lower duct than is present.

The 12-h prediction was for the duct to descend and to be a surface duct with a top of 600m. The 1215GMT sounding, Fig 4.4, indicates layers from the surface to 100m and from 550m to 800m. The upper duct lowered as the NPS model predicted. Again, the lower duct is probably caused by the inaccuracies in the radiosonde specific humidity below 100m due to the problems discussed in section 4A. The 24-h forecast of 0 to 550m does not verify with the 0030GMT sounding from 6 September 1983 which shows a duct from 700m to 1100m. The observed duct is higher because of a weak mid-level low developing over Cyprus and a surface trough moving south from the southern coast of Turkey. Both of these occurrences will cause the inversion to weaken and rise.

The initial sounding at 1215GMT, Fig. 4.4, shows two ducts from the surface to 100m and from 550m to 800m. Again, the lower duct is incorrect for reasons discussed in section 4A. The simplified initializing profile, as shown in Fig. 4.4, simulates the observed sounding fairly well. The NPS model initializing profile indicates a duct between 250m and 600m. The 12 and 24-h forecasts are both invalid due to the developing mid-level low over Cyprus and the surface trough moving south from the southern coast of Turkey.

3. 6 September 1983

The mid-level low and surface trough which were located over the southern coast of Turkey moved south and

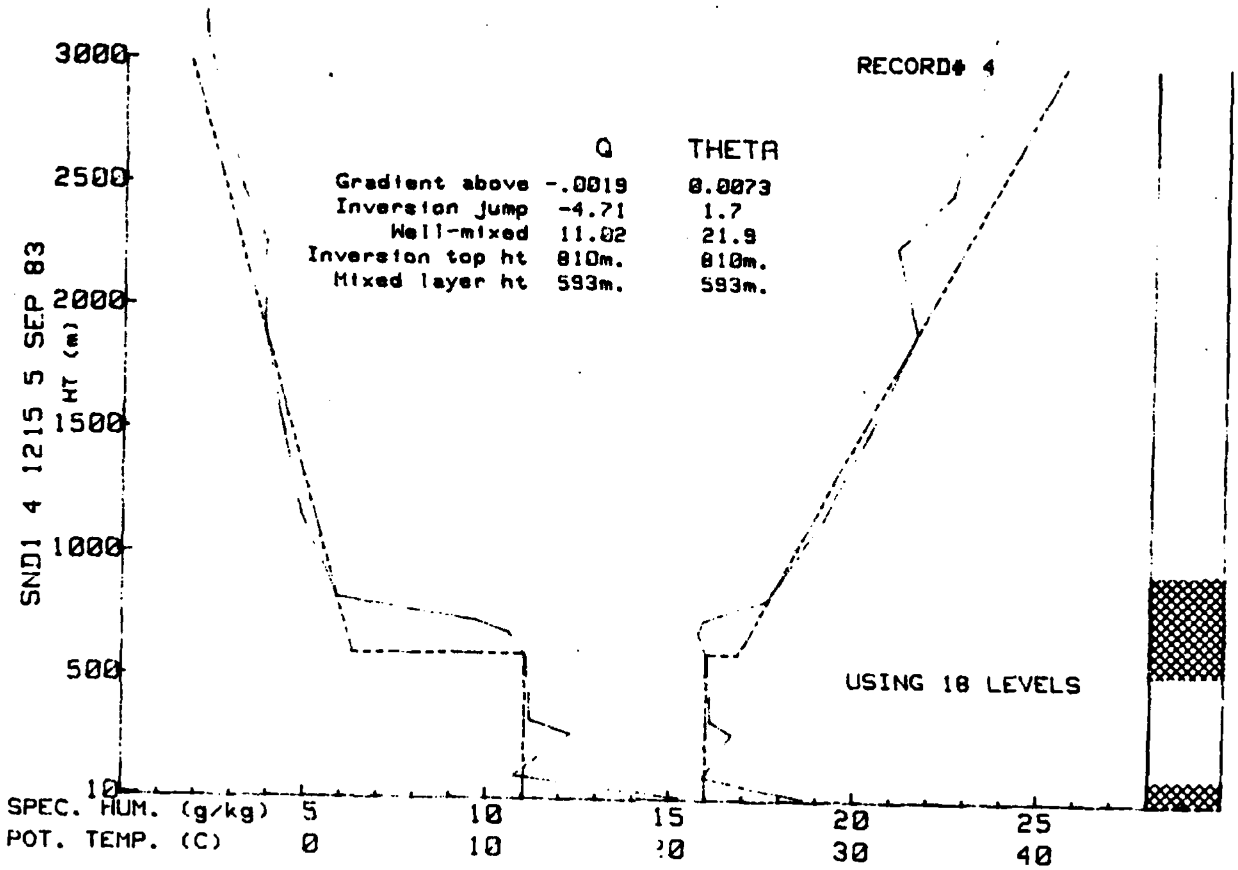

Figure 4.4 1215GMT 5 September 1983 Sounding and Initializing Profile

caused convective activity over the area around Cypress. The 0030GMT observed data, Fig. 4.5, shows a duct of 700m to 1100m. The NPS model initial profile indicates a duct from 100m to 600m. The cause of this difference is the lack of a well defined inversion layer. The specific humidity profile indicates the inversion is about 400m thick. The simplified NPS initialization cannot simulate this because of the assumption that the inversion is thin and the change of the specific humidity and potential temperature in the inversion is instantaneous. The weakening inversion is caused by the mid-level low and the trough south of the southern coast of Turkey. The 12 and 24-h forecasts are inconsistent due to the convective activity taking place at the time of the radiosonde launch.

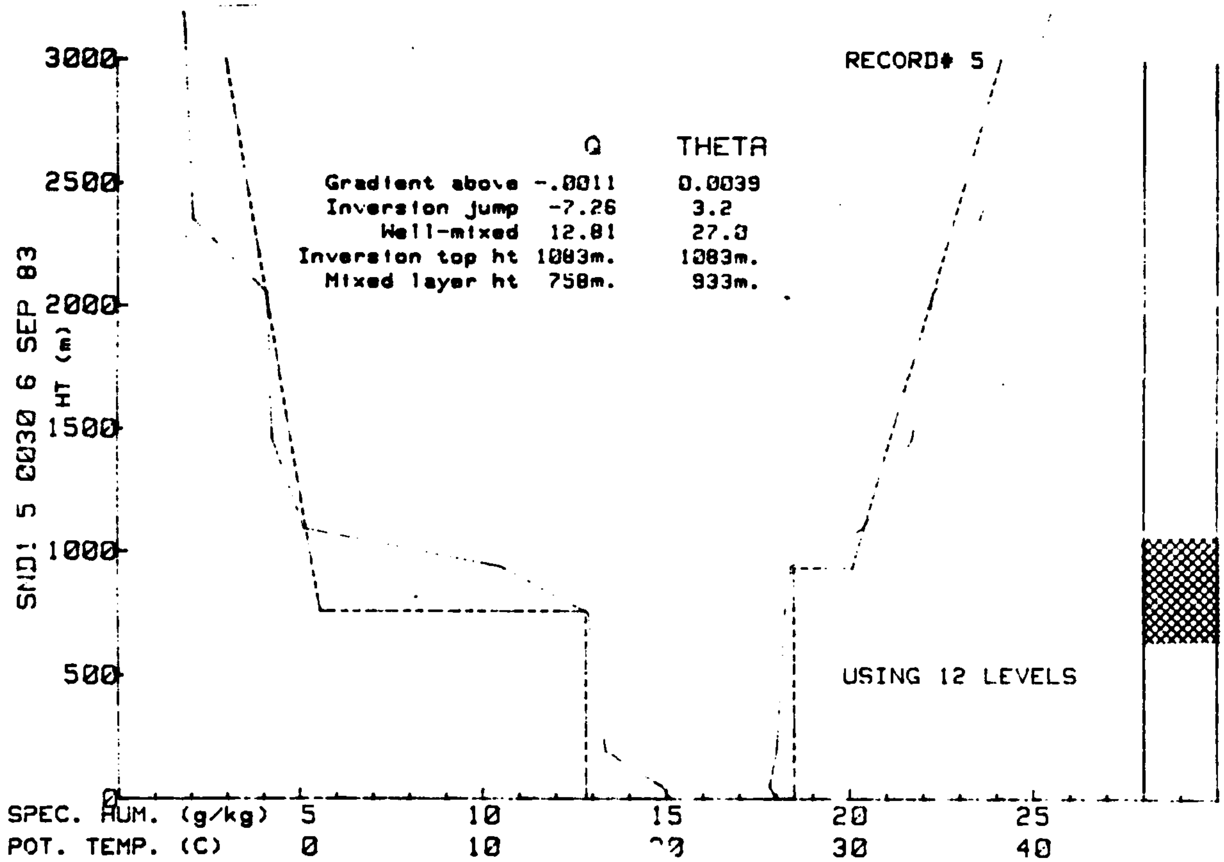

Figure 4.5 0030GMT 6 September 1983 Sounding and Initializing Profile

The 1155GMT observed data indicate a duct between 600m and 1150m. The NPS model's simplified initialization profile, Fig. 4.6, indicates a duct from 300m to 950m. This verifies with the observed sounding. However, the convection occurring in the vicinity is causing significant vertical mixing. Due to the inversion being weakened by the vertical mixing, the 12-h forecast did not verify. There was no verification launch corresponding to the 24-h forecast.

4. 7 September 1983

The synoptic conditions in the vicinity of the Eisenhower caused convective activity to occur in association with the weak trough located over Cyprus. This

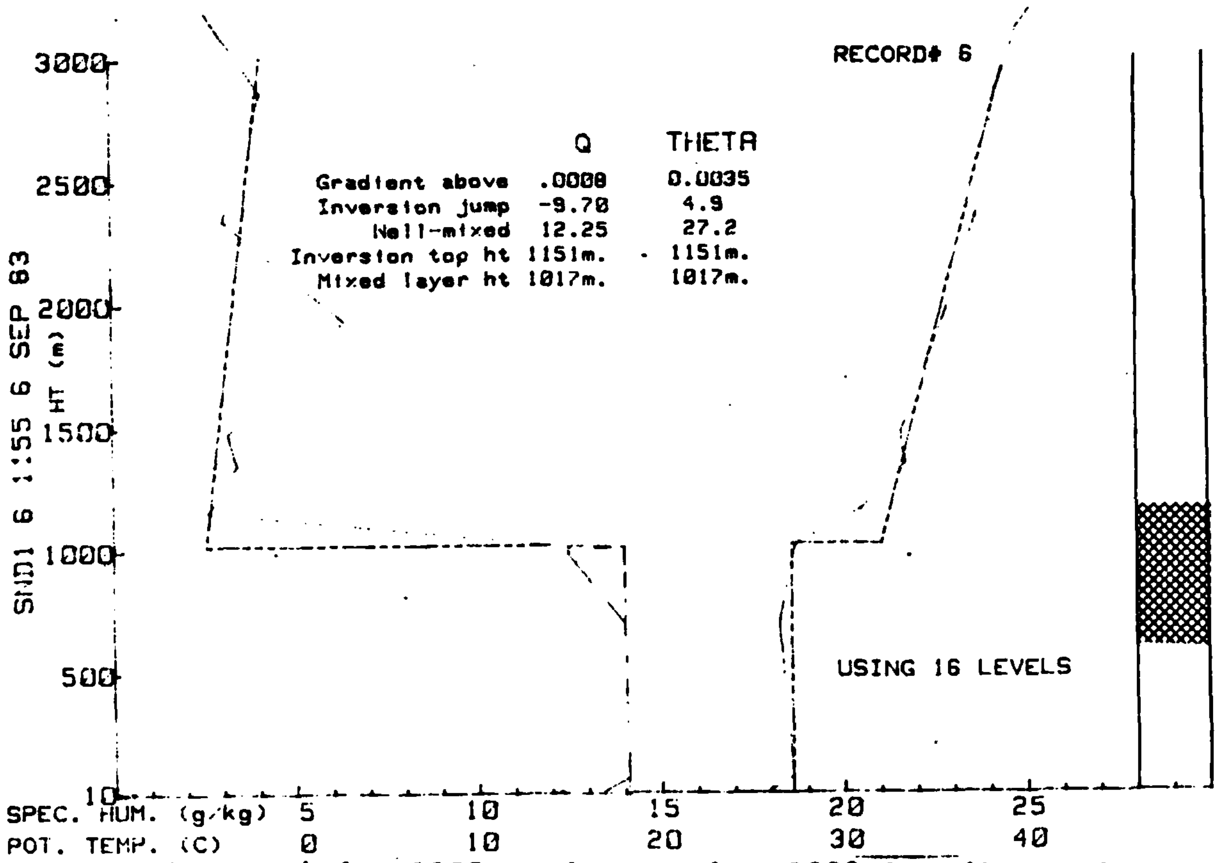

Figure 4.6 1155GMT 6 September 1983 Sounding and Initializing Profile

inhibited the formation of a strong inversion layer. Also the calculated subsidence values will be incorrect due to the convection influencing the mixed layer humidity budget during the 12-h preceding the 0100GMT launch on 7 September. A single station forecast for this day would be invalid due to both reasons discussed above.

5. <u>8 September 1983</u>

The mid-level low over Cyprus dissipated and the trough returned to the southern coast of Turkey. The convective activity continued but the inversion established itself as the day progressed. The 0052GMT observed sounding shows a surface duct up to 100m. The NPS model had a duct from the surface to 400m in the initial profile. The sounding in Fig. 4.7 indicates a weak temperature inversion with a base at 500m. The 12 and 24-h forecasts were invalid due to the weak inversion and inability of the simplified initialization profile to simulate.

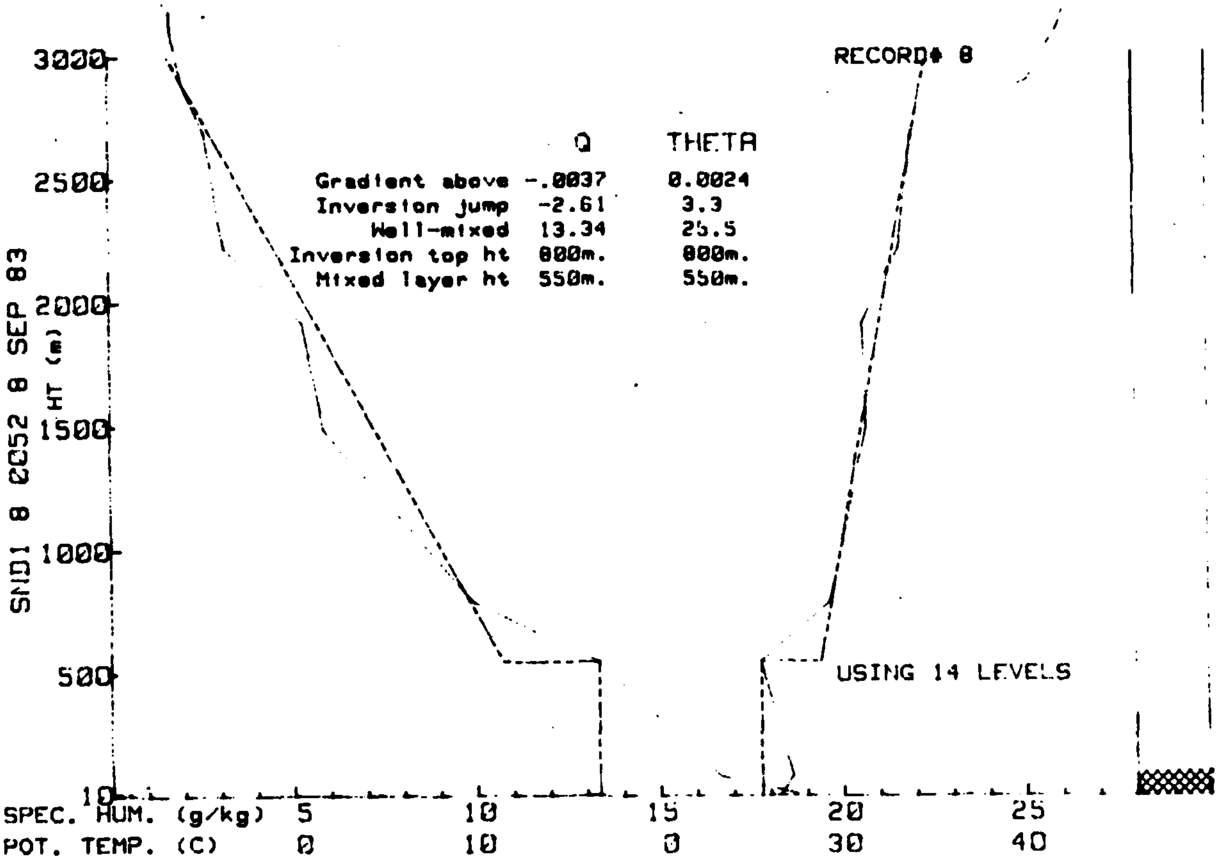

Figure 4.7 0052GMT 8 September 1983 Sounding and Initializing Profile

The sounding used for initialization at 1430GMT, Fig. 4.8, shows a single duct between 350m and 800m. As shown in Fig. 4.8 the inversion has strengthened and a well-mixed layer has formed in the boundary layer. This leads to the NPS model's initial profile verifying by having a duct between 550m and 800m. The 12-h prediction was for a duct from 950m to 1400m which differs from the verifying observed sounding in Fig 4.9 which showed two ducts below 500m. The cause of this disagreement is the low calculated value of subsidence used by the model. This low value was due to the synoptic scale changes which occurred in the 12-h preceding the initializing radiosonde. This was caused by the convection in the area during the morning before the radiosonde launch. As the afternoon progressed the subsidence increased and the inversion strengthened causing a strong low-level duct. The 24-h forecast was in error because the subsidence was underestimated.

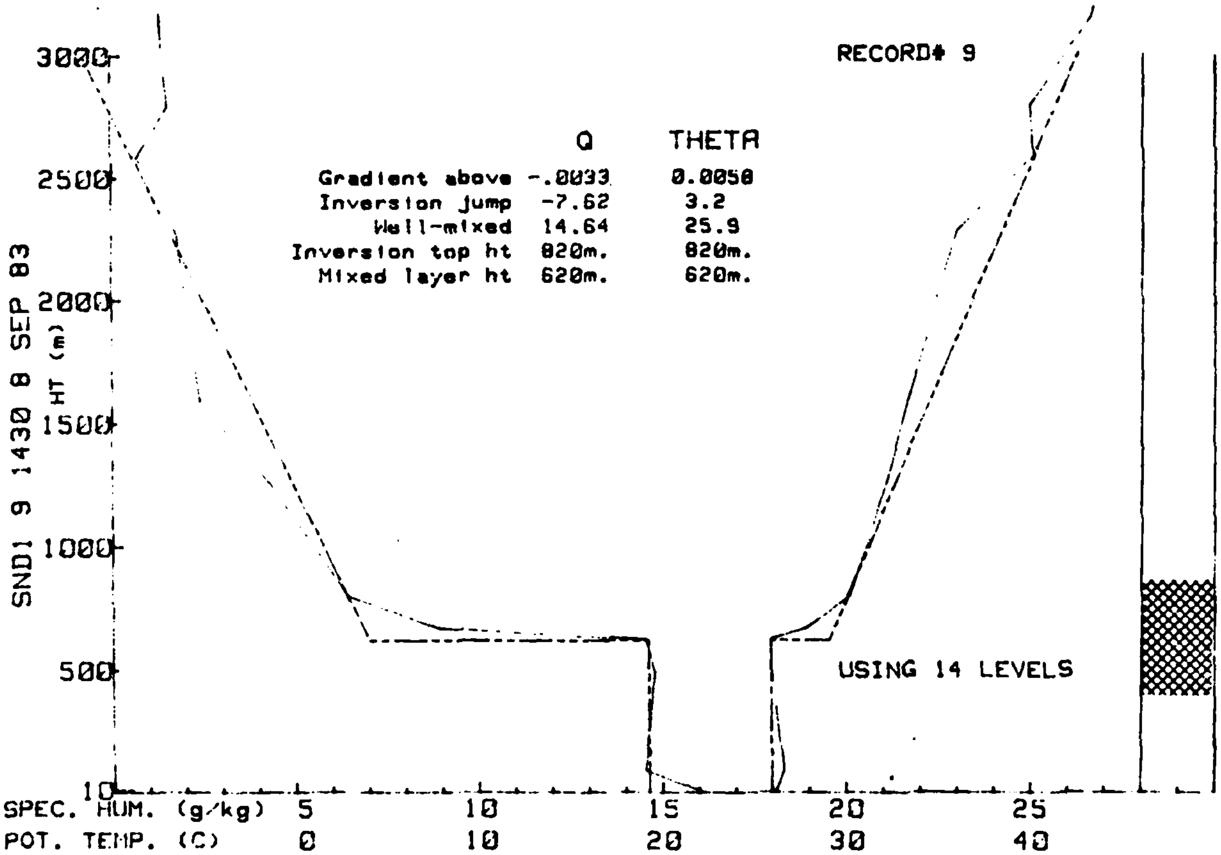

Figure 4.8 1430GMT 8 September 1983 Sounding and Initializing Profile

6. 9 September 1983

The synoptic situation continues to be dominated by a trough over southern Turkey. A low has formed over Syria and a ridge has moved over the central Mediterranean Sea. This ridge continued to support a strong inversion in the Eisenhower's vicinity, with associated ducting conditions. The 0100GMT sounding, Fig. 4.9, has two ducts. The first is a surface duct up to 100M while the second is an elevated duct between 100M and 500M. Again, the presence of the surface duct is, questionable due to the rapid decrease of the specific humidity in the bottom 100m of the sounding. The NPS model initialization indicates a duct from the surface to 250m. The simplified initial analysis was based on the inversion caused by the rapid decrease in the specific humidity at about 350m. The thickness of the observed inversion zone caused the observed duct to be higher than that in the NPS model initialization.

The 12-h forecast is for a duct between the surface and 250m compared to the observed sounding, Fig. 4.10, with ducts from the surface to 100m and from 250m to 600m. The discrepancy for the top of the upper duct is caused by the inversion thickness being 250m which caused the top of the duct in the observed sounding to be higher than the NPS model forecast. The 24-h prediction by the NPS model is a duct from the surface to 250m. The observed sounding at that time indicates a duct between the surface and 450m. The model predictions for the ducts were lower than those in the observed soundings. The verification sounding shows a duct from the surface to 450m. However, this sounding appears to be inconsistent with the synoptic scale weather patterns. This profile is discussed in the next section.

Fig. 4.10 shows the 1400GMT radiosonde profile which has two ducts. The lower one is a surface duct between the

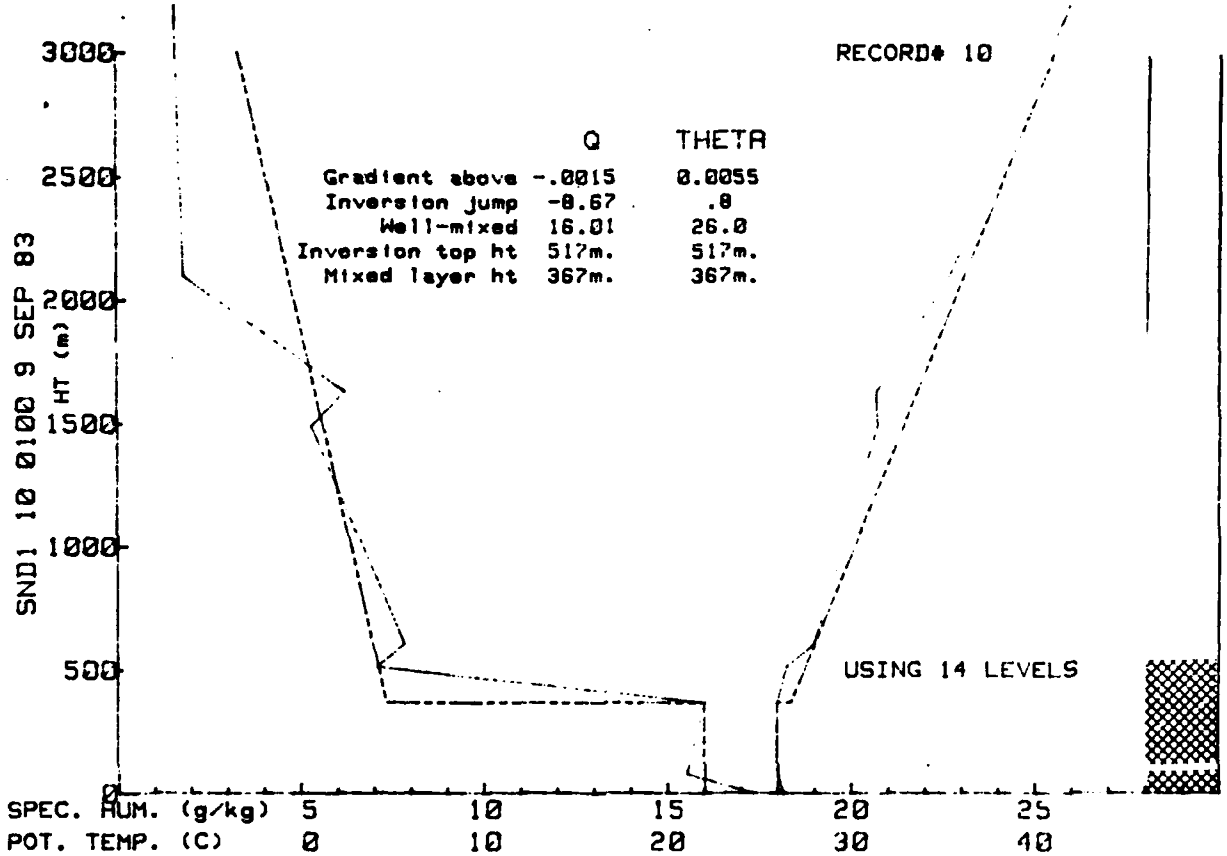

Figure 4.9 0100GMT 9 September 1983 Sounding and Initializing Profile

surface and 100m with the elevated duct between 250 and 600m. Again, the lower duct is incorrect due to the very rapid decrease of the specific humidity in the lowest 100m of the sounding. The NPS model initialization shows a duct from the surface to 200m. The inversion thickness of 300m caused the simplified initial analysis to calculate a lower duct than the observed soundings. The NPS model 12-h forecast was for a duct from the surface to 200m. This agrees with the trend between the observed soundings. The top of a surface duct descended from 600m to 450m.

The NPS model's 24-h forecast shows a surface duct up to 150m which does not verify with the observed sounding which had no duct. This disagreement is due to the models zeroth order(step) approximation for the humidity and temperature changes at the inversion. The weakening of the observed inversion is believed to be due to the surface trough located over the southern coast of Turkey slipping south over Cyprus. This caused the subsidence to decrease rapidly over the last 12-h of the forecast period.

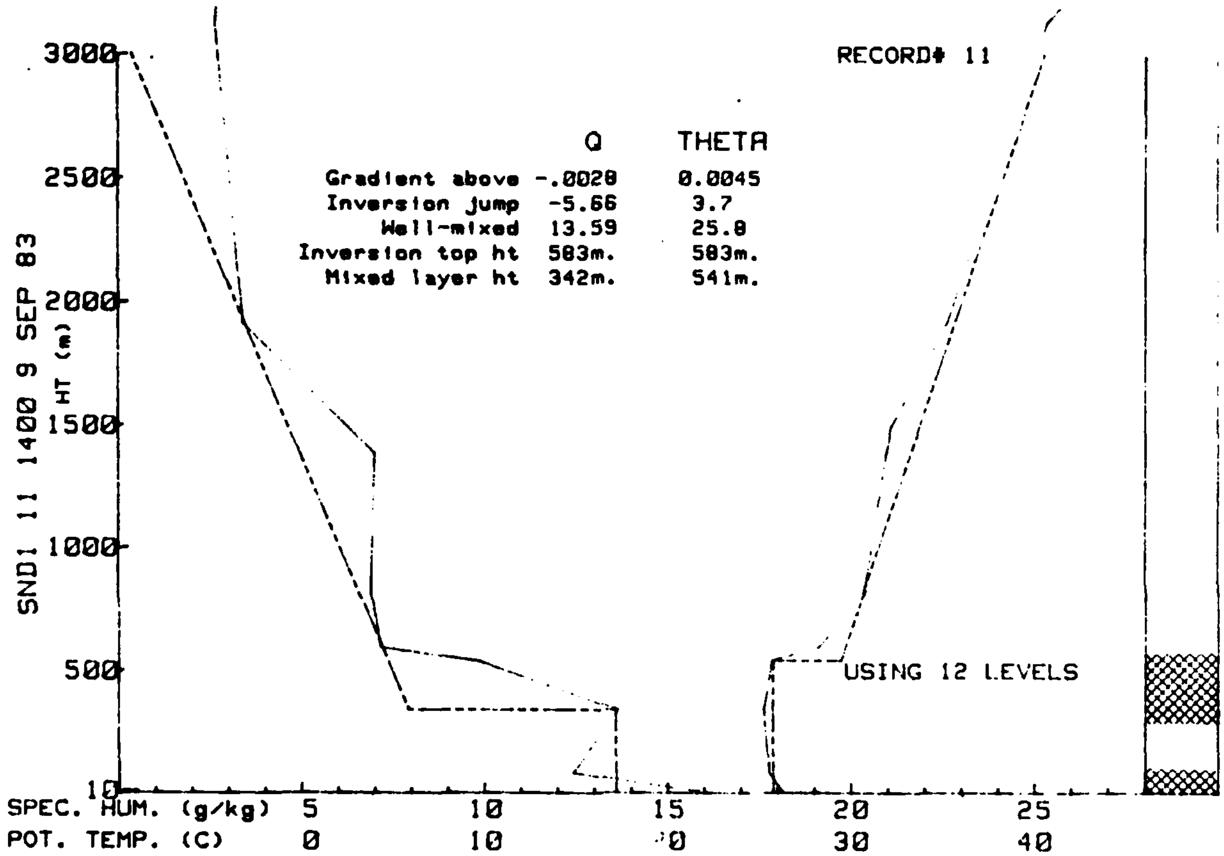

Figure 4.10 1400GMT 9 September 1983 Sounding and Initializing Profile

This day illustrates both positive and negative aspects of trying to predict small scale atmospheric phenomena. The first NPS model forecasts showed a relatively persistent duct top as did the verification soundings. This is due to the subsidence dominating the period and remaining near constant throughout it. The second model forecast, initialized at 1400GMT, is reasonably successful for the first 12 hours. However, the 24-h forecast is not good due to convective activity and due to the simplified model vertical structure.

7. 10 September 1983

The high pressure system affecting the Eisenhower's position should have caused strong subsidence to persist from the previous period. As can be seen in Fig. 4.11, the sounding at 0116GMT did not support this subsidence. The large increase in specific humidity above 1000 meters indicates that the sounding is inconsistent. The soundings before and after 0116GMT indicate that turbulent mixing was present. This indicates that the radiosonde malfunctioned. Any initialization profile or verification from this sounding would not be representative.

The 1215GMT sounding, Fig 4.12, indicates no existing duct but the NPS model indicates a surface duct up to 350m as the initiating profile. This difference is due to the weak inversion shown in sounding but not taken into account by the simplified initial analysis. The NPS model's 12-h forecast is for a duct from the surface to 350m. This verifies with the 0100GMT sounding of 11 September which predicts a duct between the surface and 250m. This agreement exists because the inversion has strengthened slightly. This strengthening is due to the trough shifting to the north. However, the twenty-four hour forecast does not verify because a low is developing over Cyprus.

8. 11 September 1983

The synoptic situation in the Eisenhower's vicinity shows a trough to the north and to the east. Both of these will inhibit the persistence of a strong inversion. The poor ducting conditions from 10 September will carry forward through 11 September. Due to the synoptic scale conditions the NPS model's forecasts will be invalid.

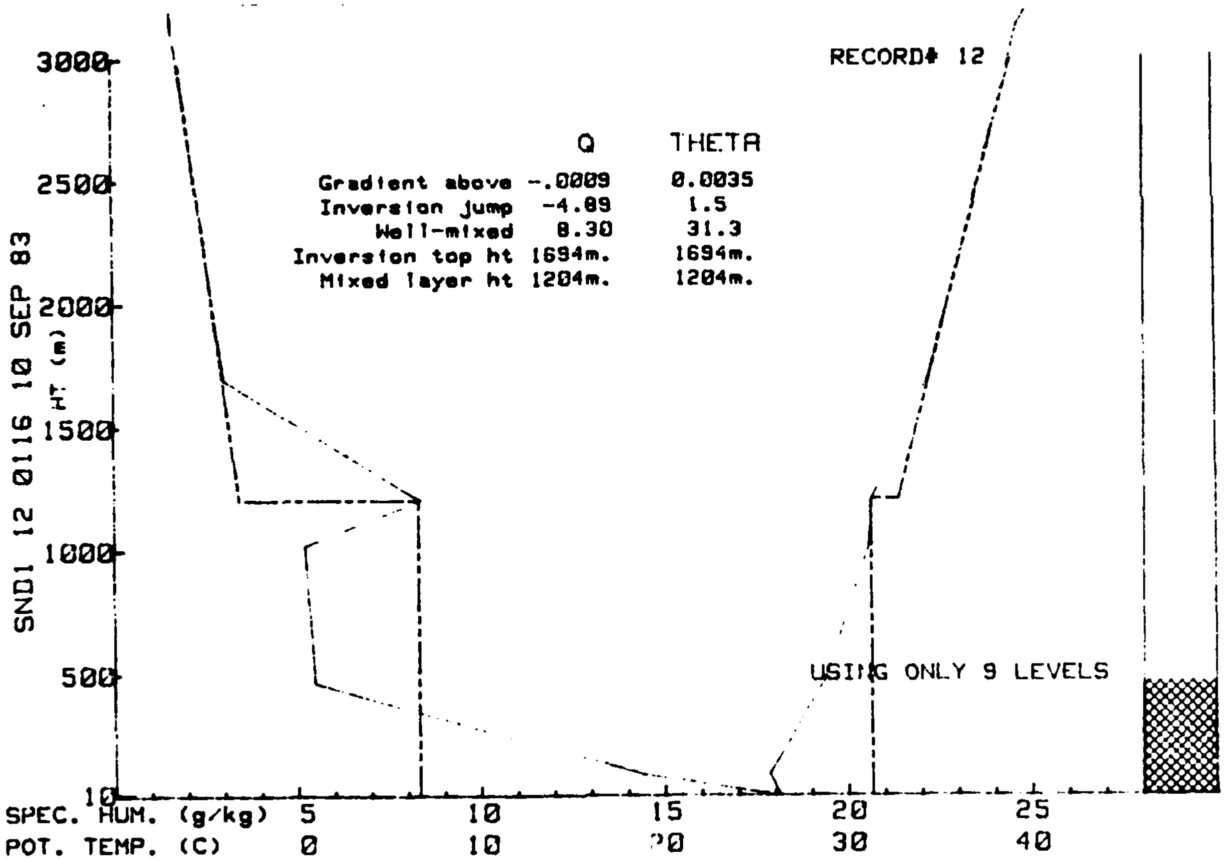

Figure 4.11 0116GMT 10 September 1983 Sounding and Initializing Profile

B. SUMMARY OF DAILY FORECAST RESULTS

The NPS model is based on the assumptions of a horizontal homogeneous and an inversion capped well-mixed boundary layer. The basic model is inappropriate under conditions of strong convection. The land masses of Cyprus, Turkey, Isreal and Lebanon affect the region in which the USS Eisenhower was underway. These synoptic scale factors definitely caused problems with the 12 and 24-h forecasts of every day covered by this thesis.

Using the criterion that part of the predicted duct should fall within the duct shown in the observed sounding, the NPS model 12-h forecast verifies in eight of thirteen

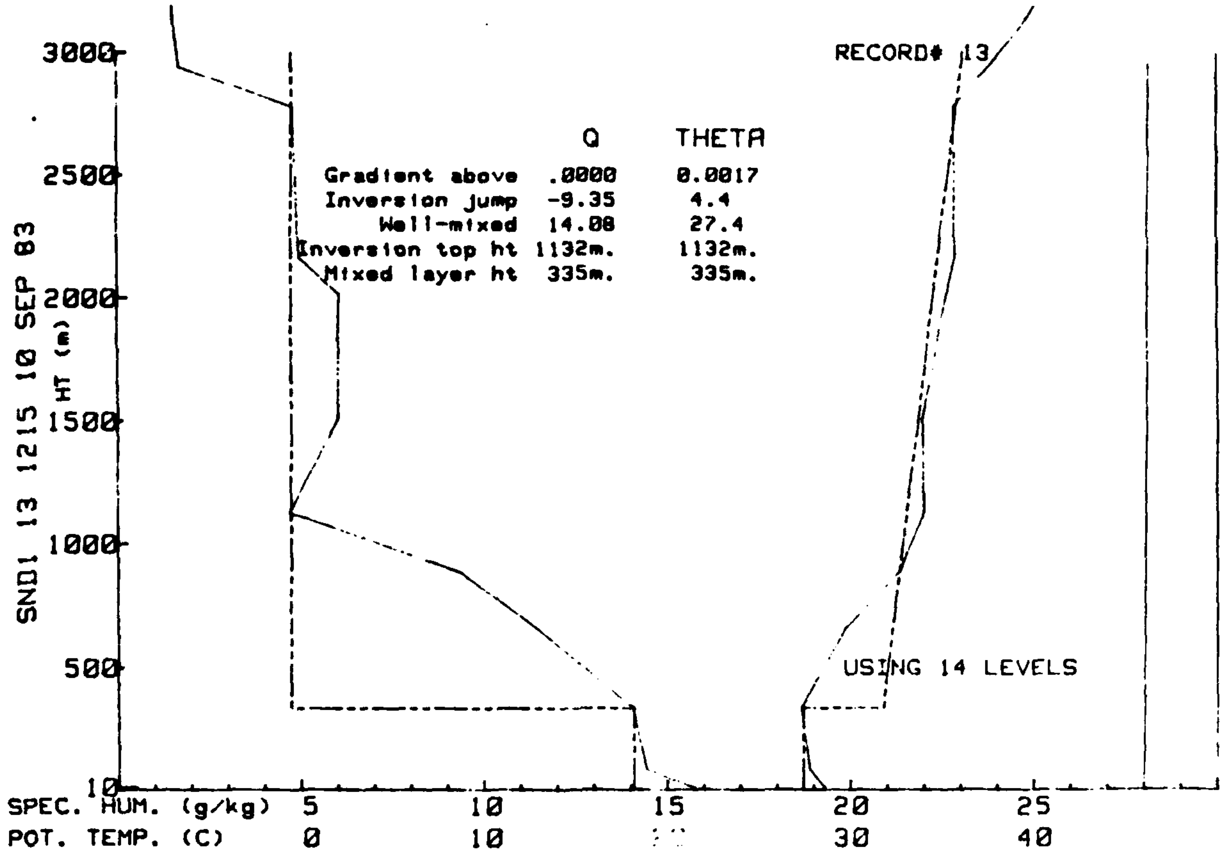

Figure 4.12 1215Z 10 September Sounding and Initializing Profile

launches. Using the same criterion, the 24-h forecasts were valid in only six of thirteen cases. These results indicate that the 12-h forecasts are useful but the 24-h forecasts are not. The 24-h forecast appeared to be no better than persistence. This was due , in part, to synoptic scale changes of the atmosphere with the associated convective action.

The refractivity predictions can be made more useful by taking into account the synoptic scale weather forecasts. If the predicted weather conditions are conducive to ducting, the single station forecast, if initialized with an accurate sounding, would appear to be of value. Most important, this indicates that the NPS model is useful as a first step in predicting the refractivity conditions but the quality of its predictions is dependent on the quality of the sounding data and the user's understanding of the model's limitations.

V. DISCUSSION OF TACTICAL APPLICATIONS AND CONCLUSIONS

A. TACTICAL APPLICATIONS

The effects of radar ducting have to be considered by the tactical planner when he is trying to determine the most effective use of the platforms available. Tactics which depend on ducting conditions are:

(1) Positioning of the screening ships for the optimum yse of their sensors and weapons.

(2) Assigning the correct flight altitude for surveillance aircraft as well as attacking aircraft.

(3) Selecting the Emission Control(EMCON) plan takes advantage of the refractivity conditions.

The correct choices in the above warfare-related areas may determine which force succeeds and which is vanquished.

The Navy is presently using the Integrated Refractive Effects Prediction System(IREPS) to determine the refractive effects. This system calculates the refractivity profile from the radiosonde data which is used to calculate the ducting conditions and give a sensor performance profile. IREPS is a prediction system only in the sense that it predicts the refractivity effects from observed radiosonde data. The program does not forecast the future atmospheric conditions.

The NPS model evaluated in this thesis predicts the refractivity conditions for the 12 and 24-h forecasts after the radiosonde launch time. The NPS model predicts the ducting characteristics from the surface to the top of the marine atmospheric boundary layer (about 1000m). This ability would make the NPS model useful to the operational commander. The forecasts will give the planner information on future extended ranges and holes for radars. This is of vital importance to any platform which is attacking or defending itself. If the unit does not know the propagation patterns it cannot use its weapons systems efficiently.

The tactical use of a single station 12 to 24 hour forecast model must be based on the knowledge of the limitations of the intialization data and the assumptions used in the prediction program. Limits on both are due to the assumptions of a horizontally homogeneous atmosphere and a well mixed boundary layer. Also, it is limited by the problems inherent to a single station forecast such as estimating the subsidence and advective effects.

B. CONCLUSIONS

Evaluations in this thesis have led to the conclusion that in almost every considered sounding and resulting forecast there was an inaccurate represention of the ducting conditions. The observed soundings and the initialization profiles were definitely affected by the inaccuracies in the first few data points. These low-level data points are extremely important for EM propagation assessment and for the NPS model initialization.

There appears to have been systematic errors which affected the radiosonde data up to about 100M. This could have been due to the radiosonde itself not being able to respond to the changes in the atmosphere for the first few meters. These errors also could be caused by the thermal island effects of the aircraft carrier. The ship acts as a local heat source causing the first few temperature and humidity reports to be much different than the surrounding atmosphere.

These aspects of the observed data in this study bring into focus the problem of the Navy's dependence on the single shipboard radiosonde used to determine the EM/EO conditions. These data must be accurate descriptions of the atmosphere for single station assessments. The radiosondes used have been tested, but more studies of the soundings from ships need to be undertaken.

The other major outcome of analysis in this thesis is the affect of the changing synoptic scale weather patterns in the eastern Mediterranean Sea. Single station forecasting procedures for this region which do not take into account the unique meso- and synoptic- scale systems will not be suitable. This study clearly shows that the refractivity conditions in this region are dependent on both the local effects and the synoptic-scale conditions over a twelve-hour time scale. In the eastern Mediterranean Sea these synoptic-scale systems moved through the area almost every other day.

To resolve the problems associated with the synoptic scale weather, the single station forecaster can look at the weather conditions, the radiosonde data and the refractivity and determine if the latter are unreliable. When this occurs the ship can take another sounding. This will permit the ship to maintain an accurate description of the environmental conditions and take advantage of any changes as they occur. The planner will then have to fall back on more traditional tactics and positioning of units until the duct forecasts became reliable again.

In summary, a comparison of the observed soundings and the NPS model's results cannot be used to successfully evaluate either one due to the errors in the soundings and the changes in the synoptic scale systems in the eastern Mediterranean Sea. The primary suggestion from this thesis is that the prediction of EM ducting conditions is dependent on an accurate initialization which, in turn, depends on the accuracy of the sounding.

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4.	Professor W.J. Shaw, Code 63Sh Department of Meteorology Naval Postgraduate School Monterey, CA 93943-5100	1
5.	Professor K.L. Davidson, Code 63Da Department of Meteorology Naval Postgraduate School Monterey, CA 93943-5100	5
8.	Commanding Officer Naval Environmental Prediction Research Facility Monterey, CA 93940	1
9.	Chairman, Code 68Mr Department of Meteorology Naval Postgraduate School Monterey, CA 93943-5100	1
10.	C.E.Sellers,Lcdr. USN. 306 Willow Rd. Savannah, Georgia 31406	4

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