THE FLORIDA STATE UNIVERSITY

COLLEGE OF ARTS AND SCIENCES

DEPARTMENT OF METEOROLOGY

AN INVESTIGATION OF A SEA BREEZE EVENT ON THE CENTRAL OREGON COAST IN AUGUST 1972

By
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Department of Meteorology
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ABSTRACT

A series of meteorological observations including aircraft, pilot balloon (pibal), rawinsonde, surface buoy, and special land-based surface observations was taken on 23-24 August 1972, on the central Oregon coast to investigate the mesoscale thermal and kinematic responses of the lowest 4 km of the atmosphere during a sea breeze event.

A description of those field observations is given. Vertical cross-sections of the wind field on a line perpendicular to the coast, extending 60 km inland from data obtained at three pibal stations, are presented and discussed. Time sections of the wind field for each station and of the temperature and humidity fields at the coast are discussed. Mesoscale features are presented and related to prevailing synoptic-scale changes occurring aloft during the observational period.

The sea breeze event on 23 August exhibited the following important characteristics: a) a sea breeze front, distinguishable in the zonal wind field, which penetrated more than 60 km inland; b) a distinct wind maximum which followed the front inland; c) the surface onshore flow at the coast which took place below the main inversion, deepening the marine layer at the onset, and d) a return flow above the inversion which appeared in quasi-periodic surges in response to surges in the sea breeze flow.

ACKNOWLEDGMENTS

This is a contribution to the Coastal Upwelling Ecosystems Analysis Program (CUEA), a program of the International Decade of Ocean Exploration (IDOE), NSF Grant No. GX-33502. Support for this work has been provided by the Office of Naval Research, the Oceanography Section of the National Science Foundation (Grant GA29734), and the International Decade of Ocean Exploration Program of NSF (Grant CX-28746). This is a contribution to CUE (Coastal Upwelling Experiment).

The portable rawinsonde station and two optical theodolites were borrowed from Dr. William Elliott of Oregon State University (Grant No. NSF GA31141). Another optical theodolite as well as a part of the expendables used in the pibal observations were contributed by Mr. Gerry Burdwell (Advisory Marine Meteorologist, NOAA, National Weather Service).

Deepest appreciation is extended to Dr. J. J. O'Brien for his dedicated assistance and guidance vital to the formulation and the writing of this thesis; and also to Dr. D. W. Stuart for his indispensable advice in the organizational aspects. Drs. C. L. Jordan and R. C. Staley also deserve sincerest gratitude for their recommendations and consultation.

Many thanks are also extended to Mr. Richard Egami, Oregon State University, who assisted in designing the observational network and whose efforts were instrumental in making the field operations truly
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successful.

Sincerest appreciation is offered to Mr. Gerry Burdwell, Clay Creech, Richard McNider, Dennis Elliott, Cleveland Holliday, and Monte Peffley for their assistance in various tasks associated with data collection and processing.

The Florida State University Computing Center provided a portion of the CDC 6500 computer time necessary for reduction of the upper winds into components.

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CHAPTER I

INTRODUCTION

The land-sea breeze circulation is one of the most interesting mesoscale atmospheric phenomena observed in coastal regions during periods of fair weather. As a simple example of one of the most fundamental atmospheric processes (i.e., the generation of motion by differential heating), the sea breeze occurs in many areas with extraordinary strength and persistency. It may differ considerably in character from one area to another, varying in direction, intensity and time according to local conditions (Flohn, 1969). Interaction with other local wind systems may complicate the diurnal wind pattern of a particular area making it difficult to extract those atmospheric responses related directly to a sea breeze event. The prevailing large scale synoptic flow also has a direct effect on the strength and landward penetration of sea breezes. Koschmieder (1935), Haurwitz (1947), Estoque (1962), and Frizzola and Fisher (1963) have presented many examples illustrating this interdependence.

Along the Pacific coast of the United States, a unique combination of physiographic and oceanographic characteristics strongly influence the local meteorological conditions during summer. The presence of the large sea level Pacific anticyclone dominates the large scale air flow near the surface. Along the eastern fringe of the high, the immediate inland areas receive intense daytime heating which produces a large scale

the surface. Along the eastern fringe of the high, the immediate inland areas receive intense daytime heating which produces a large scale

gradient wind flow from the north along the coast. This persistent northerly component in the local surface winds accounts for the coastal upwelling phenomenon which acts to reduce nearshore sea surface temperatures. This combination of intense heating inland and the cold sea surface produces very high coastal thermal gradients which leads to the development of a sea breeze circulation. Primary evidence of such a circulation on the central Oregon coast is expected to be found in the diurnal variation of the zonal wind component since the coastline is oriented north-south.

It is the purpose of this study to attempt to evaluate the character of the zonal wind variability on the central Oregon coast based on observations of a sea breeze event on 23 August 1972, at Newport, Oregon. The observations were taken during the summer of 1972 as part of the Coastal Upwelling Experiment (CUE I), a project of the International Decade of Ocean Exploration of the National Science Foundation. The experiment represented an intense effort to explore the phenomenon of coastal upwelling.

Although the major observational effort was primarily oceanographic, an important, though limited, meteorological observation program was undertaken. These observations concentrated on surface winds in order to determine the temporal and spatial wind stress pattern, the forcing function for the observed intense upwelling.

The following sections of this paper will provide a complete description of a series of special field observations documenting a sea breeze event. Included are interpretations of the observed mesoscale changes in the vertical structure of the lowest 4 km of the atmosphere

breeze event. Included are interpretations of the observed mesoscale changes in the vertical structure of the lowest 4 km of the atmosphere

during the event.

The field observations are described in Section 2. A complete analysis of the data obtained from the field observations with main emphasis on a discussion of the 23 August sea breeze event is contained in Section 3. Section 4 is devoted entirely to comparing the results of this study to those of previous investigations. The summary and conclusions are presented in Section 5.

CHAPTER II

THE FIELD OBSERVATIONS

The purpose of this section is to provide a description of the special meteorological field observation program during a 42-hour period from 0500PDT, 23 August 1972, through 0000PDT, 25 August 1972. These observations form the basis for the description of the sea breeze occurrence.

Fig. 1 is a map of the CUE I area showing the land stations and buoys at which meteorological observations were taken during the summer of 1972.

2.1 Surface observations

As a part of the overall CUE I meteorological observation program, five portable recording anemometers were installed along the coast to the north and south of Newport, Oregon during August. Surface winds were also observed at the south jetty at Newport, and at five surface buoys moored within 30 nautical miles of the coast. Air temperature records were also available from these buoys and from Newport. Special surface temperature and relative humidity observations were made during 23 August at Ellmaker State Park and Corvallis to assist in the documentation of a sea breeze event.

2.2 Aircraft observations

2.2 Aircraft observations

The NCAR (National Center for Atmospheric Research, Boulder, Colo.) Queen Air aircraft, based in Corvallis during 4-31 August, played an

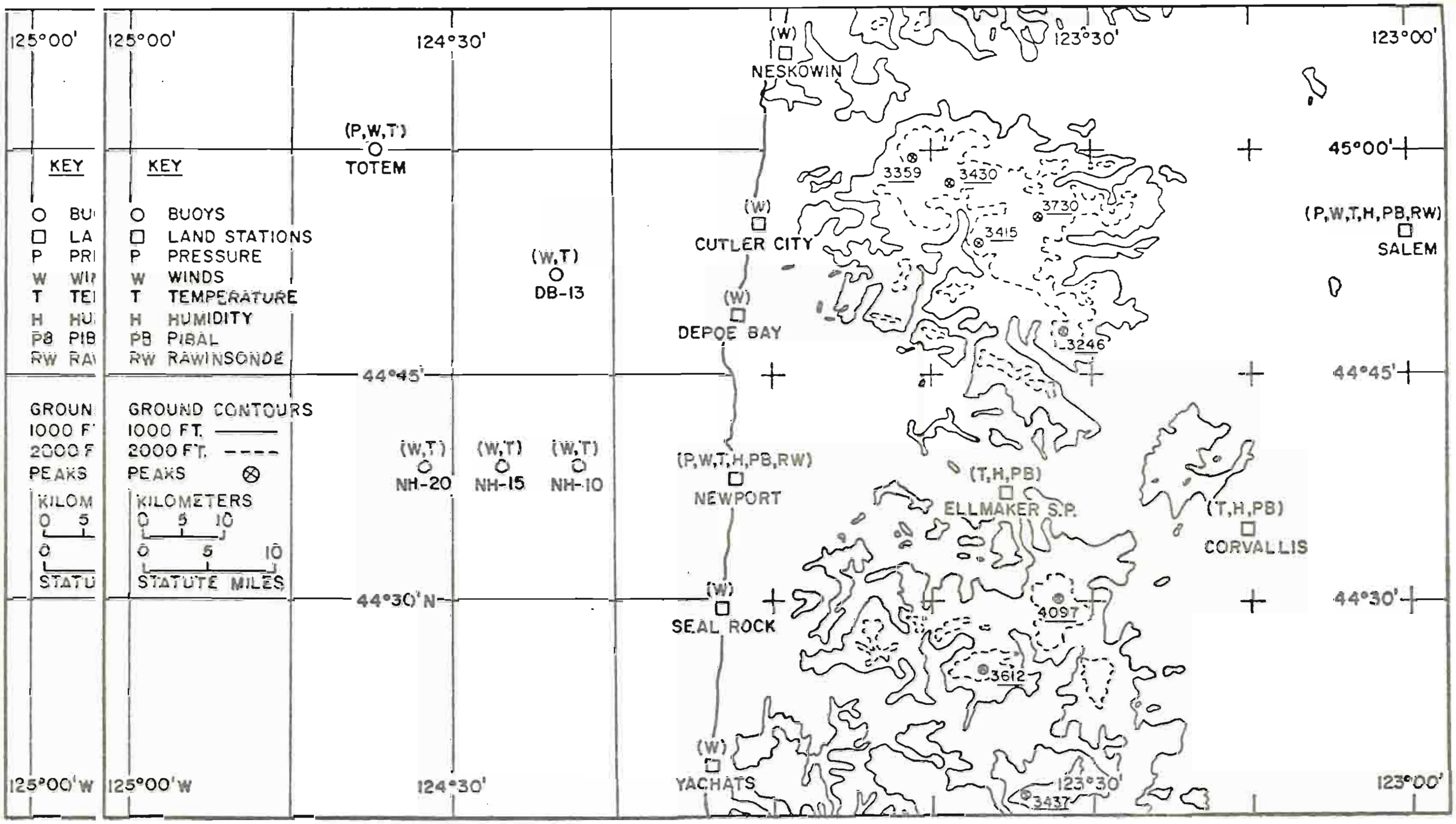

Fig. 1. Map of central Oregon coastal area showing meteorological observing stations

important role in CUE I observations. In addition to measuring sea surface temperatures with an infrared radiometer, the aircraft recorded flight level winds, air temperature, and dew-point temperature. Generally, flights were made at 500 ft along radial tracks from Newport, extending 35 nautical miles seaward, and at 5000 ft between Newport and Corvallis. In addition, the aircraft made vertical soundings of temperature and dew point via spiral ascents and descents over Corvallis, Newport, and at a point approximately 35 nautical miles west-northwest of Newport.

Weather permitting, the low-level flight tracks over the ocean were flown during each aircraft flight. On 23 August, however, dense fog immediately offshore (which was later advected onshore) prohibited such operations. Nevertheless, two short flights were made during 23 August in addition to two full flights on 24 August to supplement the documentation of atmospheric structure during the observational period. These flights produced valuable vertical soundings of temperature and humidity but compass failure within the Doppler radar system prevented any useable wind observations.

2.3 Pibal and rawinsonde observations

Through the cooperation of Dr. William Elliott and the assistance of Mr. Richard Egami, both of the School of Oceanography at Oregon State University, limited use of a portable rawinsonde station (Weather-measure Corp., RD-65) and two optical theodolites was made possible. Since resources were limited, a 42-hour observational program was

measure Corp., RD-65) and two optical theodolites was made possible. Since resources were limited, a 42-hour observational program was

planned. Some flexibility in planning was possible, and 23-24 August was chosen as the observational period based on a forecast synoptic situation considered conducive to a local sea breeze event.

Routine pibal observations had been taken at the Marine Science Center in Newport throughout the month of August. On 23 and 24 August, 2-hourly (every two hours) pibals were taken at Newport. Simultaneously, on 23 August only, 2-hourly pibal observations were taken in Corvallis. At Ellmaker State Park hourly pibals were taken. The Ellmaker and Corvallis observations were taken between 0600-2000PDT 23 August, while those at Newport were continued through midnight 24 August. The occurrence of fog at Newport on 23 August prevented pibal observations there from noon until 2000PDT. Winds were available during this time, however, from the 4-hourly rawinsonde observations described next.

On 23 August, rawinsonde observations were taken every four hours at Newport, beginning at 0500PDT, 23 August and ending after 0500PDT, 24 August. The rawinsonde sensors were tracked semi-automatically by manual control of servo-motors controlling the orientation of a parabolic receiving antenna. Balloon positions were recorded each minute of flight yielding wind observations for approximately every 300 m. Each sounding was terminated after 30 min of flight and the data were processed up to 700 mb (approximately 3 km).

In summary, the main observations taken during 23-24 August, in connection with this study, are presented in Table 1.

In order to obtain some feeling for the character of the diurnal variability of the surface winds on the Oregon coast, Fig. 2 is a time series for the winds observed at Newport for the period 12-31 August 1972.

series for the winds observed at Newport for the period 12-31 August 1972.

The observational period for this study falls within the dotted lines. The v-component (northward) is given in the upper portion of the figure

Table 1.--Data summary.

A. Hourly surface wind observations

  a. Newport (South Jetty)
  b. Five surface buoys
    1. NH-10 (10 n mi west of Newport)
    2. NH-15 (15 n mi west of Newport)
    3. NH-20 (20 n mi west of Newport)
    4. DB-13 (13 n mi northwest of Depoe Bay)
    5. Totem (25 n mi northwest of Depoe Bay)
  c. Five portable anemometer sites
    1. Neskowin (29 n mi north of Newport)
    2. Salishan-Cutler City (19 n mi north of Newport)
    3. Depoe Bay (11 n mi north of Newport
    4. Seal Rock (8 n mi south of Newport)
    5. Yachats (18 n mi south of Newport)

B. Aircraft observations

  a. Vertical soundings to 5000 ft
    1. Newport
      a. Aug. 23, 0945, 1415 PDT
      b. Aug. 24, 1015, 1615 PDT
    2. Corvallis
      a. Aug. 23 0925, 1005, 1350, 1440 PDT
      b. Aug. 24 0955, 1630 PDT
    3. Over ocean (35 n mi WNW of Newport)
      a. Aug. 24, 1120, 1520 PDT

  b. Level flight data (winds, temp., dew point)
    1. Corvallis-Newport (5000 ft only)
      a. Aug. 23, 0929-0939 PDT, 0952-1000 PDT
         1357-1406, 1426-1438 PDT
      b. Aug. 24, 0959-1008 PDT, 1617-1626 PDT
    2. Over Newport (special; ± 5 n mi across coastline)
      a. Aug. 23, 1405-1428 PDT at 2000, 3000, 4000, 5000 ft

C. Pibal observations (with special surface temperature and humidity observations for each pibal)

    a. Newport (2-hourly)
      1. Aug. 23: 0600-1200, 2000 PDT
      2. Aug. 24: 0600-2400 PDT
    b. Ellmaker State Park (hourly)
      1. Aug. 23: 0600-2400 PDT
    c. Corvallis (2-hourly)
      1. Aug. 23: 0600-2000 PDT

D. Rawinsonde observations (to 700 mb)

  a. Newport (4-hourly)
    1. Aug. 23: 0500-2100 PDT

D. Rawinsonde observations (to 700 mb)

  a. Newport (4-hourly)
    1. Aug. 23: 0500-2100 PDT
    2. Aug. 24: 0100-0500 PDT

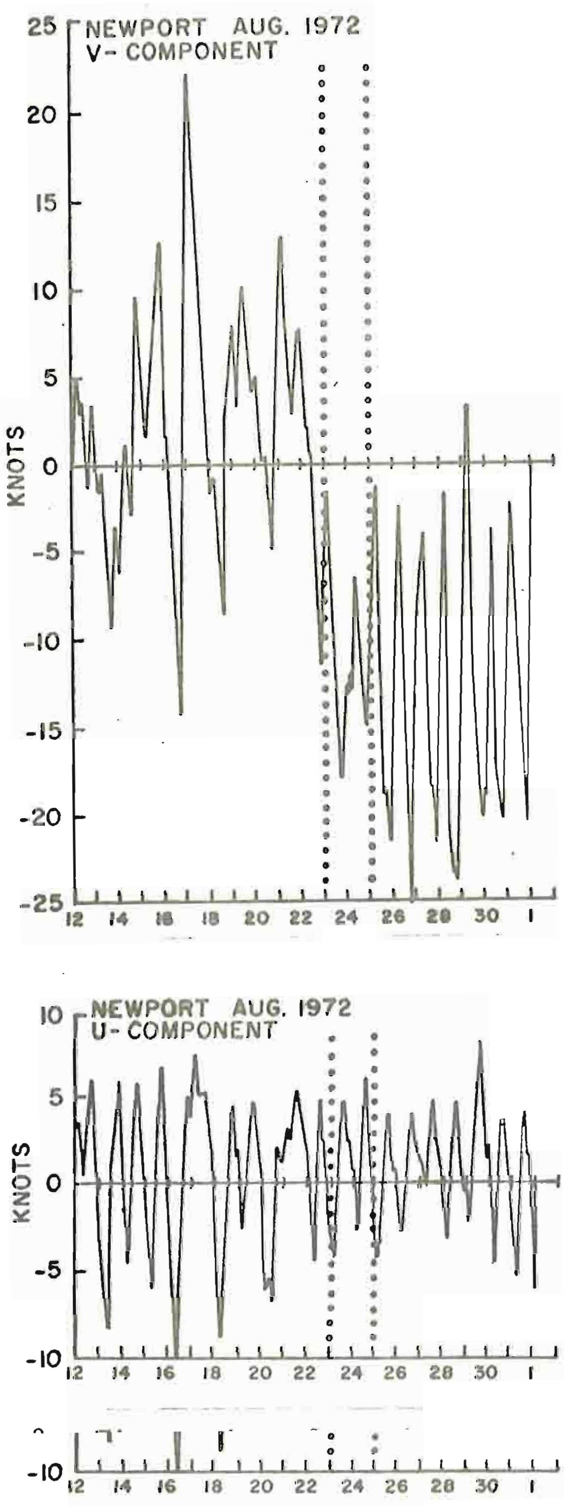

Fig. 2. Time series of zonal and meridional winds for Newport during 12-31 August 1972. Observational period for this study lies within the dotted lines.

and the u-component (eastward) in the lower portion. The vertical axis is labeled in knots and the horizontal axis in days.

Of particular interest is the higher magnitude of diurnal variability of the v-component in general (varying between -2 kt and -24 kt, while the u-component ranges between -2 kt and +7 kt). This high persistence of northerly winds and the large diurnal variability lead many local residents to improperly refer to this change as a sea breeze.

CHAPTER III

THE 23 AUGUST SEA BREEZE EVENT

In order to interpret the mesoscale structure of the 23 August sea breeze event from the observations made for this study, a general summary of synoptic scale features present during the observational period is necessary. In addition to sea level pressure patterns and upper air charts, vertical cross sections and vertical profiles of the wind field are presented. The vertical temperature and humidity structure is examined at the coast in a time section analysis of the soundings taken at Newport. The horizontal surface temperature distributions are also discussed comparing the diurnal temperature variations at several stations on a line perpendicular to the coast.

3.1 Synoptic scale flow

Figs. 3a, b, and c show the upper level synoptic pattern for the Pacific coast at 850 mb, 700 mb, and 500 mb for 1700PDT, 23 August; approximately half-way into the observational period. The 700 mb and 850 mb charts have been analyzed at 30 m intervals while a 60 m interval has been used at the 500 mb level.

The low centered in western Wyoming at 500 mb is a remnant of a major trough which was located some 300 km west of the coastline for more than 10 days previous to the sea breeze observational period. During this time the surface pattern for the Pacific coast was dominated

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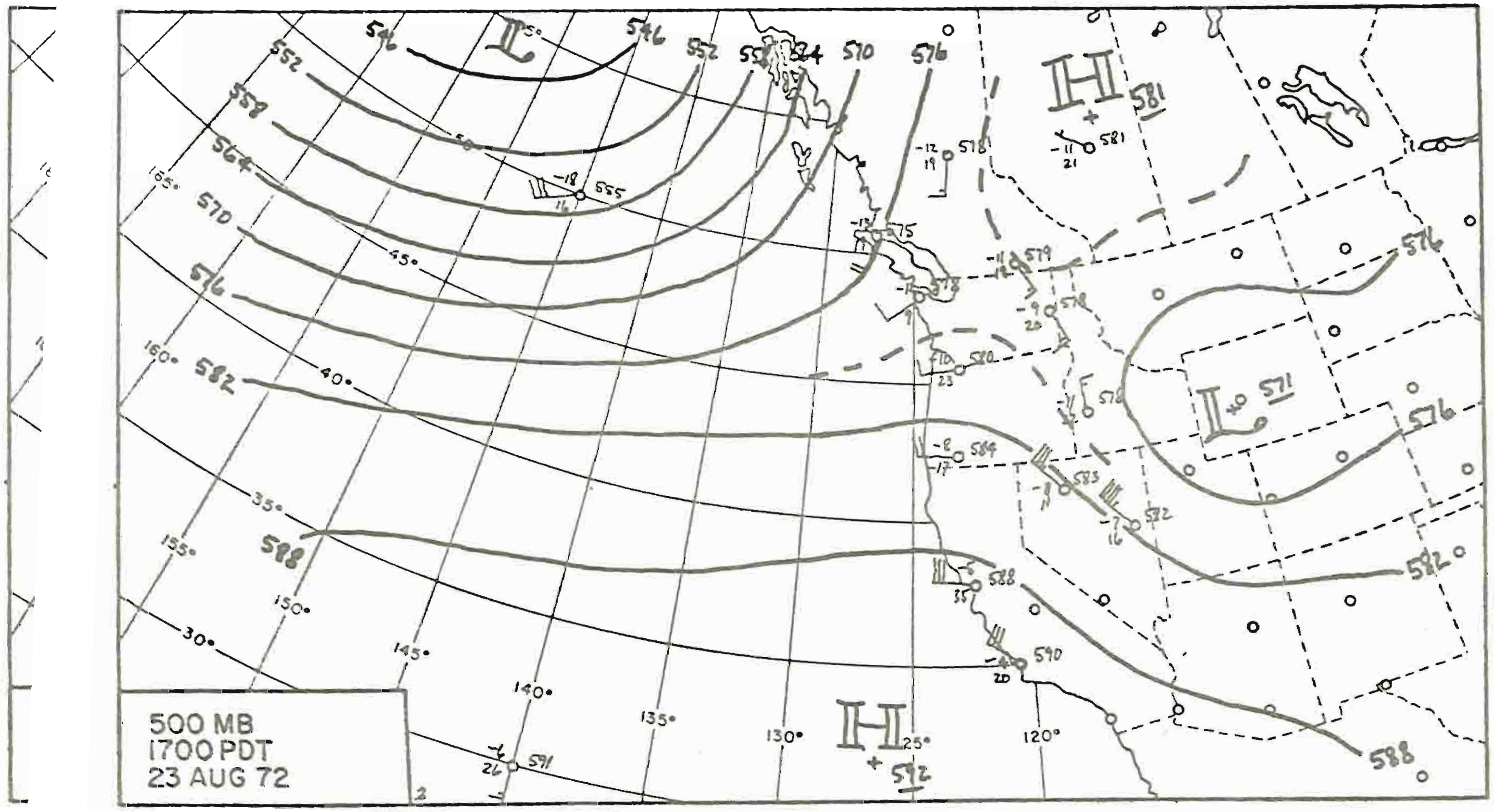


Fig. 3. a) 500 mb contour analysis for Pacific coast area

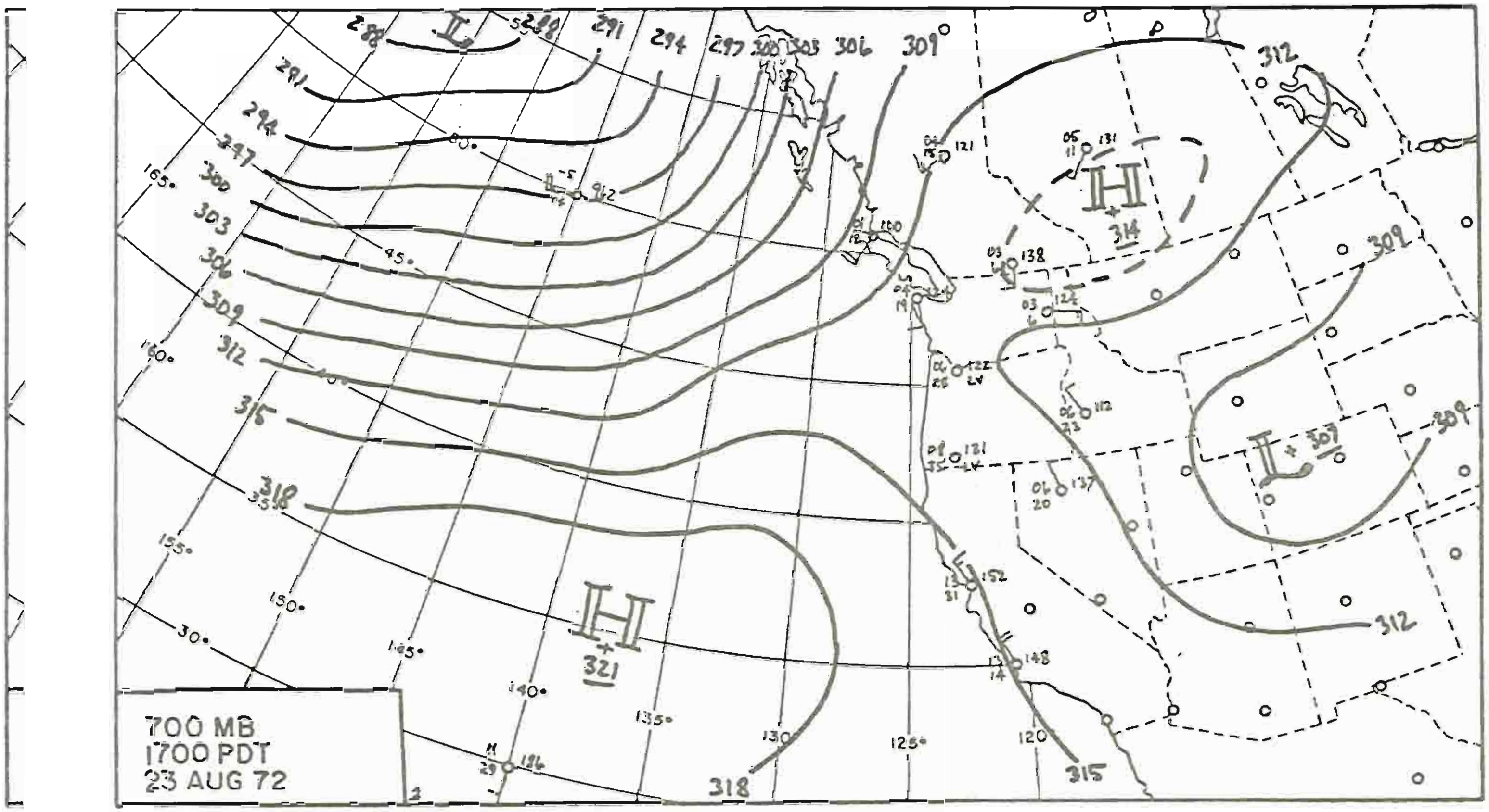


Fig. 3. b) 700 mb contour analysis for Pacific coast area

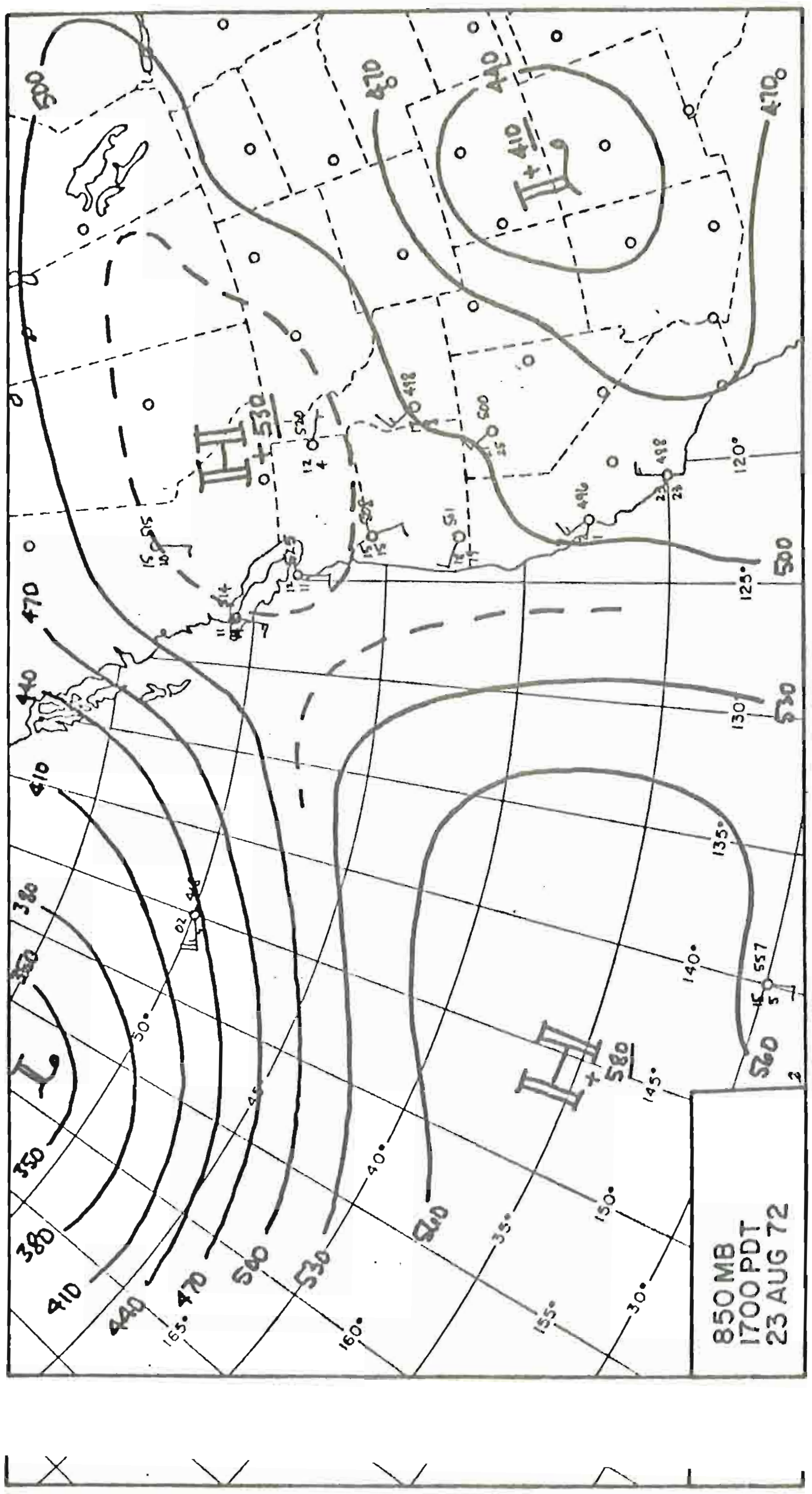


Fig. 3. c) 850 mb contour analysis for Pacific coast area

by generally very weak pressure gradients and weak westerly or southerly flow, interrupted briefly by occasional weak lows moving through the area.

The upper trough finally moved inland on 22 August while subsequent ridging aloft behind the trough induced a rapid northeastward extension of the Pacific High at lower levels. The northern portion of the ridge eventually became detached and drifted ESE 12 hours later. This sequence of events produced easterly flow over the central Oregon coast at 850 mb. At the surface (Fig. 4), the extension of the ridge restored a northerly flow producing a sudden onset of upwelling along the coast.

Large scale meteorological changes aloft were responsible for the development of the surface conditions shown in Fig. 4 which were conducive to the wind flow that eventually produced the onset of upwelling. This is now known to the CUE I oceanographers as *the August upwelling event*.

3.2 Mesoscale sea level pressure pattern

As is generally the case, the large scale subsidence due to ridging aloft during this event allowed intense heating inland and development of a thermal low. This is seen at the surface (Fig. 4) as a northward extension of the California thermal trough. This reduction of pressure inland further increases the coastal pressure gradient and subsequent northerly flow along the Oregon coast.

The mesoscale pressure patterns clearly show the thermal trough development in central Oregon on 23 August (Figs. 5 and 6). The maps are analyzed at 1 mb intervals and are presented for every 3 hours beginning at 0800PDT, 23 August. At 0800PDT (Fig. 5, top), the primary trough analyzed at 1 mb intervals and are presented for every 3 hours beginning at 0800PDT, 23 August. At 0800PDT (Fig. 5, top), the primary trough axis is positioned close to the coast. One reason for this occurrence is a decrease in relative vorticity of the northerly flow ascending the

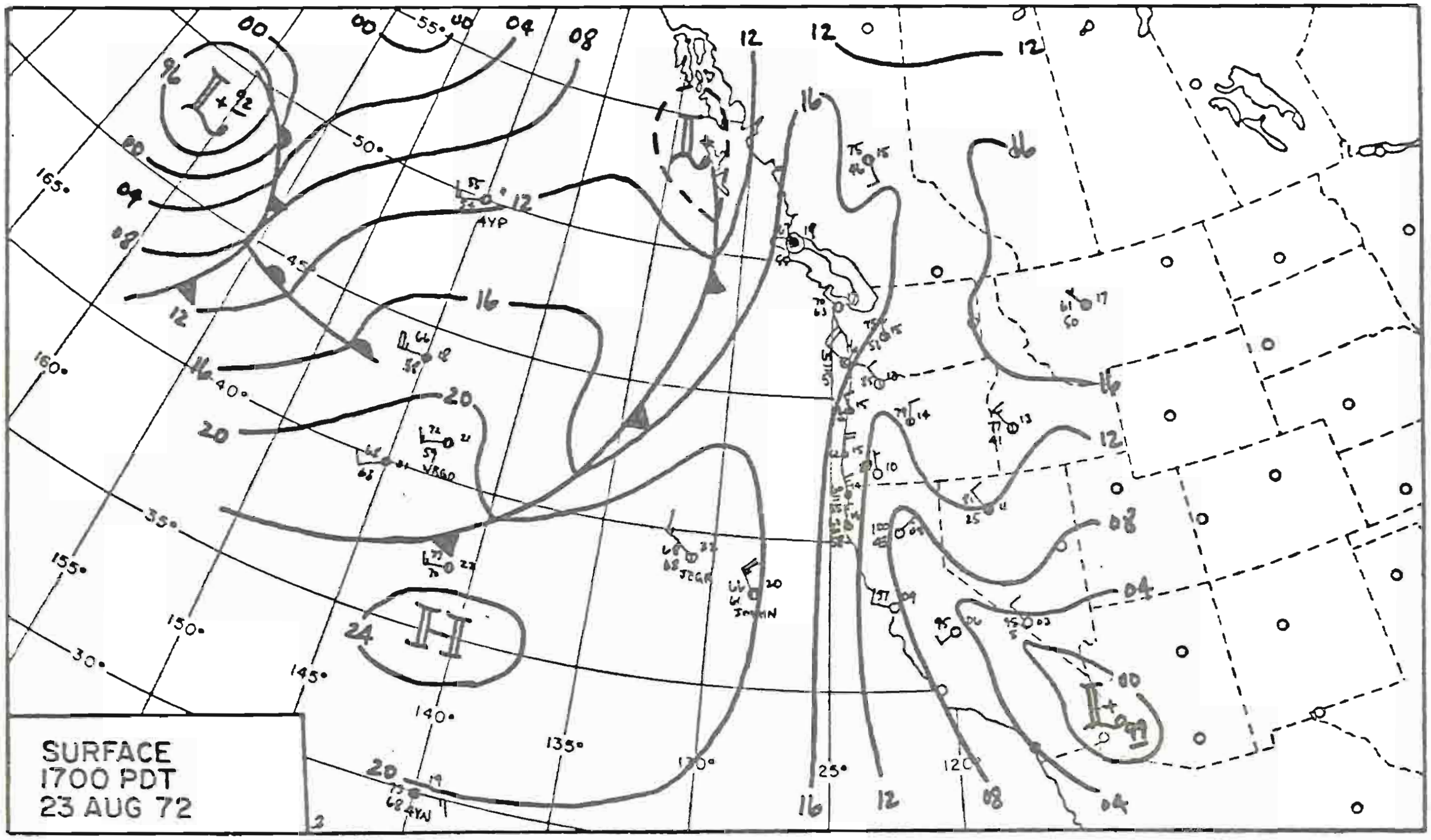
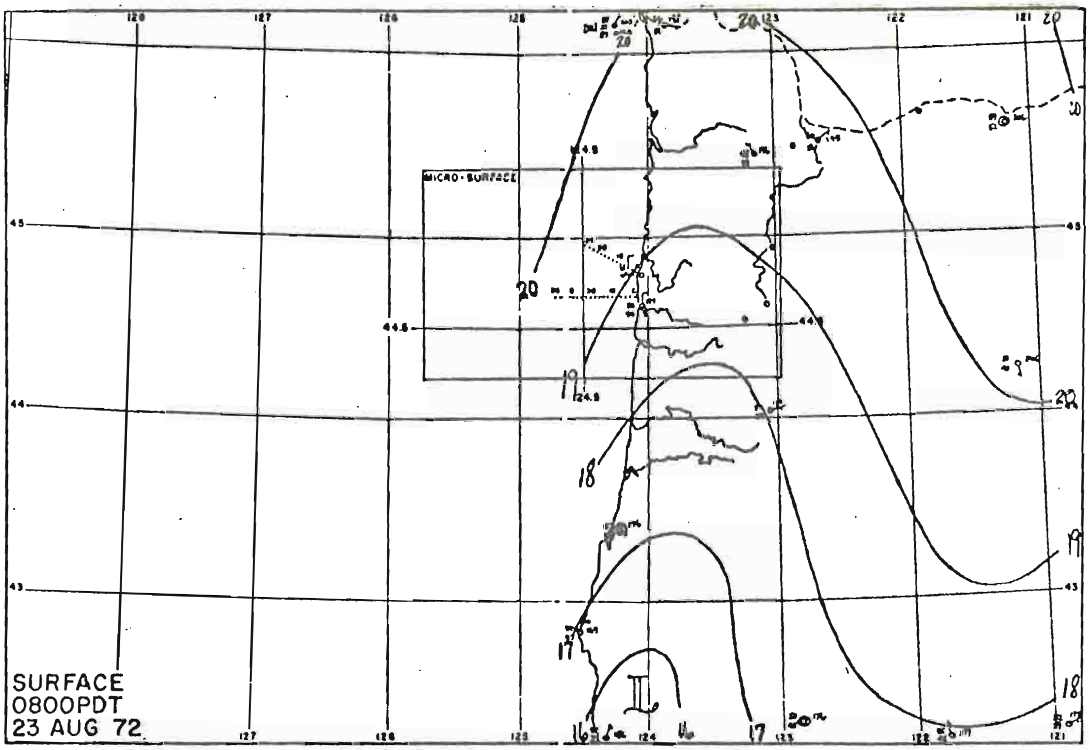


Fig. 4. Synoptic scale sea level pressure analysis for the Pacific coast (O'Brien, 1972)



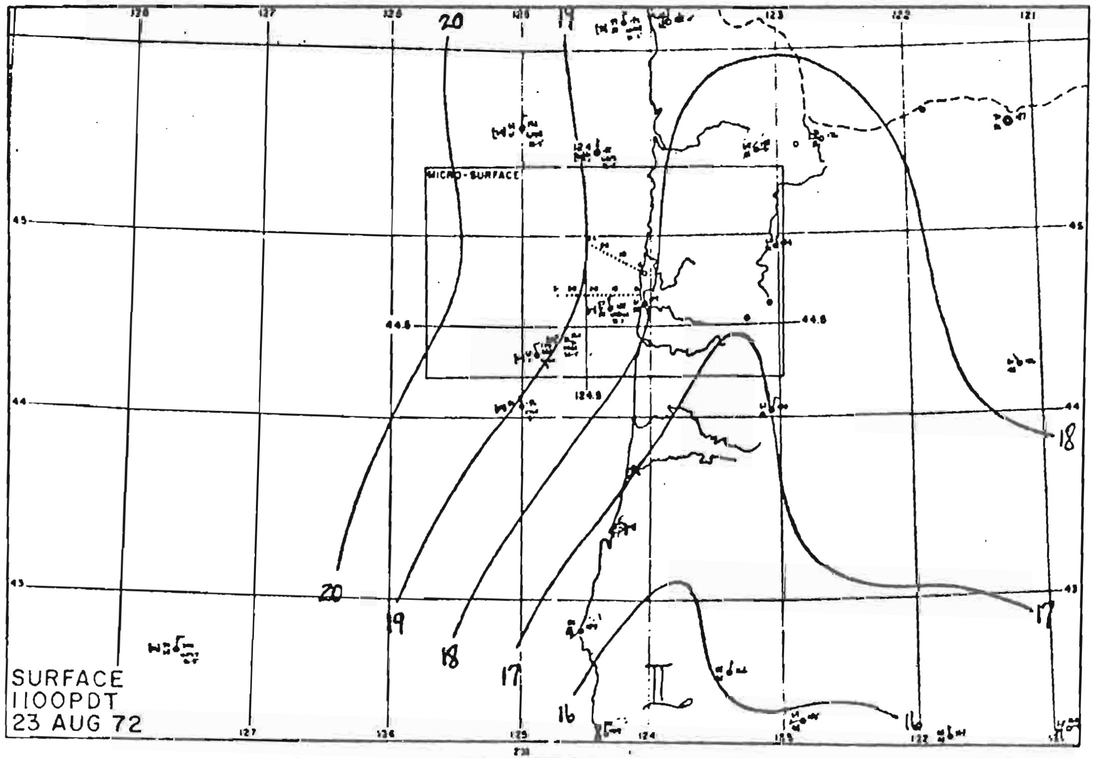


Fig. 5. Mesoscale sea level pressure analyses for the

1100PDT
23 AUG 72

Fig. 5. Mesoscale sea level pressure analyses for the Oregon coast (O'Brien, 1972)

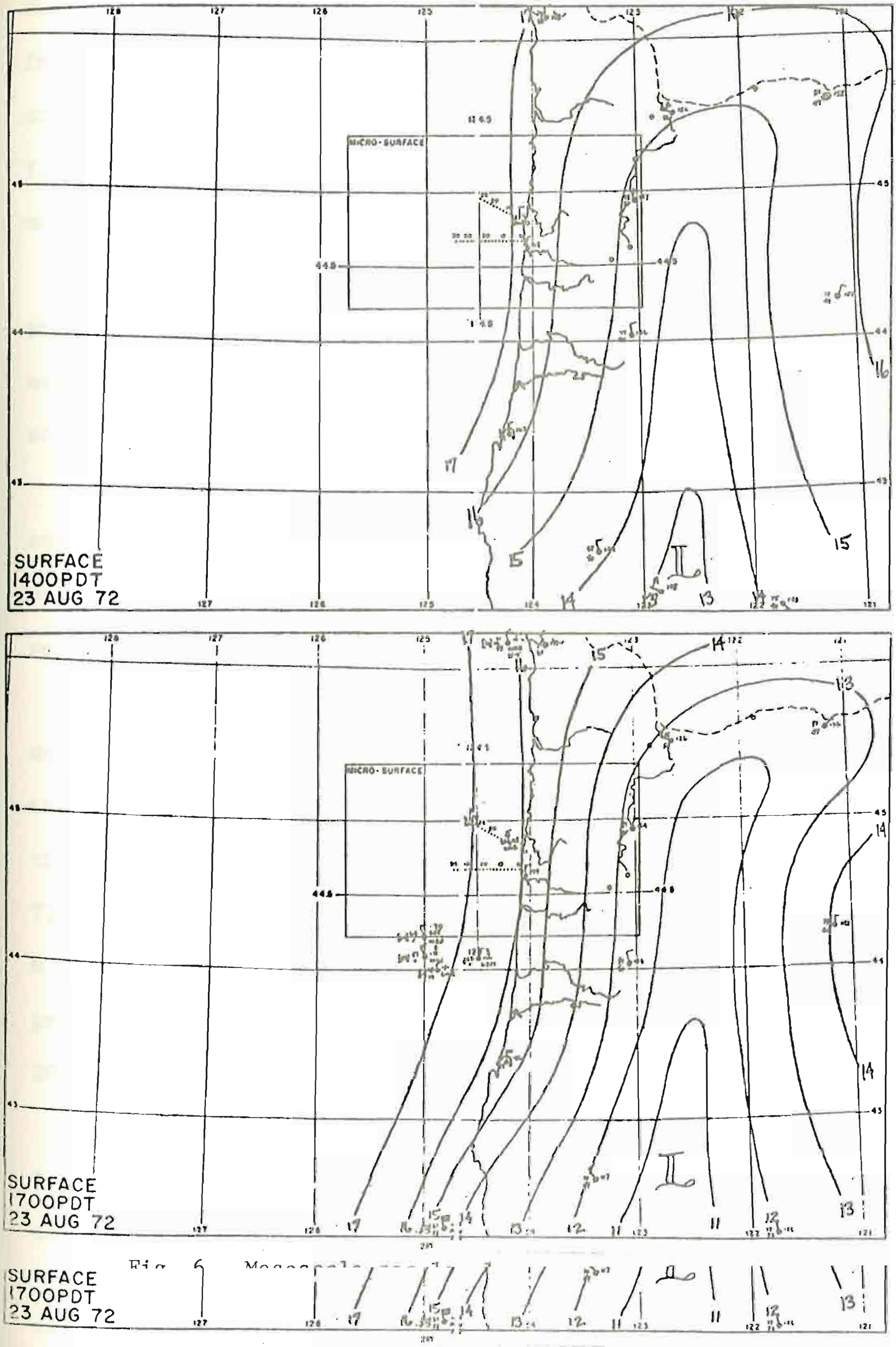


Fig. 6. Mesoscale sea level pressure analyses for the Oregon coast (O'Brien, 1972)

Siskiyou Mountain range at the southern coast of Oregon (Capell, 1953). In most cases, this effect maintains a persistent trough axis near the southwestern Oregon coast under the influence of a large scale gradient flow, but it is only in the early stages of the thermal trough development in the interior that it supports the primary trough axis.

By 1100PDT (Fig. 5, bottom), surface heating begins to reduce pressures in the interior valleys and the trough axis starts to move eastward into the northern interior; but no movement is detected to the southwest.

By 1400PDT (Fig. 6, top), the intense heating inland provides good support for trough development and the primary trough axis becomes oriented north-south through the interior valleys while the original axis near the south coast becomes secondary and is difficult to detect.

The increase in the meridional wind component observed at Newport during this period appears to be in direct response to the increase in the east-west pressure gradient. During this trough development process, the pressure gradient between Newport and Corvallis nearly triples (Fig. 7) while the magnitude of the meridional wind at Newport increases from 6 kt to 17 kt (Fig. 8). For both 23 and 24 August, a minimum east-west pressure gradient is observed at 0800PDT while a maximum is observed at 2000PDT.

Once the thermal trough becomes established in western Oregon, a large diurnal variation of the east-west pressure gradient near the coast is frequently observed.

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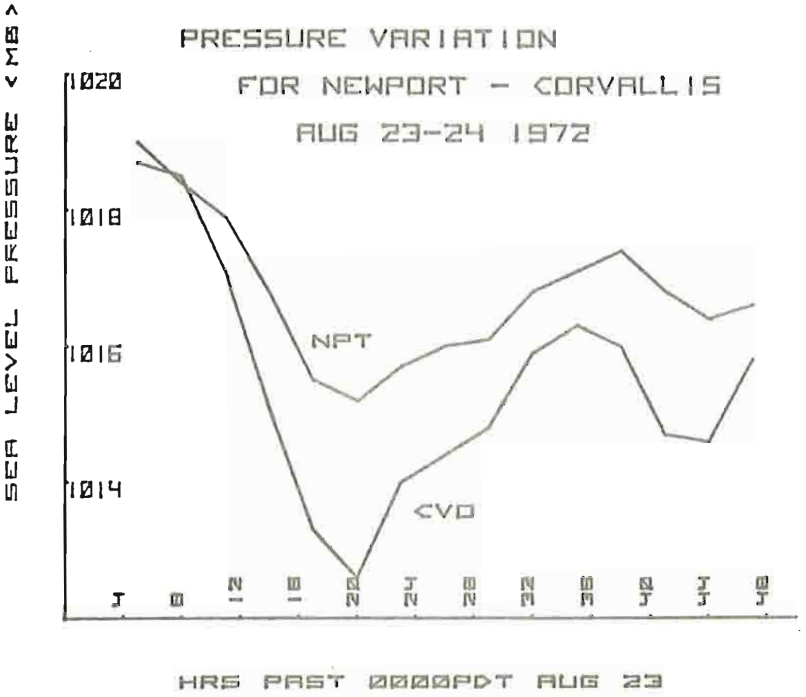

Fig. 7. Time series of sea level pressures for Newport and Corvallis, 23-24 August 1972

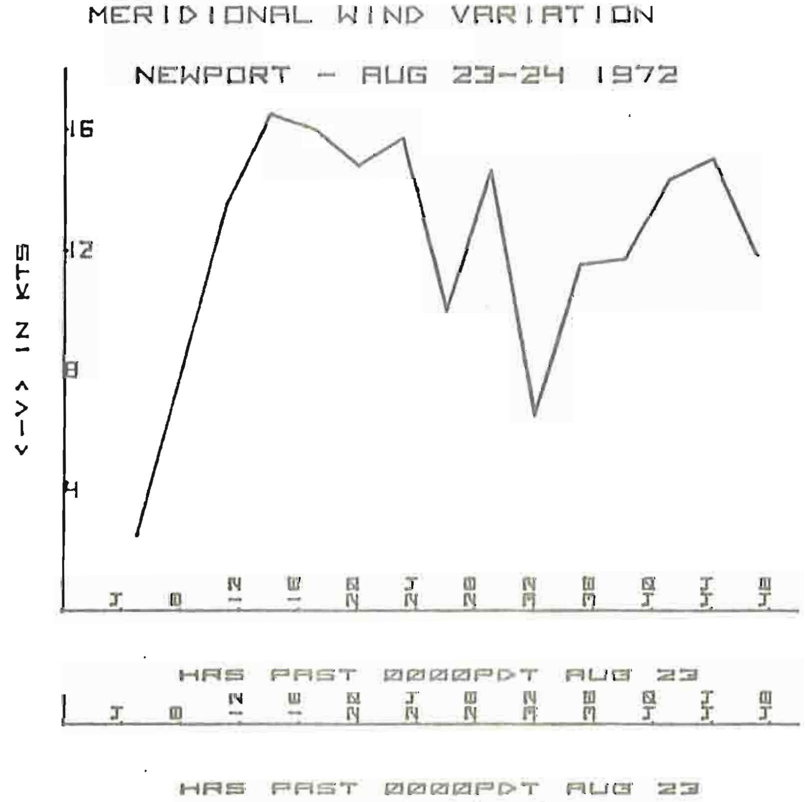

Fig. 8. Time series of meridional wind observed at Newport, 23-24 August 1972

3.3 Cross section of the wind field

Vertical cross sections of the wind field between Newport and Corvallis for 23 August are shown in Figs. 9 through 16. Easterlies and southerlies are given by dashed isotachs, westerlies and northerlies by solid lines, and the zero line for each component is represented by a dotted line. The vertical lines above each station indicate the heights to which data were available for the analysis. Vertical lines are dashed where no observation was made but the analysis was completed on the basis of continuity from the time section for that station.

The zonal wind cross sections presented here show that a sea breeze front is distinguishable in the wind field and has penetrated more that 60 km inland while a distinct maximum in the westerly flow behind the front increased in magnitude as it followed the front inland. The only indication of a related return flow in the circulation appears to be some increase in the depth of the easterlies above the level of maximum low level westerlies.

The zonal wind component at approximately 0630PDT (Fig. 9, top) is easterly at all levels up through 3500 m with two distinct maxima separated by a minimum at 2 km. At 0800PDT (Fig. 9, bottom), the lower easterly maximum has risen to 800 m and increased to 15 kt while the upper maximum is maintained at the same height and intensity.

At 1000PDT (Fig. 10, top), marked changes in the easterlies have taken place, where for the first time, low level westerlies emerge. The easterly maximum aloft has rapidly decreased in intensity and has split into a double maxima; one over Newport at 3200 m, and one over Corvallis which has lowered to 2300 m. The lower easterly maximum is still rising

taken place, where for the first time, low level westerlies emerge. The
easterly maximum aloft has rapidly decreased in intensity and has split

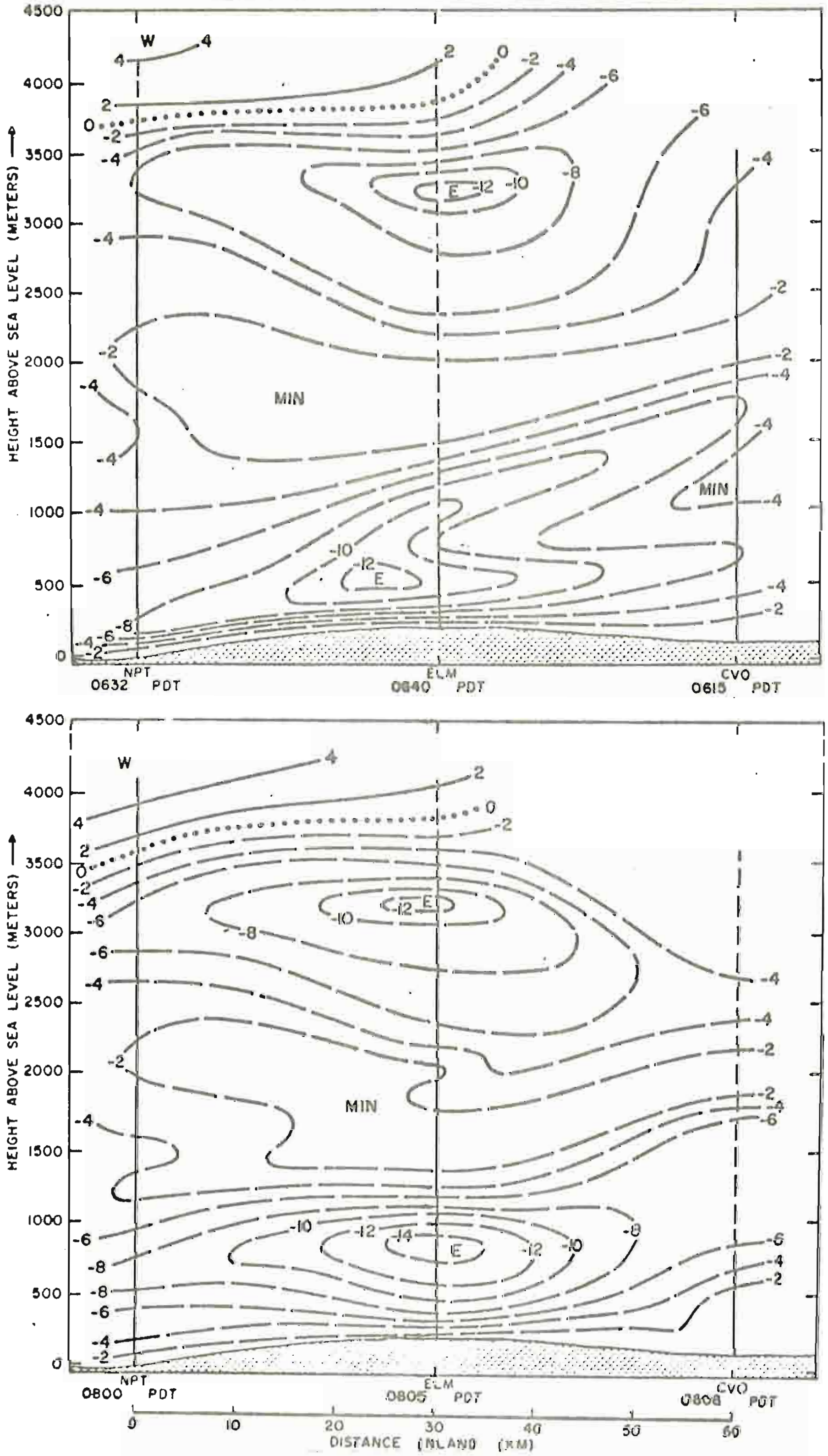

Fig. 9. Early morning zonal wind cross sections

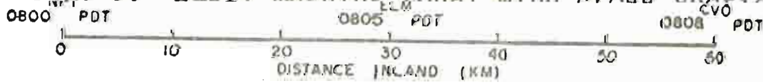

Fig. 9. Early morning zonal wind cross sections, 23 August 1972 (wind speed in knots)

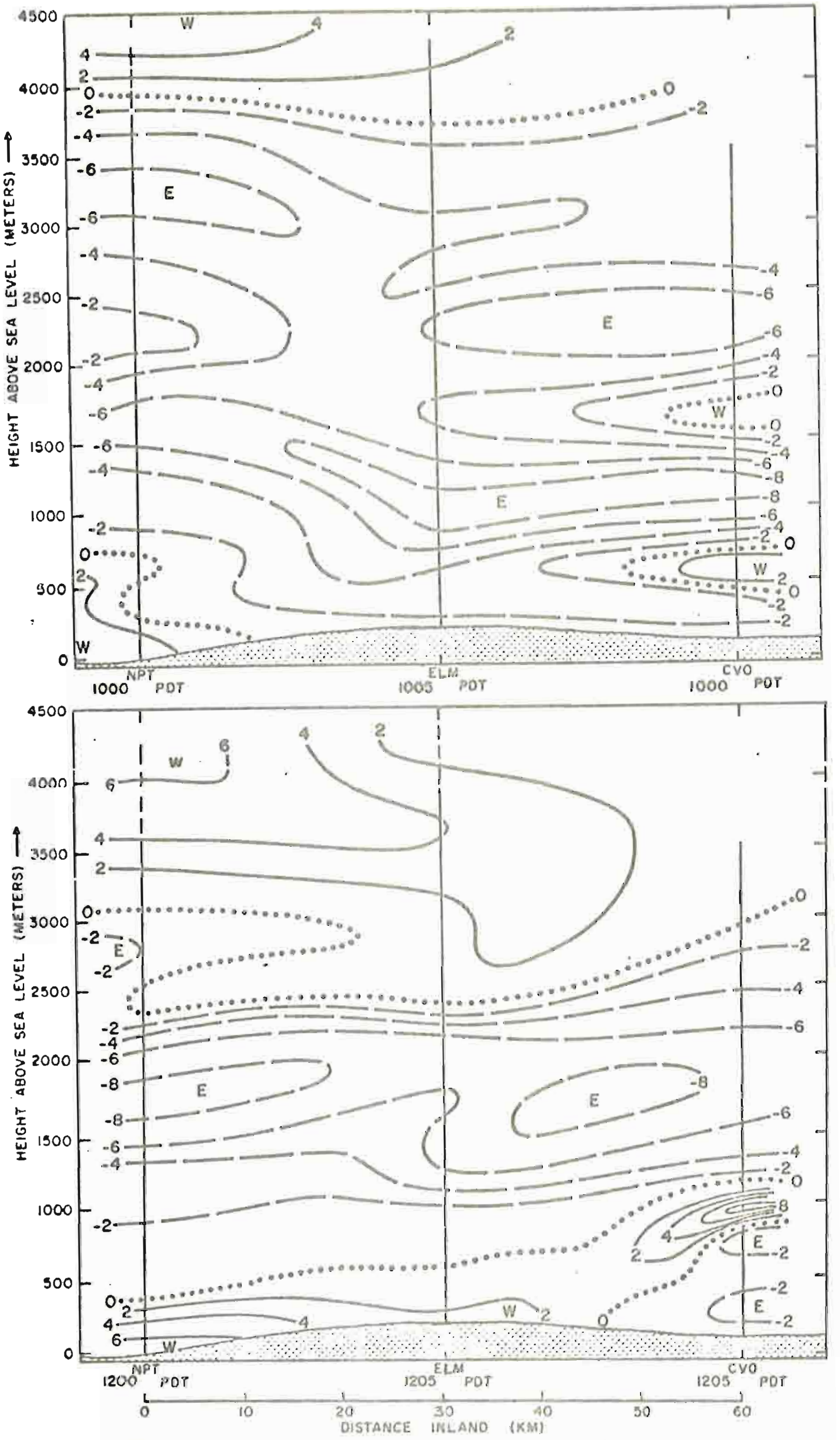

Fig. 10. Late morning zonal wind cross sections, 23 August 1972 (wind speed in knots)

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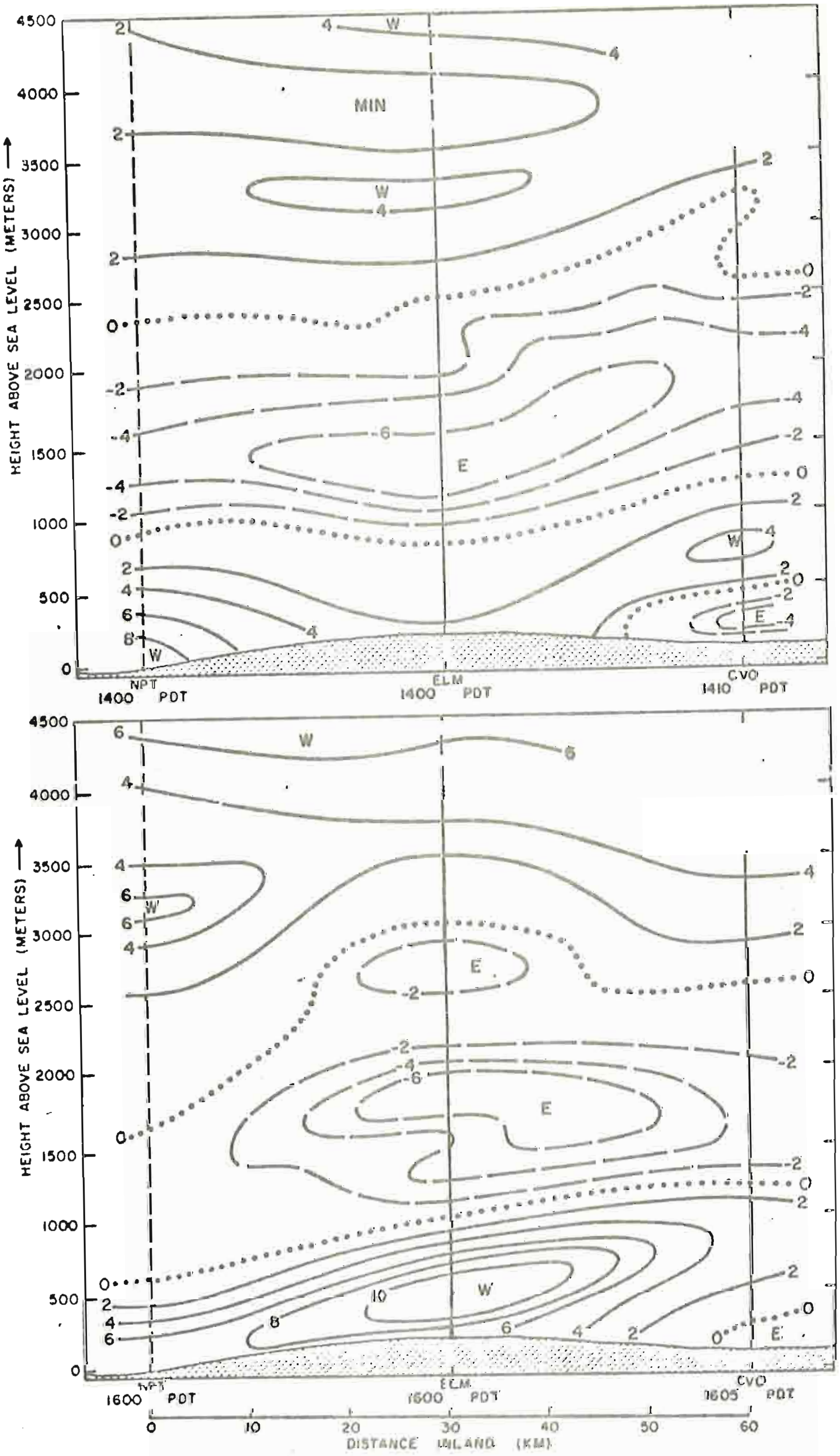

Fig. 11. Afternoon zonal wind cross sections,
23 August 1972

Fig. 11. Afternoon zonal wind cross sections,
23 August 1972 (wind speed in knots)

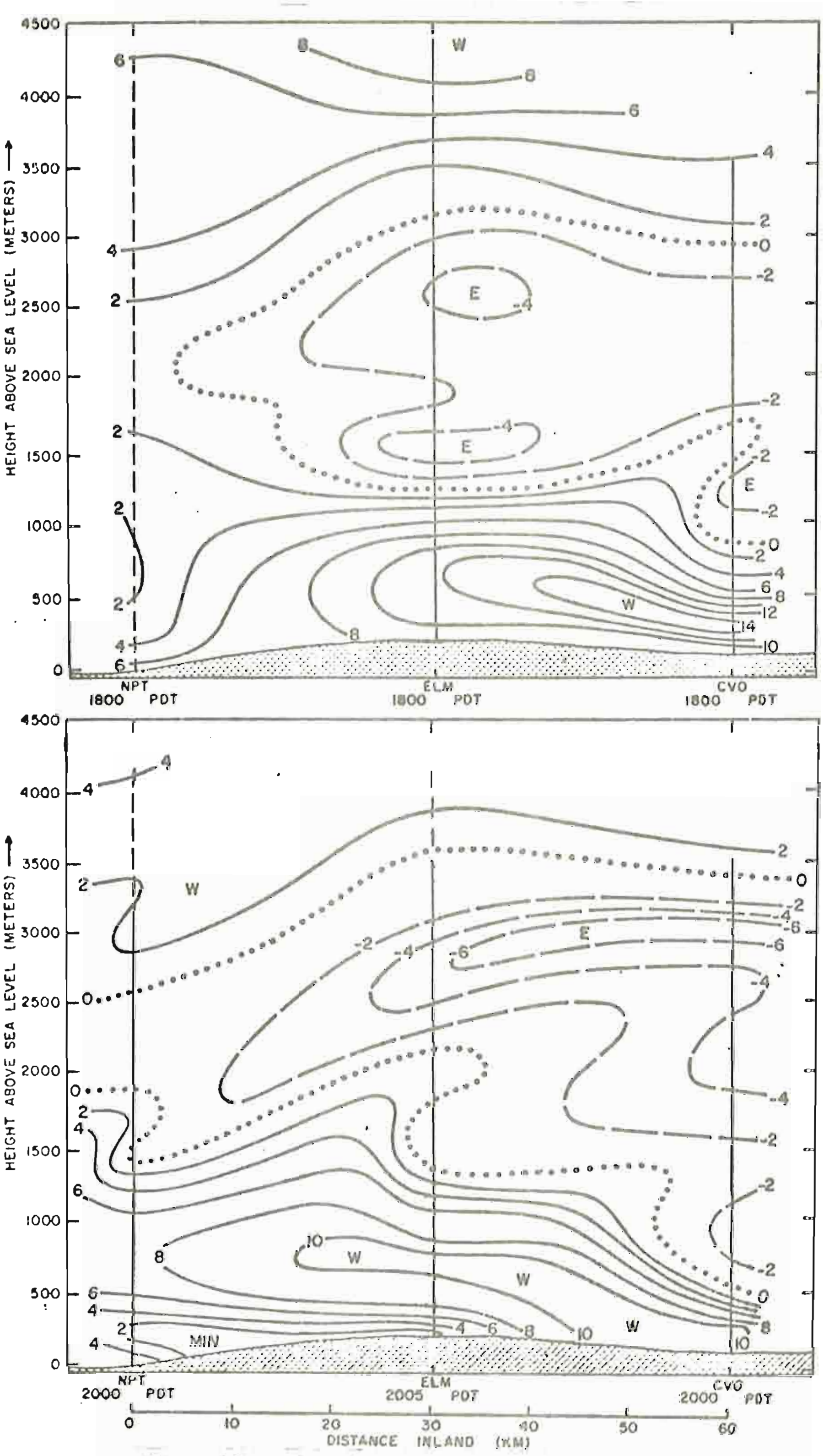

Fig. 12. Evening zonal wind cross sections, 23 August 1972 (wind speed in knots)

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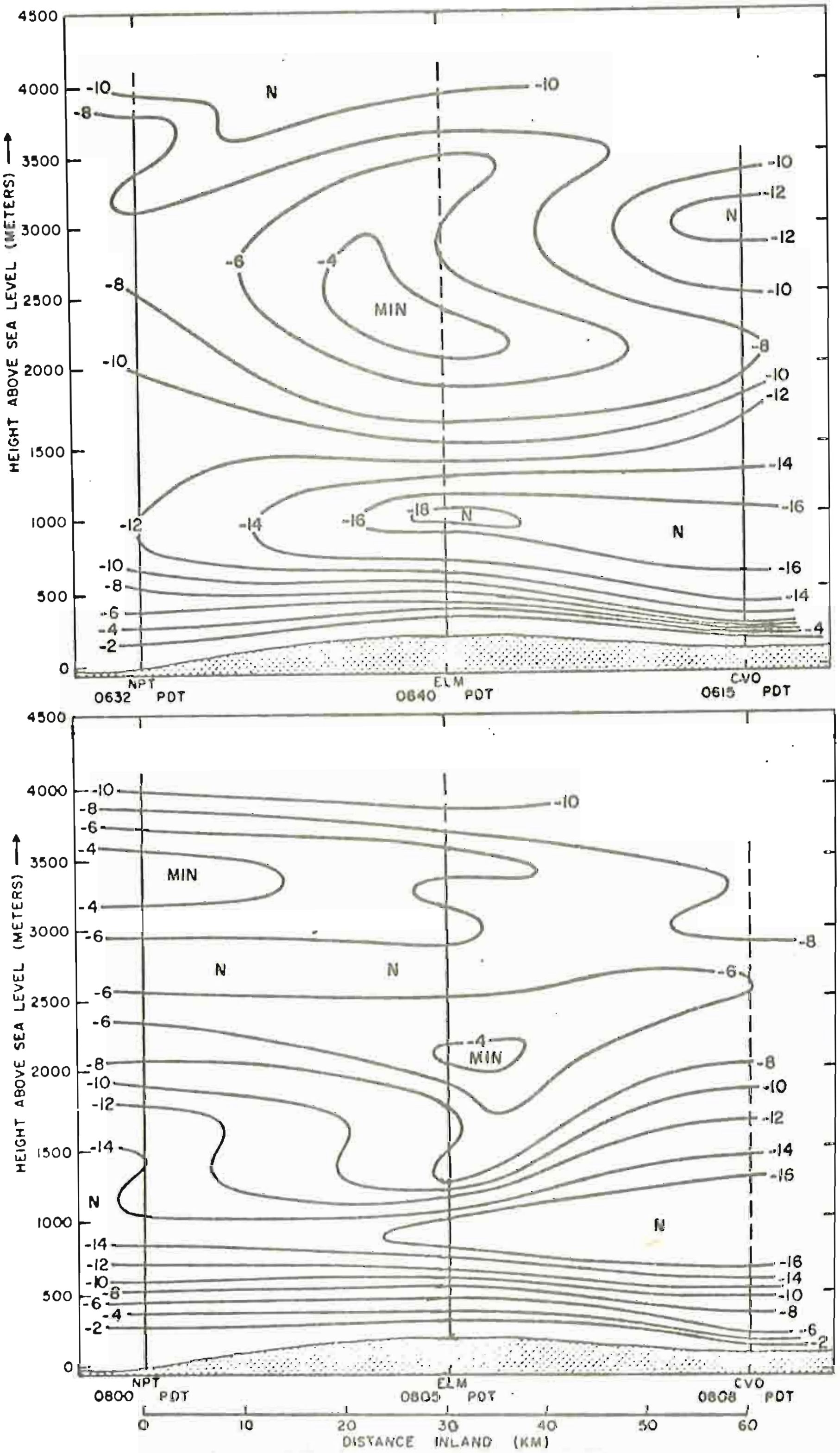


Fig. 13. Early morning meridional wind cross sections,

Fig. 13. Early morning meridional wind cross sections, 23 August 1972 (wind speed in knots)

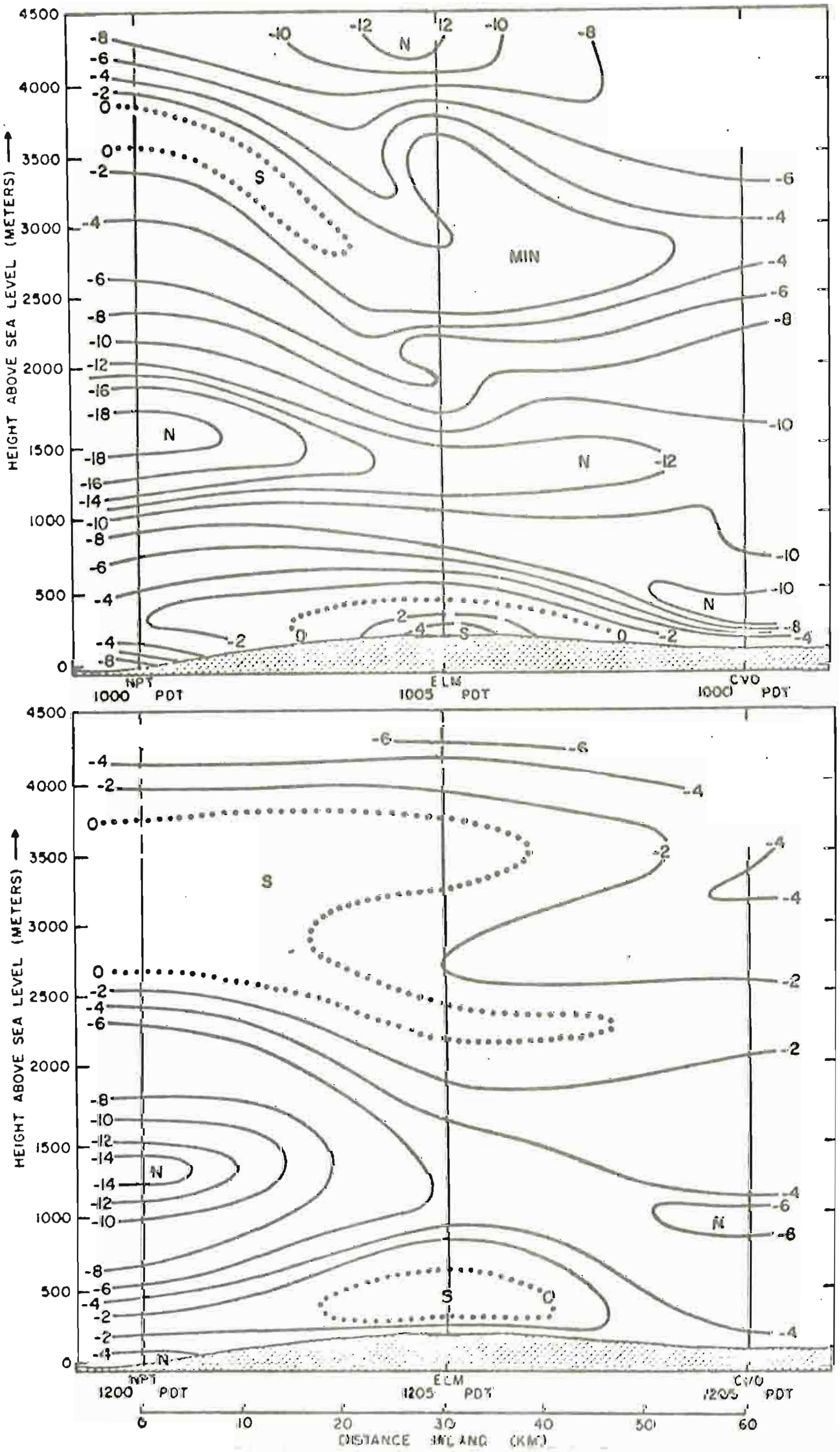


Fig. 14. Late morning meridional wind cross sections,

1200 PDT 1205 PDT 1205 PDT
0 10 20 30 40 50 60
DISTANCE INLAND (KM)

Fig. 14. Late morning meridional wind cross sections,

23 August 1972 (wind speed in knots)

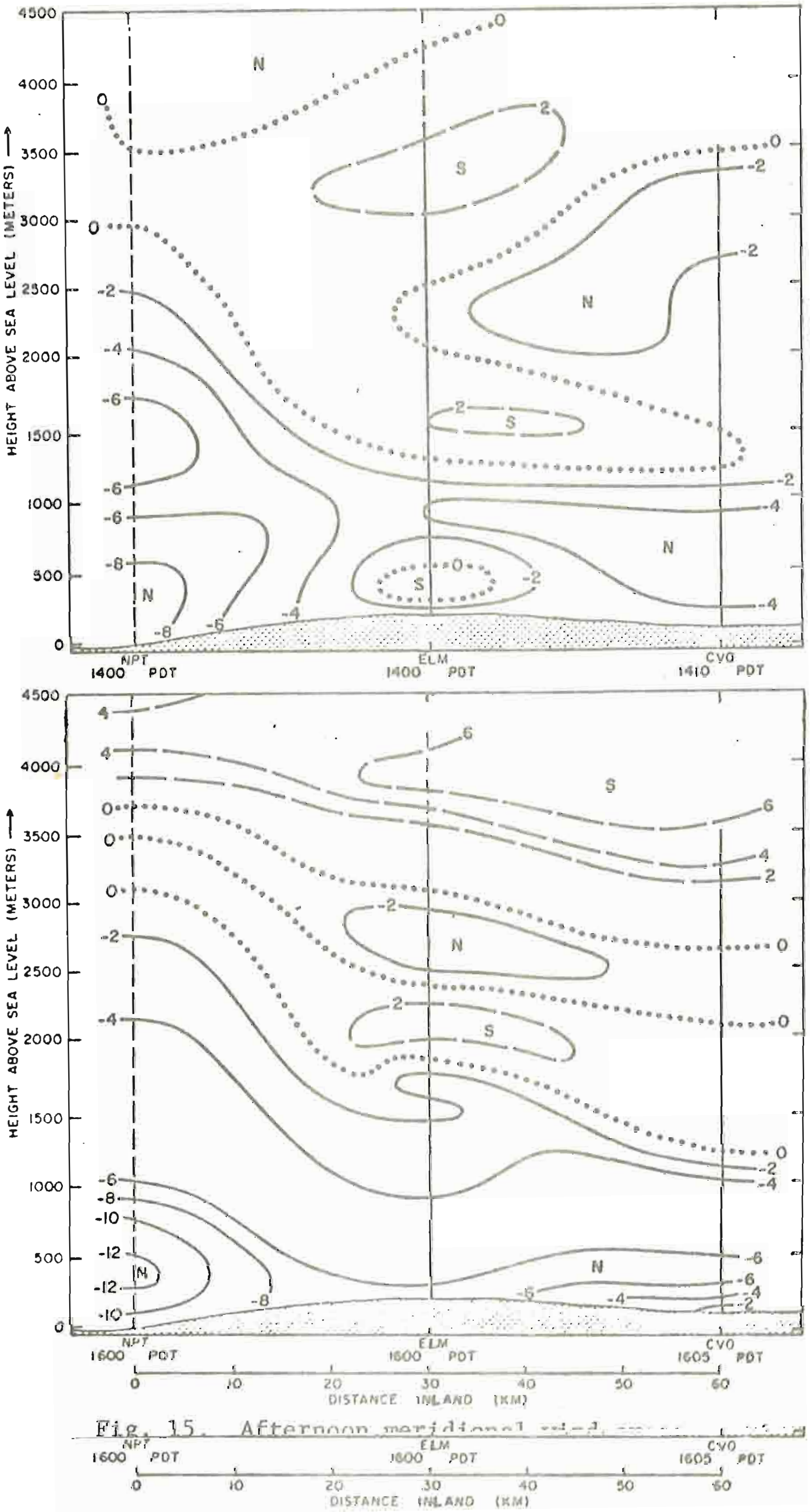


Fig. 15. Afternoon meridional wind

Fig. 15. Afternoon meridional wind cross sections, 23 August 1972 (wind speed in knots)

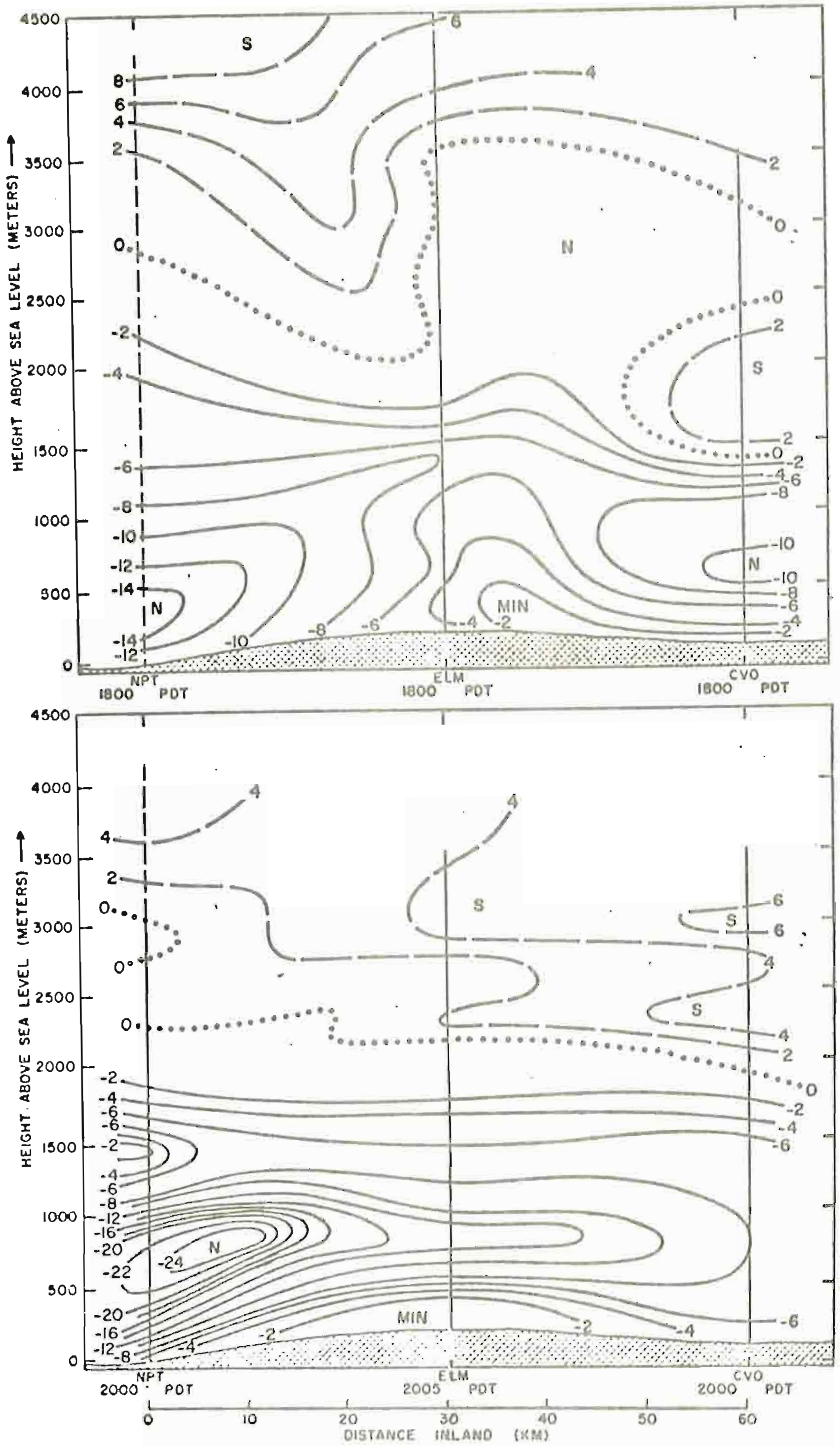


Fig. 16. Evening meridional wind cross sections, 23 August 1972 (wind speed in knots)

Fig. 16. Evening meridional wind cross sections, 23 August 1972 (wind speed in knots)

in altitude and is now near 1200 m and has decreased to 9 kt. The upper and lower easterlies are separated by very light westerlies (1 kt or less) at 1600 m. The onset of a sea breeze at the coast is manifest in the wind field as a low level westerly intrusion in the lowest 700 m at Newport.

By noon (Fig. 10, bottom), the sea breeze has penetrated inland past Ellmaker State Park with the front moving at about 9 kt at the surface. The easterlies are now confined between 1 km and 2 km and the westerlies aloft have lowered to 2500 m reflecting the upper level changes outlined previously. Note the strong westerlies at 900 m over Corvallis. There is some semblance of this configuration to that seen with a sea breeze onset above a nocturnal boundary layer, but the occurrence at this time of day precludes making this physical analogy here.

By 1400PDT (Fig. 11, top), the sea breeze front is advancing at less than 2 kt as the depth of the low level westerlies increases to 1 km over Newport and Ellmaker. The strength of the sea breeze has increased at Newport with an increase in westerlies near the surface at Newport and Ellmaker. The easterlies are still confined between 1 km and 2 km. The maximum westerly strength over Corvallis has decreased to 4.5 kt and is approximately 100 m lower than at noon. The westerlies aloft have deccreased over the coast but the zero line has not changed height.

At 1600PDT (Fig. 11, bottom), the sea breeze front is only 3 km from Corvallis moving eastward at 2 kt. The maximum low level westerly flow has increased to 11 kt and has elevated to 500 m while moving inland to Ellmaker. Easterly flow has deepened over Ellmaker and has decreased to less than 2 kt at Newport.

to Ellmaker. Easterly flow has deepened over Ellmaker and has decreased to less than 2 kt at Newport.

By 1800PDT (Fig. 12, top), the sea breeze front has passed Corvallis and the maximum low level westerly flow has increased to 15 kt and has reached Corvallis at 300 m. The easterly flow has decreased in magnitude over all stations, disappearing entirely at Newport, but occurring through a greater depth at Corvallis than at 1600PDT.

At 2000PDT (Fig. 12, bottom), the low level westerlies are decreasing in magnitude and depth at Corvallis as the easterly flow deepens and intensifies above it. Maximum westerly flow at Newport, for the first time during the observational period, is elevated to 700 m. However, a secondary maximum is still detectable near the surface.

Turning to the meridional component of the wind, Fig. 13 shows a maximum northerly flow at 0630PDT and 0800PDT at 1 km over all stations. By 1000PDT (Fig. 14, top), this northerly flow has elevated to approximately 1500 m and increased to 19 kt at Newport while decreasing at Ellmaker and Corvallis. A low level southerly flow at Ellmaker is maintained through 1400PDT while Newport's northerlies decrease both in altitude and magnitude (Figs. 14 and 15).

At 1600PDT (Fig. 15, bottom), low level northerlies begin increasing everywhere but only briefly at Ellmaker and Corvallis. At Newport, this flow continues to increase and becomes elevated to between 700 m and 800 m at 2000PDT (Fig. 16). Low level northerlies begin decreasing at Ellmaker after 1600PDT and at Corvallis after 1800PDT.

The meridional wind sections indicate that the observed increase in low level northerlies is related to the sea breeze and to the increasing east-west pressure gradient. A brief increase in the northerly flow is observed near the surface at all three stations which very closely

ing east-west pressure gradient. A brief increase in the northerly flow
is observed near the surface at all three stations which very closely

coincides with the onset of low level westerlies behind the sea breeze front. At Newport after this brief increase, the northerlies again increase strongly through the end of the period. This is in phase with the steadily increasing east-west pressure gradient shown in Fig. 7.

3.4 Time sections of the wind field

Time sections for all stations were analyzed for each wind component. Very weak shallow low level westerlies arrive at Ellmaker as early as 1130PDT (Fig. 17) but the first major surge arrives at 1500PDT followed by a second surge near 1800PDT. There are three distinct maxima in the easterlies between 1000 m and 1500 m coinciding with each westerly surge as well as the sea breeze onset. This strongly suggests that the flow aloft is participating in a return circulation to some extent.

The meridional wind time section for Ellmaker (Fig. 18) mainly accentuates the main features observed in the cross sections discussed previously. A brief increase in the northerlies at 1230PDT near the surface occurs within an hour of the onset of westerlies while a second brief increase is observed near 1500PDT at the time of the first major westerly surge. These are followed by a steady increase of northerlies near 600 m in response to the increasing pressure gradient.

The zonal wind variation over Corvallis (Fig. 19) shows the sea breeze onset at 1630PDT with the major surge at 1800PDT. Weak westerlies were first observed at approximately 0900PDT near 500 m and 1500 m. The lower westerly is observed only briefly as the upper descends and increases in intensity reaching its highest magnitude near 1230PDT after which it decreases and descends further giving way to the sea breeze. The meridional wind time section for Corvallis (Fig. 20) shows again a

which it decreases and descends further giving way to the sea breeze. The meridional wind time section for Corvallis (Fig. 20) shows again a

brief increase in low level northerlies associated with the onset of westerlies following the sea breeze front.

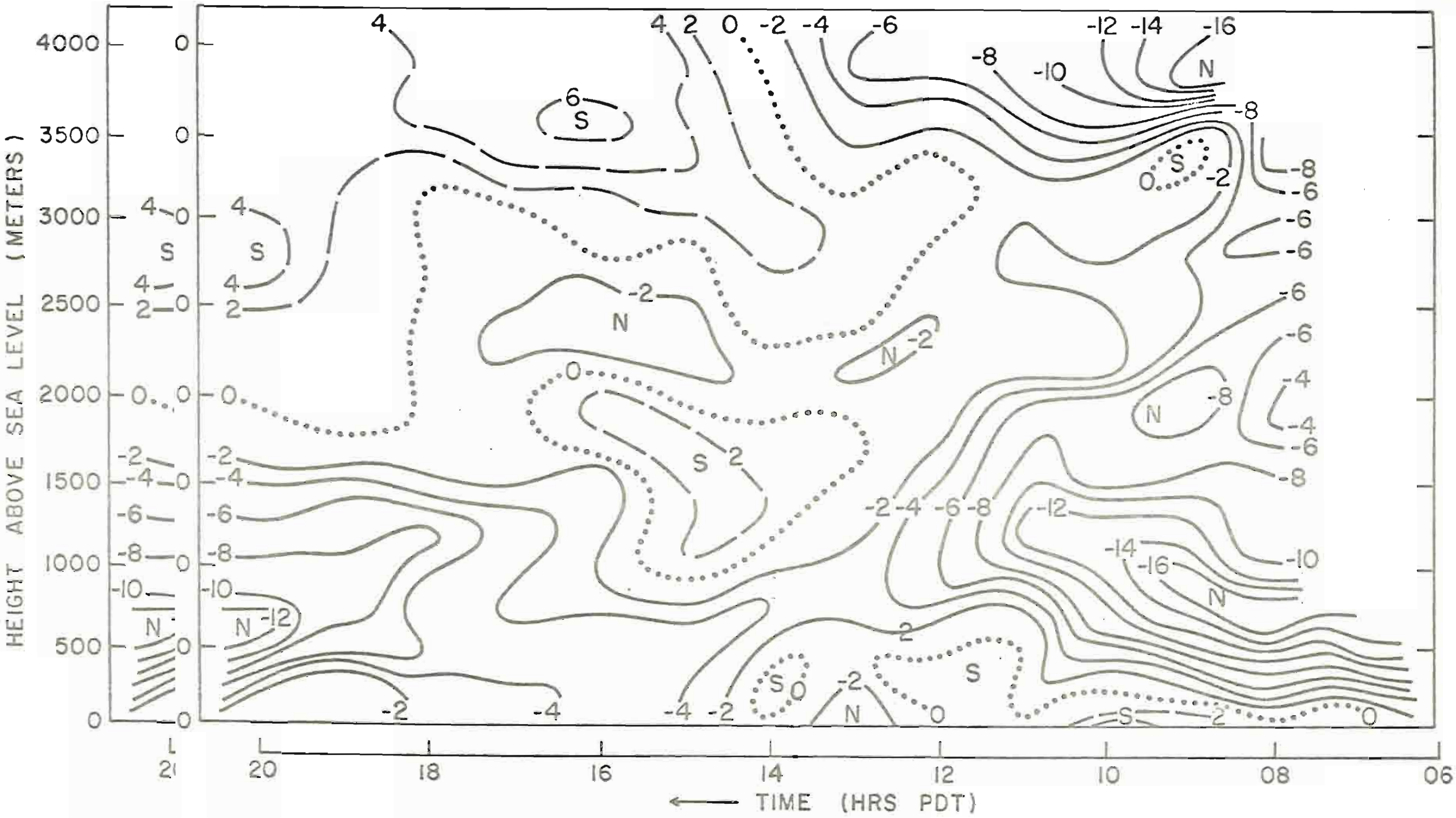


Fig. 18.ig. 18. **Ellmaker State Park** meridional wind time section, 23 August 1972 (wind speed in knots)

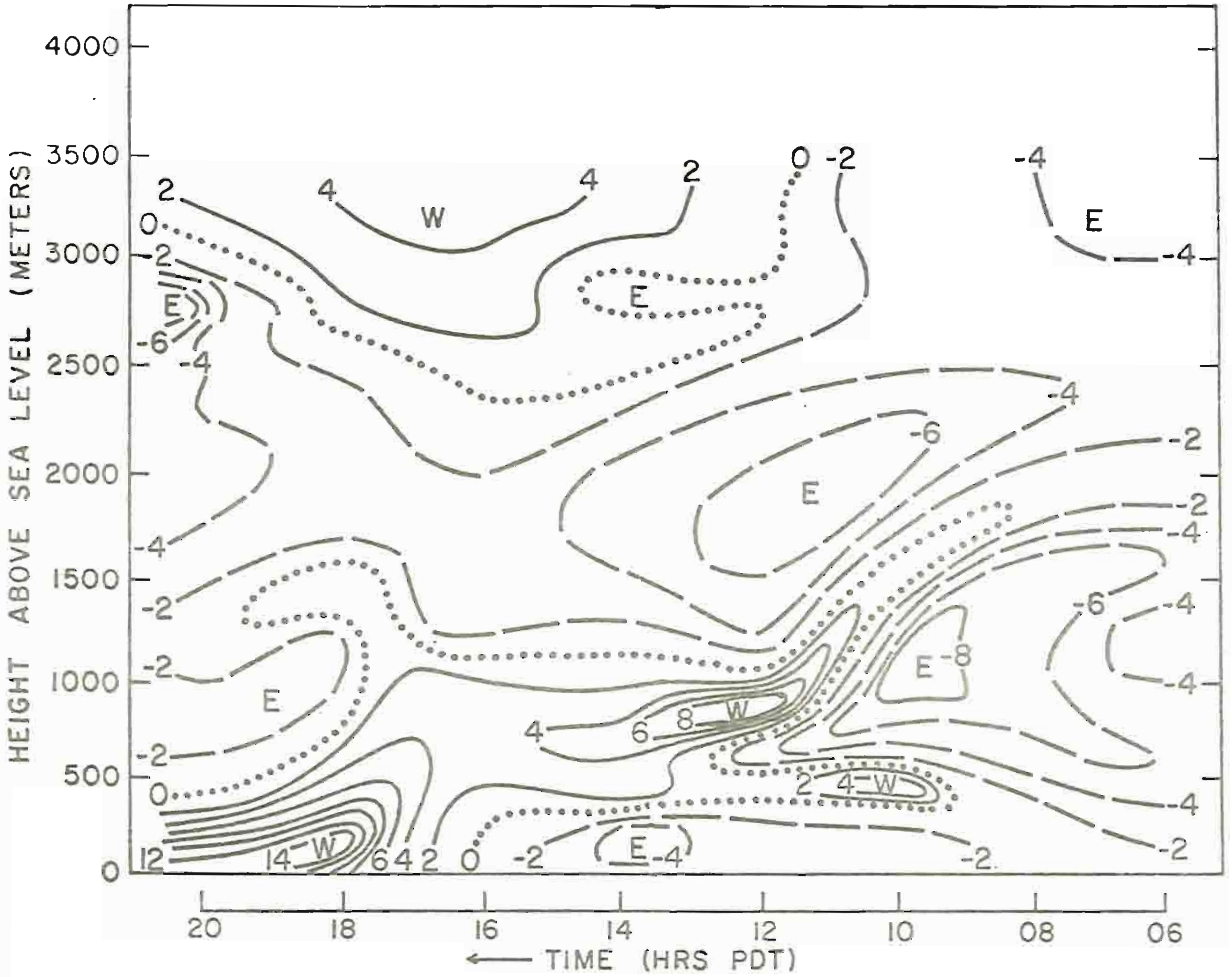
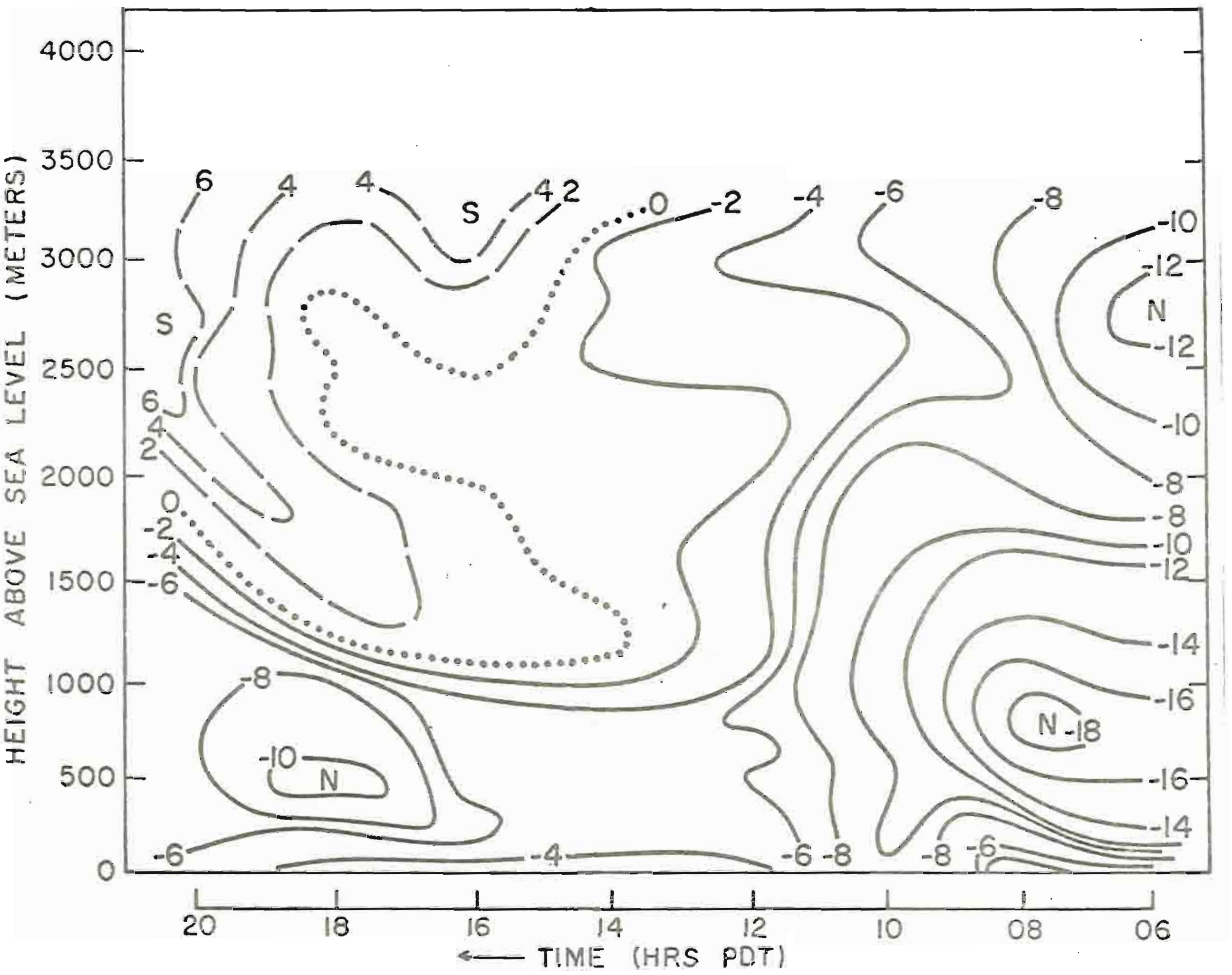


Fig. 19. Corvallis zonal wind time section, 23 August 1972 (wind speed in knots)



Fig

Fig. 20. Corvallis meridional wind time section, 23 August 1972 (wind speed in knots)

Fig. 21 shows the variation of each wind component for Newport during the entire 42-hour period. The zonal wind pattern (upper part of Fig. 21) shows two distinct sea breeze events; one on 23 August, and the other on 24 August. On the 23rd, the onset of low level westerlies occurred at approximately 0900PDT. This flow increased in magnitude near the surface reaching a maximum near 1500PDT. A second maximum was observed between 2000PDT and 2200PDT when the depth of the flow reached a maximum of 2 km. These westerlies finally subside after midnight giving way to a short-lived easterly land breeze which reached its peak near 0400PDT on the 24th. The next sea breeze onset occurred at approximately 0800PDT from which maximum westerlies are observed between 1300PDT and 1400PDT. Maximum depth of this flow reaches only 1 km and does so between 1800PDT and 2000PDT; approximately 2 hours earlier than on the 23rd. This sea breeze finally subsides by 2300PDT. On the 24th, the easterly maxima just above the westerlies are in fair phase relationship with increases in the sea breeze, whereas, on the 23rd, this is not observed. In general, all aspects of the event on the 24th appear to occur approximately one hour earlier than those of the 23rd.

The meridional wind time section for Newport during this period shows maximum northerlies at 600 m for both days near the time of observed maximum east-west pressure gradient. Also evident from this analysis is a tendency for an increase in low level northerlies below 500 m accompanying the increasing low level westerlies in the same manner as observed at Ellmaker and Corvallis previously discussed. This effect

as observed at Ellmaker and Corvallis previously discussed. This effect

is much stronger at Newport on 24 August than on 23 August where it is barely distinguishable from this analysis.

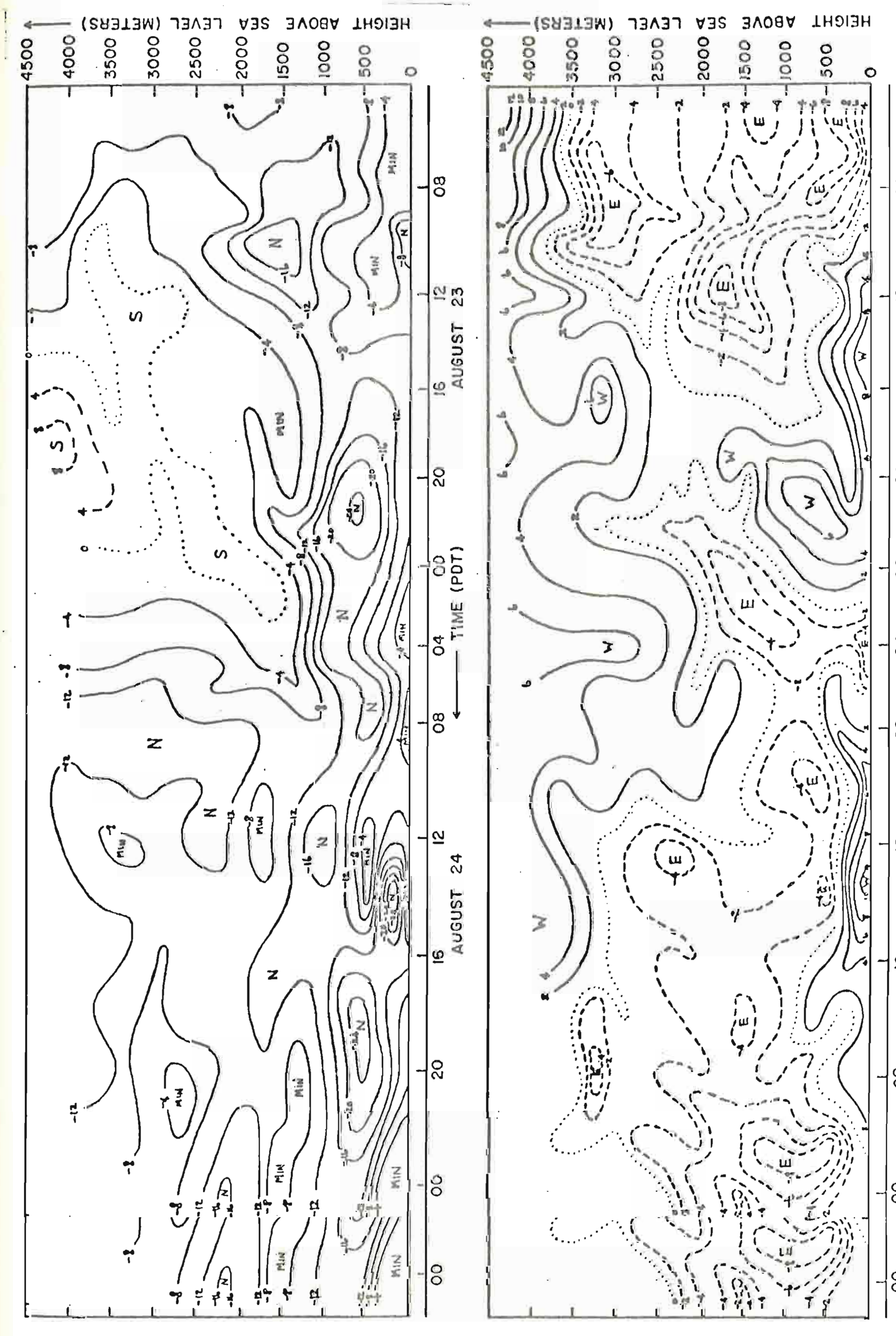


Fig. 21. Newport meridional wind (top: analyzed at 4 kt intervals) and zonal wind (bottom: analyzed at 2 kt intervals) time sections, 23-24 August 1972.

3.5 Vertical profiles of the winds

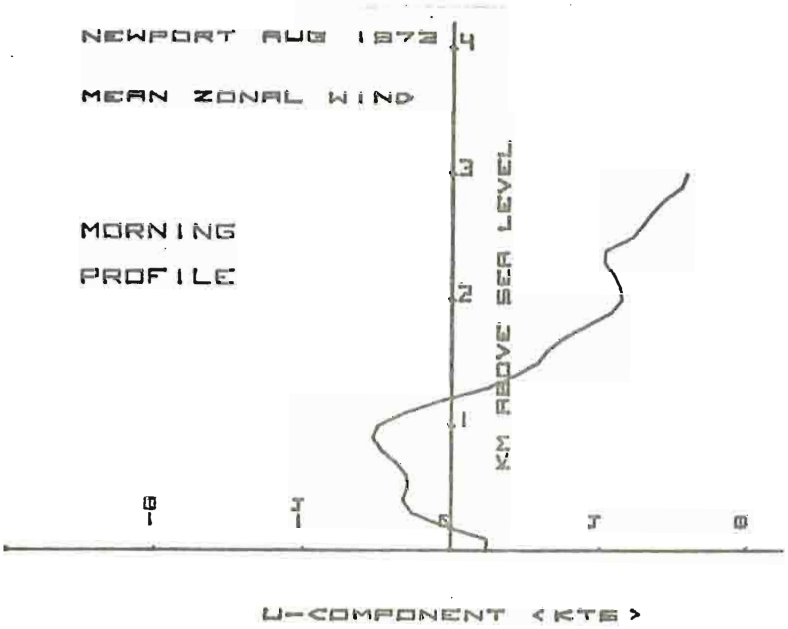
Vertical profiles of the mean zonal and mean meridional winds observed from selected morning and afternoon pibal soundings taken at Newport during August, are shown in Figs. 22 and 23. The cases used here were selected on the basis of synoptic similarity of the large scale surface pressure pattern to that of 23-24 August 1972. A total of six cases were selected for days when the Pacific anticyclone was close to the Oregon coast with an established thermal trough immediately inland. The morning soundings were all taken between 0930-1030PDT and the afternoon soundings between 1530-1650PDT.

Since the sample is small, the variances are frequently large for many levels. Emphasis in the discussion is therefore placed on differences between the morning and afternoon soundings for each component.

Fig. 22 shows that in the mean, the zonal wind participates in both the direct sea breeze low level flow and a return flow. Also evident here is the fact that the transition between westerlies and easterlies in the afternoon occurs at the mean height of the inversion base. The mean meridional wind profiles (Fig. 23) show the very large diurnal variation noted earlier near the surface. But the diurnal variation just above the mean height of the inversion base is much less than that below, exemplifying the decoupling effects of the inversion in the mean.

Individual vertical profiles of the winds for each pibal station are presented in Appendix A.

Individual vertical profiles of the winds for each pibal station are presented in Appendix A.



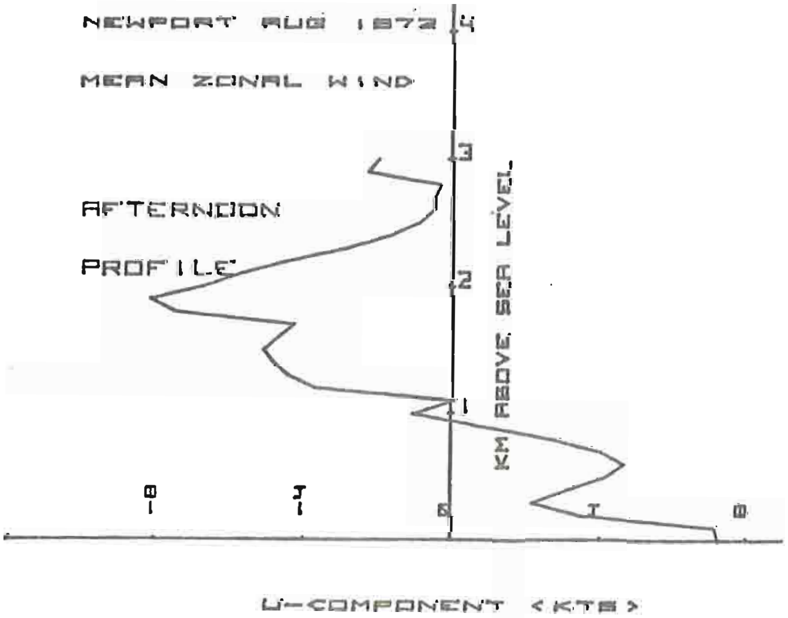
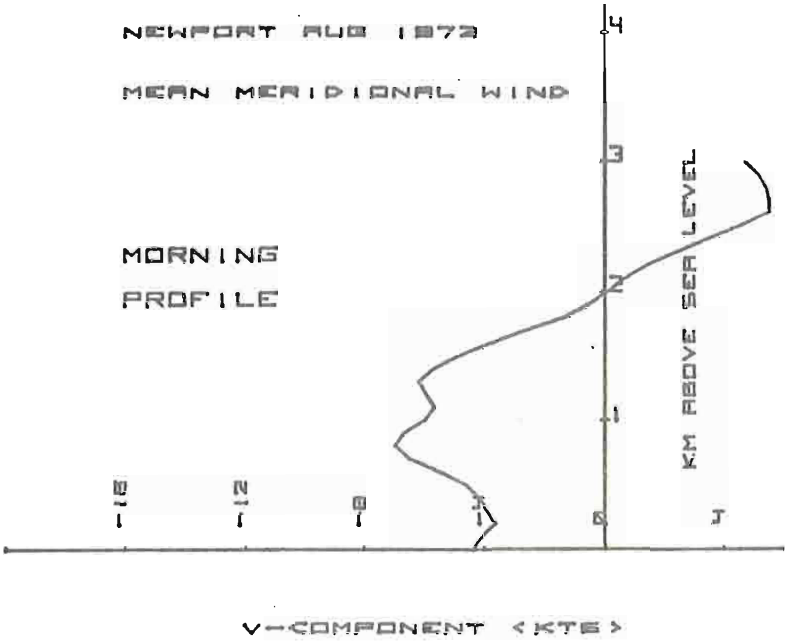


Fig. 22. Vertical profiles of mean zonal wind at Newport for selected mornings (0930-1030PDT) and selected afternoons (1530-1630PDT) in August 1972

wind at Newport for selected mornings (0930-1030PDT) and selected afternoons (1530-1630PDT) in August 1972



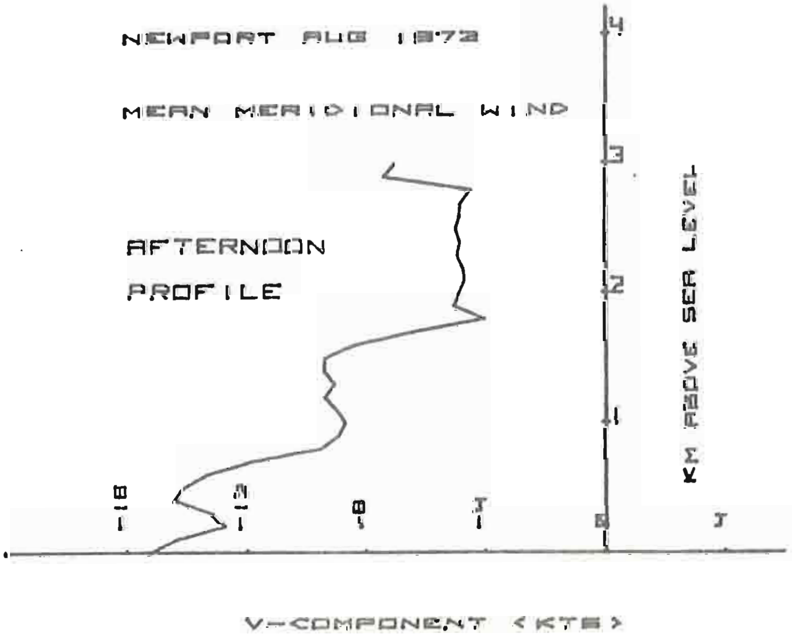


Fig. 23. Vertical profiles of mean meridional wind at Newport for selected mornings (0930-1030PDT) and selected afternoons (1530-

Fig. 23. Vertical profiles of mean meridional wind at Newport for selected mornings (0930-1030PDT) and selected afternoons (1530-1630PDT) in August 1972

3.6 Temperature and humidity structure

Vertical time sections of temperature and humidity distributions observed at Newport are discussed here in addition to the horizontal surface temperature variation between NH-15 and Corvallis during 23-24 August 1972.

Fig. 24 (top) is a time series representation of all the vertical temperature soundings taken at Newport during 23-24 August. Each sounding shown has been superimposed from Skew-T thermodynamic diagrams and the appropriate slopes for isotherms and adiabats are given in the analysis. Stable layers indicated in the figure were analyzed from the soundings and are defined in terms of their stability as being at least vertically isothermal and laterally nearly isentropic.

Fig. 25 contains the time sections of the vertical distributions of temperature and potential temperature obtained from Newport soundings given in Fig. 24. The stable layers as defined previously are shown in each of the fields shown here and the analysis has been done for every degree Celsius.

Early in the day on 23 August, the structure is very complex with the lowest 2 km containing four weak stable layers. A rapid increase in height of the upper three layers occurs immediately following the onset of the sea breeze at 0900PDT. By 1600PDT the lowest three layers have joined to form a single stronger inversion layer between 200 m and 700 m. The base of this layer then increases to a maximum height of 700 m at 2200PDT at the time when the low level westerlies were at a maximum depth and low level northerlies were at maximum strength (see Fig. 21). During

2200PDT at the time when the low level westerlies were at a maximum depth and low level northerlies were at maximum strength (see Fig. 21). During

this time the inversion intensifies in terms of the temperature increase

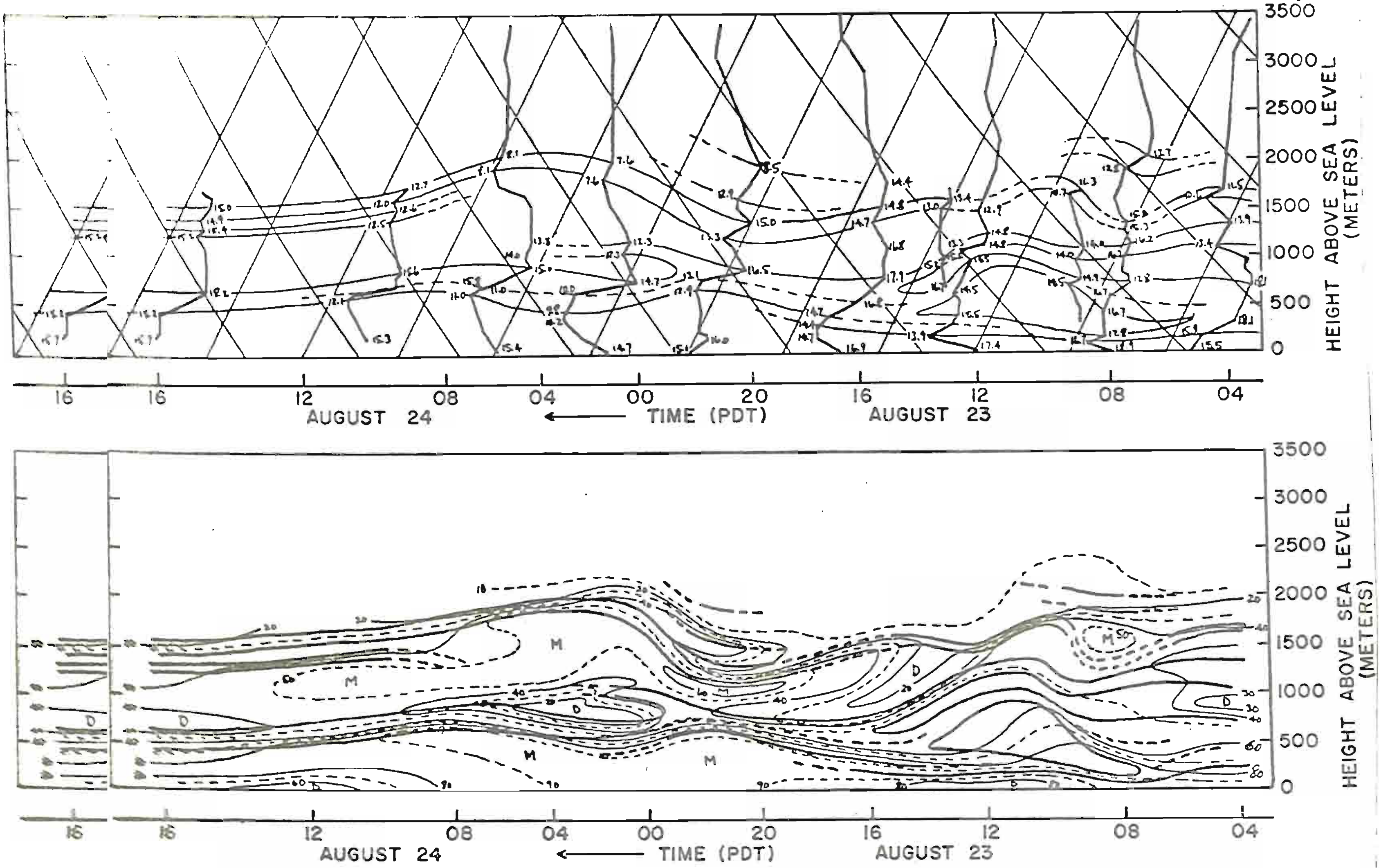


Fig. 24. Time series of vertical temperature soundings (top) and vertical time section of relative humidity (bottom) for Newport, 23-24 August 1972. Analysis includes stable layers and humidity isopleths at intervals of 10 per cent

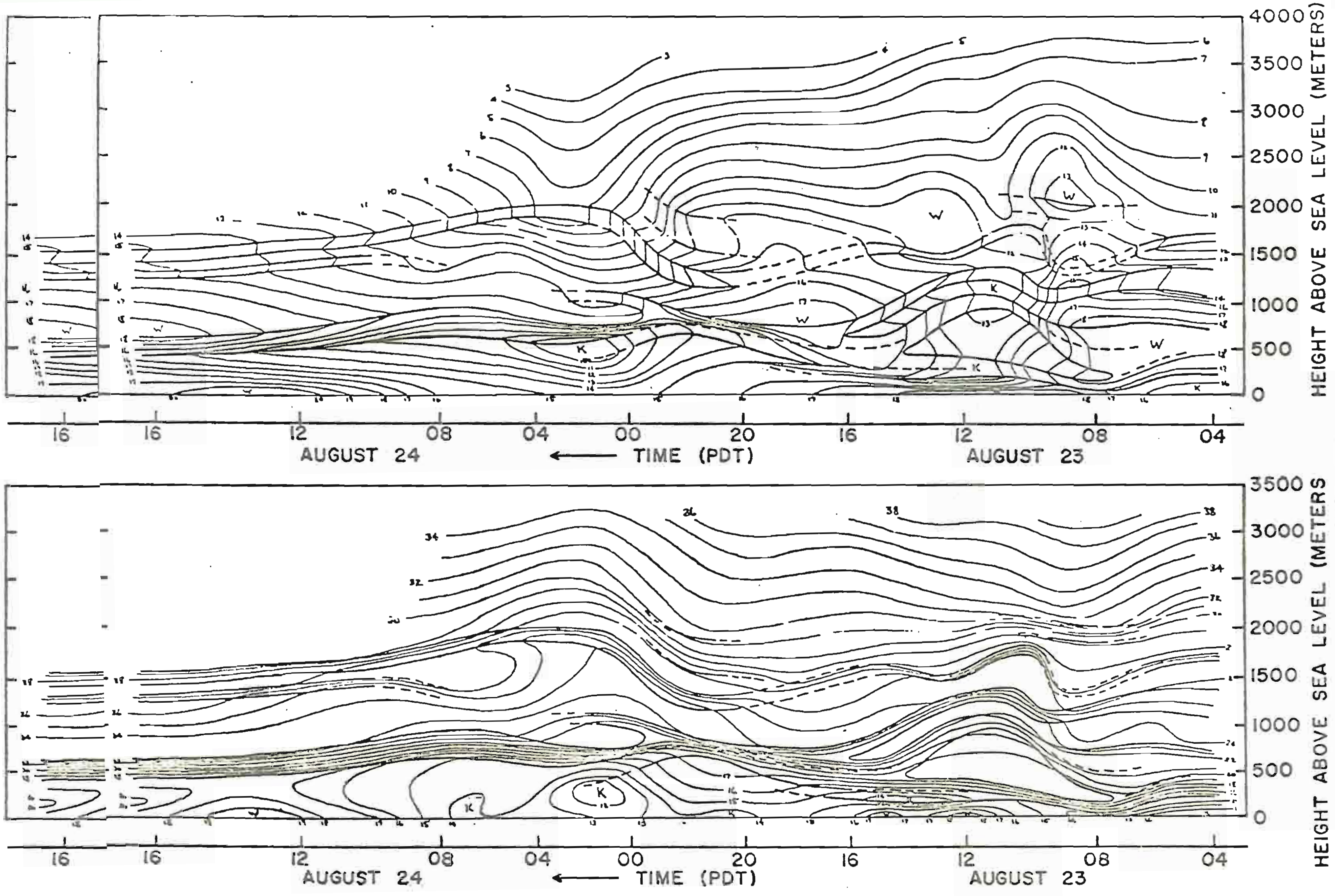


Fig. 25. Vertical time sections of potential temperature (top) and temperature (bott (bottom) analyzed for every degree Celsius at Newport, 23-24 August 1972

with height through it, to approximately 3.3C. From this point the inversion layer undergoes a change, splitting and becoming more complex; but the main layer of high stability descends to 500 m, eventually intensifying into the main inversion again later on 24 August. This descent between approximately 2300PDT and 0300PDT occurs during the time when low level westerlies subside and a brief land breeze begins (Fig. 21). At 0800PDT, the inversion again briefly rises at the onset of the sea breeze, descending gradually throughout the remainder of the period.

Table 2 outlines the above structural changes observed at Newport in comparison with the mean structure (Neiburger et al., 1961) of the marine inversion for August. Although the height of the inversion varies considerably during 23-24 August 1972, it is consistently lower than the mean. Before 2200PDT, 23 August, the thickness, intensity, and vertical humidity gradients are all very close to the mean. At 2200PDT, the thickness decreases to half that of the mean as the vertical gradients of both temperature and relative humidity suddenly become approximately twice that of the mean.

Table 2. Inversion structure

		Ht. of base	Thickness	$\frac{\partial T}{\partial z}$ (°C/100m)	$\frac{\partial \theta}{\partial z}$(°C/100m)	$\frac{\partial}{\partial z}$RH(%/100m)
August mean		900 m	500 m	0.7	1.8	9.6
Observed:						
23 Aug.	0600PDT	200	500	0.5	0.2	8
	1600	200	500	0.4	2.0	12
	2200	700	200	1.7	3.3	15
24 Aug.	0300PDT	500	200	2.4	2.3	20
	2200	700	200	1.7	3.3	15
24 Aug.	0300PDT	500	200	2.4	2.3	20
	0800	600	300	1.0	2.3	17
	1400	400	200	1.6	2.9	20

Fig. 24 (bottom) is a time section of the vertical distribution of relative humidity from the Newport soundings for 23 and 24 August. The relative humidity is analyzed at intervals of 10 per cent and the diagram clearly shows that the lower inversion layer is the one which defines the depth of the marine layer below. During the afternoon of 23 August, dense fog occurred at Newport as the depth of the marine layer averaged only 250 m while the average relative humidity through the layer was nearly 90 per cent. On 24 August the average humidity was 75 per cent through a much deeper marine layer. No fog was observed at Newport on 24 August.

The sharp drying which takes place through the marine inversion was most striking during 23-24 August at Newport. Observed vertical relative humidity gradients ranged from 8 to 20 per cent per 100 m through the main inversion. Also evident from these time sections is a positive correlation between tendencies of vertical temperature gradients and vertical relative humidity gradients.

A definite pattern of diurnal variability of the marine inversion cannot be distinguished here, but it is noted that there appears to be an increase in height in response to the sea breeze onset. This is physically reasonable and perhaps expected due to low level convergence at the sea breeze front.

A sea surface temperature map (from the NCAR Queen Air radiometer data) for the morning of 24 August 1972 (Fig. 26) shows a representative surface sea water temperature distribution during the sea breeze observational period (O'Brien, 1972). Of particular interest is the fact that the coldest water lies within 10 nautical miles of the coast.

tional period (O'Brien, 1972). Of particular interest is the fact that the coldest water lies within 10 nautical miles of the coast.

Fig. 27 contains a time series of surface air temperatures observed at the three land stations as well as two buoys. The temperature curves

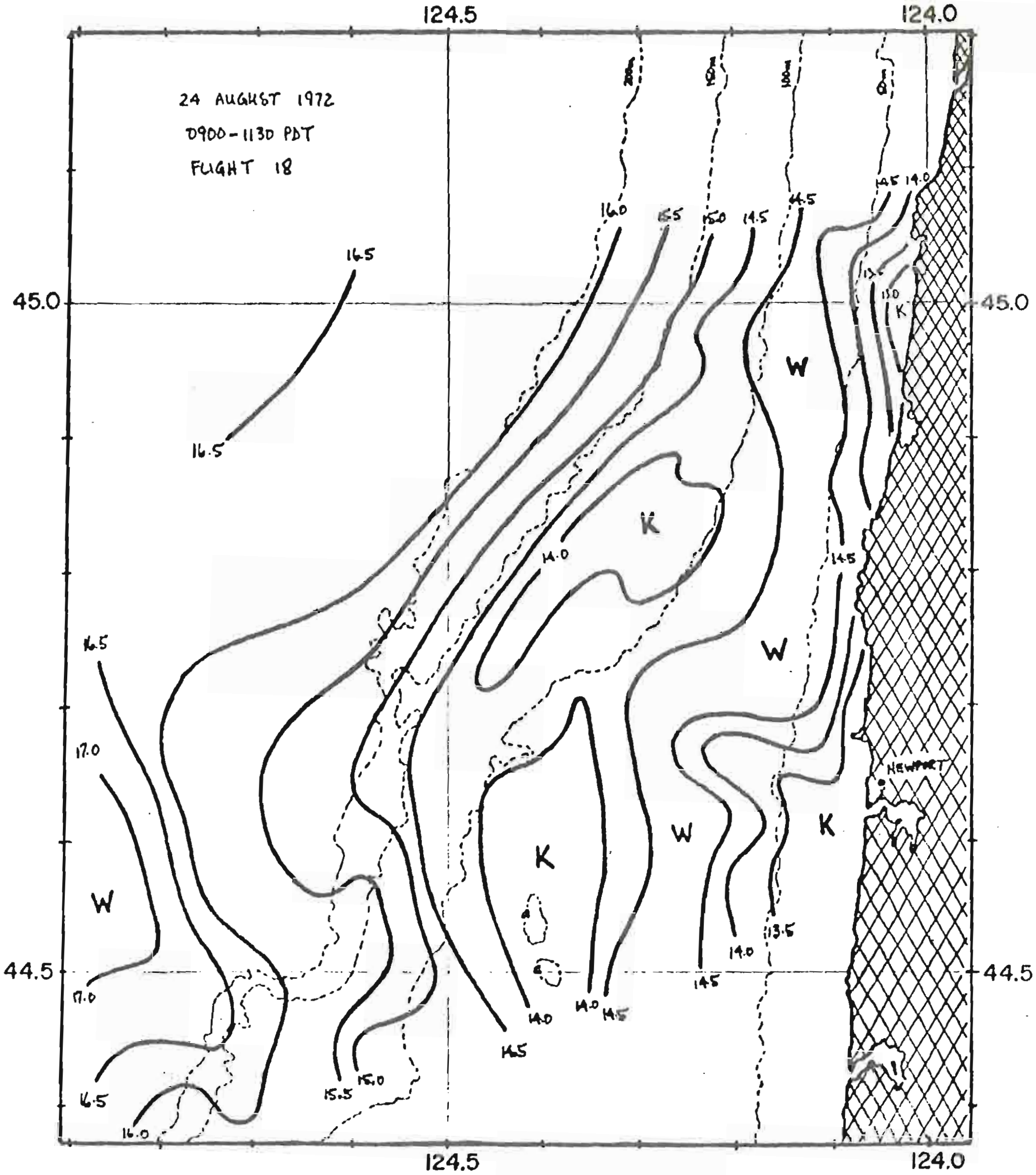


Fig. 26. Sea surface temperature map for Central Oregon coast for morning of 24 August 1972 (O'Brien, 1972)

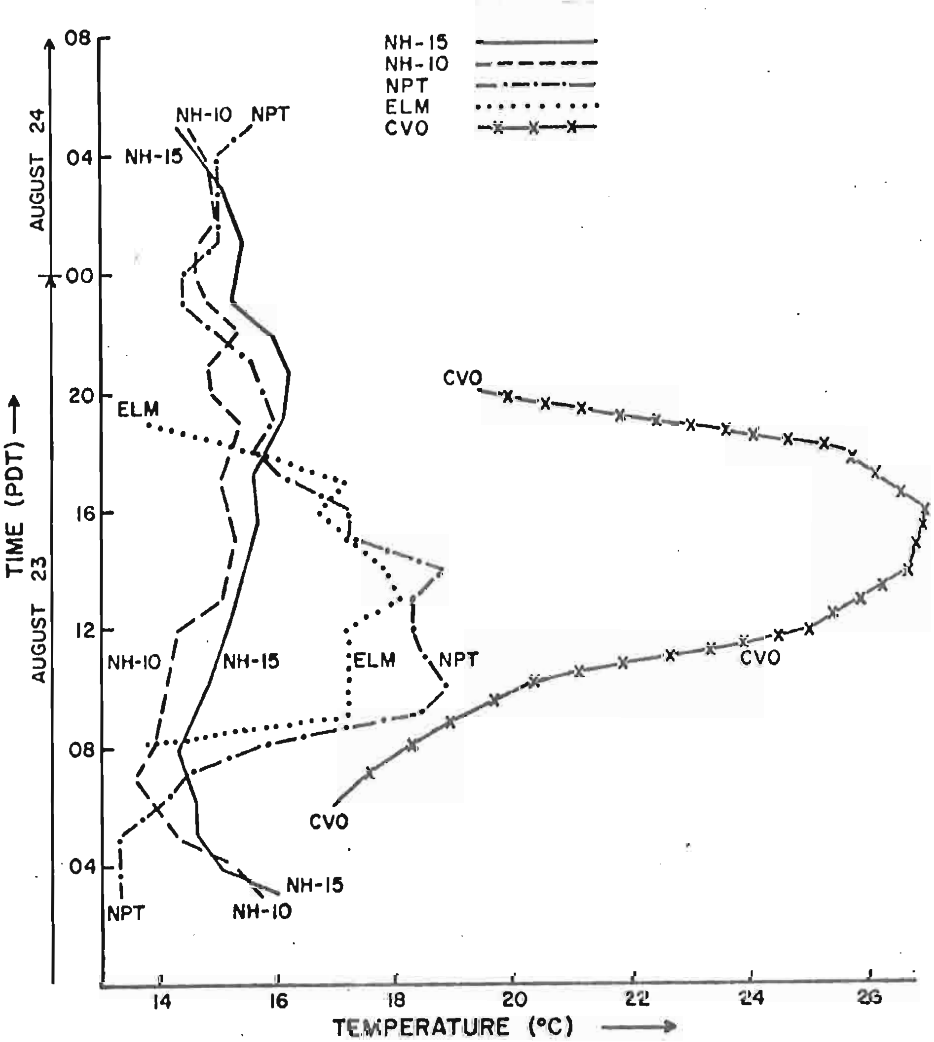


Fig. 27. Time series of surface air temperatures observed on a line perpendicular to the coast, 23-24 August 1972

indicate the possible existence of two scales of thermal forcing. On one scale (between NH-15 and Corvallis) the temperature difference ranges between approximately 2C and 11C with a mean near 7C. On a smaller scale (between NH-10 and Newport) the temperature difference ranges between approximately -2C and +5C with a mean near 1C. Thus, the larger scale of thermal forcing exists between the open ocean and the interior valley with a temperature gradient of 7C per 100 km and a smaller scale forcing exists due to diurnal surface heating and cooling of the land mass, causing an intense temperature gradient near the coast (as high as 5C per 20 km).

3.7 Summary

The 23 August sea breeze event was characterized by a sequence of several distinct occurrences. Although no characteristic cloud patterns were observed, a sea breeze front was distinguishable in the vertical structure of the zonal wind. The front moved rapidly inland to the crest of the coast range of mountains after which it slowed but eventually penetrated more than 60 km inland by 2000PDT. The intrusion of marine air behind the front appeared in surges with corresponding maxima observed in the prevailing easterly flow just aloft. Observed increases in the meridional wind during the event are related to the sea breeze surges and the increasing east-west pressure gradient. The thermal structure of the lower atmosphere at the coast during the event was dominated by a changing but intensifying marine inversion.

by a changing but intensifying marine inversion.

CHAPTER IV

COMPARISONS WITH PREVIOUS INVESTIGATIONS

A detailed study of the vertical wind structure on this scale has never before been attempted for the Oregon coast. Most sea breeze studies made previously in this area have been in terms of the horizontal distributions of temperature and humidity at the surface emphasizing only the surface wind field (Lowry, 1966; Cramer and Lynott, 1961; Cramer and Lynott, 1970).

Haurwitz (1947) theoretically demonstrated that the effects of the earth's rotation are an integral part of the sea breeze. He showed that these effects are best observed through the clockwise rotation of the surface wind vector whose end point traces an elliptical hodograph in a 24-hour period. Although no hodographs are presented here, they were examined for 23 and 24 August but no typical elliptical rotation of the surface wind vector was evident. Some late afternoon veering was observed in the Newport winds but a Coriolis contribution could not be resolved from the much stronger acceleration in the northerly gradient flow.

Estoque (1962) found that sea breeze circulations are generally weak when associated with geostrophic winds parallel to the coast with low pressure inland because frictional inflow decreases local pressure gradients. The results from this study show that since local pressure gradients are observed to increase during a sea breeze event in central

weak when associated with geostrophic winds parallel to the coast with
low pressure inland because frictional inflow decreases local pressure

Oregon, there must indeed be a much greater contribution toward intensifying this gradient by intense heating inland during the development of the thermal trough.

Fosberg's and Schroeder's (1966) results show that on days when the Pacific High penetrates northeastward toward Washington and Oregon, the marine layer near the central California coast is shallow and the sea breeze front is intense and slow moving. This agrees with the results from this study.

In another California study, Edinger (1963) observed that the top of the marine layer (he defines as a homogeneous moist layer) generally extends above the base of the inversion layer. The relative humidity time section for Newport (Fig. 28) shows that this was the case early on 23 August when the inversion layer was thickest and weakest. However, later in the period as the inversion intensified, the top of the moist layer coincides almost exactly with the inversion base.

For the case considered in this study, it was found that the onshore sea breeze flow occurs below the inversion while the return must take place above it. Edinger (1959b) found that the sea breeze over Santa Monica, California is 2000 m deep with a return flow aloft of equal depth. For the same period a mean height of 328 m was observed for a more intense inversion than that observed in this study. These results are strikingly different, probably due to the fact that the mountains in southern California extend above the inversion. The winds observed at Newport on 23 and 24 August show the same relationship to the inversion as that found

fornia extend above the inversion. The winds observed at Newport on 23
and 24 August show the same relationship to the inversion as that found

by Williams and DeMandel (1966) in the San Francisco Bay area. The sea breeze they observed diminished rapidly with height desappearing near the base of the inversion (460 m). They also found that later in the day, the sea breeze flow deepens possibly pushing the inversion upward. This also agrees with the Newport observations.

Several investigators have found that as the nocturnal inversion layer breaks down after sunrise, the subsidence inversion aloft lowers (Blackadar, et al., 1960; Gifford, 1952; Williams and DeMandell, 1966). The principal physical process considered responsible for such an occurrence is convection within the marine layer causing an oscillation of the inversion layer. The Newport observations (Fig. 27) show a lowering of the inversion base in the morning which may be due to the same effect; although a distinct noctural inversion was not present on both days.

In another coastal upwelling regime along the coast of Peru, observational evidence indicates that surface winds at several coastal stations are easterly during daytime and westerly at night; opposite the land-sea breeze convention (Lettau, 1972). Lettau's studies show that the coastal gradient flow is strengthened at night and weakened during daytime. He cites thermo-tidal oscillations as the reason a direct thermal circulation is not established.

Although observations made for this study clearly indicate the development of a direct thermal circulation near the coast, one should not rule out the possibility that thermo-tidal oscillations may have, in this particular case, weakened the development of the Oregon coast sea breeze. On the central Oregon coast, northerly winds that parallel the coast are of frequent occurrence but the extent to which they are thermo-

breeze. On the central Oregon coast, northerly winds that parallel the coast are of frequent occurrence but the extent to which they are thermo-

tidal in origin remains to be determined.

CHAPTER V

SUMMARY AND CONCLUSIONS

Although detailed observations were made during only a single sea breeze event, there are a few important characteristics of the 23 August event:

1) The low level onshore flow of the land-sea breeze circulation at the coast is contained entirely within the marine layer.
2) The return flow above the inversion appears to be in the form of impulses or surges. These appear to be in response to the surges observed in the sea breeze.
3) A distinct wind maximum follows the sea breeze front inland.
4) At the coast, the marine layer appears to deepen at the onset of the sea breeze.

Any influence of the coast range of mountains is not evident. The role of the slope winds would be in phase with the sea breeze on the western slopes but out of phase to the east. This effect may have been manifest in part in the observed rapid movement of the sea breeze front between Ellmaker and Corvallis. The expected influence is small since the average terrain height is only 2000 ft and the crestline is oriented north-south.

The contribution of the Coriolis effect on this event is not imme-
north-south.

The contribution of the Coriolis effect on this event is not immediately evident either. Some consistent late afternoon veering of the surface wind was observed at Newport but, as pointed out earlier, a Coriolis contribution could not be distinguished from a very strong acceleration of the northerly gradient flow throughout the observational period.

From this study, some insight is gained into the understanding of mesoscale vertical structure of the atmosphere in an upwelling regime during a sea breeze event. The obvious limitations of such a small sample and the inadequate understanding of the mesoscale mechanism of the sea breeze on the Oregon coast serve to emphasize the need for further investigations of this nature. In addition, the vertical structure of the atmosphere offshore should be investigated similarly (using data from aircraft, buoy, and balloon observations) in order to evaluate the seaward extent of the sea breeze circulation.

The importance of the sea breeze in central Oregon cannot be overemphasized as it represents the mesoscale vehicle through which marine air routinely penetrates the interior valleys. Knowledge of the quantity of marine air entering the valleys on any given summer day is vital to forestry operations and to air pollution interests. This quantity is a function of the strength and depth of the sea breeze and the speed with which the sea breeze front moves inland. A rapid increase in marine air and associated moisture in the valleys leads to a sudden decrease in heating and subsequently a decrease in coastal pressure gradients. This diminishes the thermal forcing necessary to maintain a sea breeze as well as the northerly gradient flow. It may even lead to a relaxation of coastal upwelling which would further reduce coastal thermal gradients

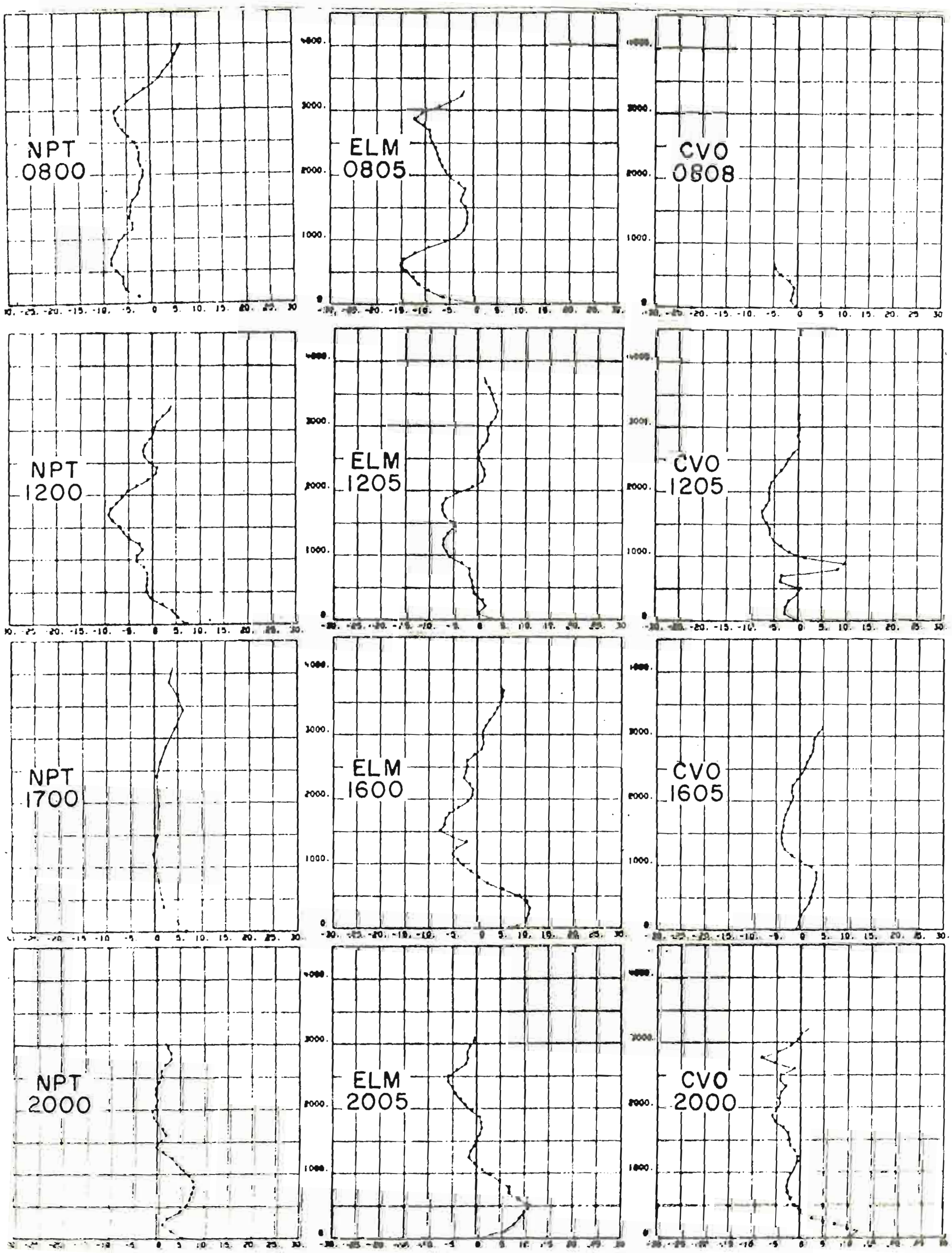
as the northerly gradient flow. It may even lead to a relaxation of coastal upwelling which would further reduce coastal thermal gradients

and sea breeze forcing. At present, we have no data to support these contentions but the sea breeze in an upwelling regime seems to represent a very important feedback mechanism between major oceanographic and meteorological processes on a larger scale and thus deserves more attention.

APPENDIX A

Vertical profiles of the zonal and meridional winds are presented in Figs. A-1 and A-2, respectively. The profiles generally reiterate the main features of the structure revealed by the vertical cross sections (Figs. 9-16). The profiles are included here for the sake of completeness to further synthesize the main character of the wind field over the observation network.

Due to fog, no pibal sounding was made from Newport at 1600PDT, therefore the less detailed winds from the 1700PDT rawinsonde observation are included in Fig. A-1. Also the 0808PDT Corvallis sounding extends to only 700 m due to a low cloud base.



A-1. Vertical profiles of zonal winds for Newport, Ellmaker State Park, and Corvallis, 23 August 1972

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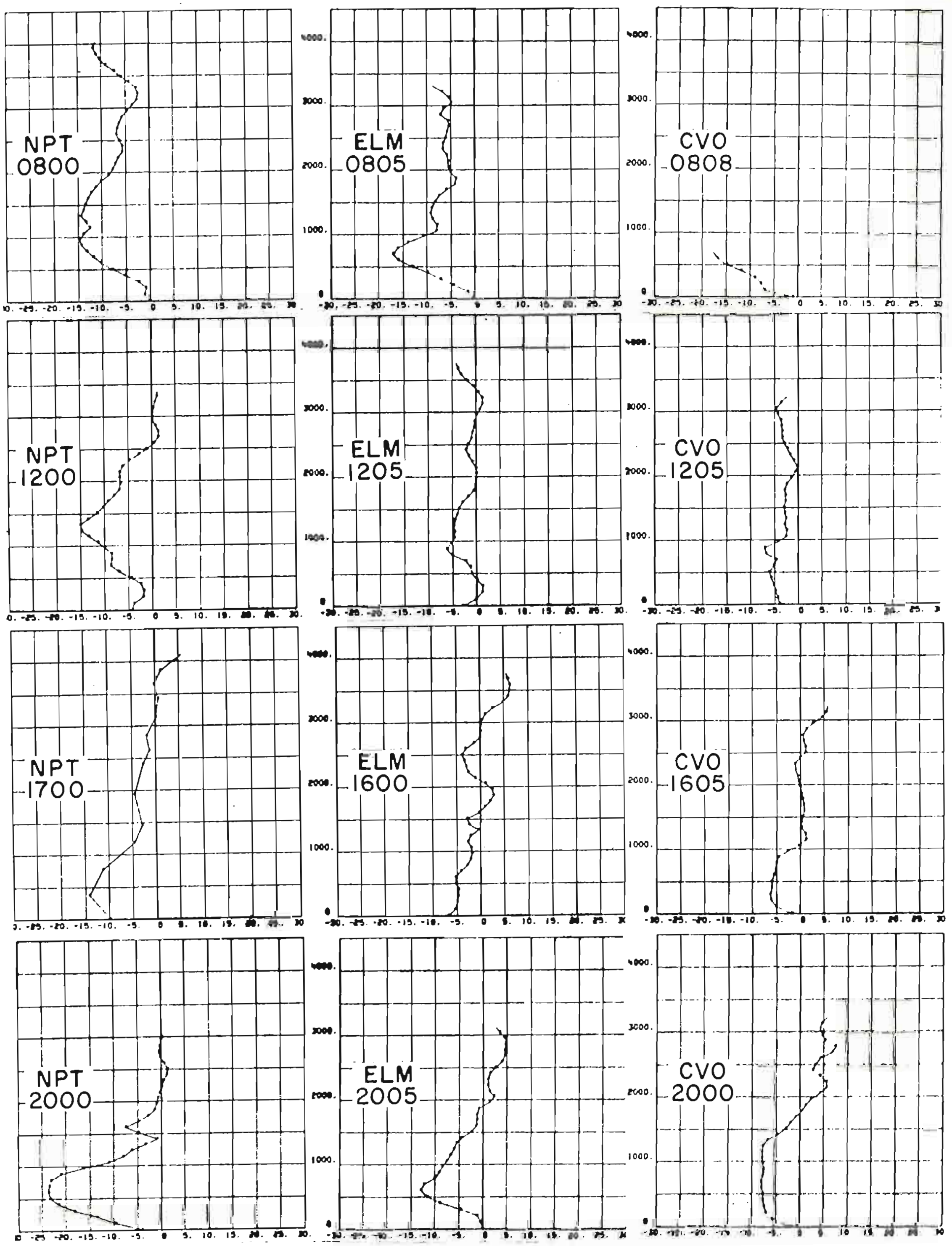

A-2. Vertical profiles of meridional winds for Newport, Ellmaker State Park, and Corvallis, 23 August 1972

A-2. Vertical profiles of meridional winds for Newport, Ellmaker State Park, and Corvallis, 23 August 1972

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