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**SHIPBOARD INTERFEROMETER SOUNDING**

**A REPORT from the**

COOPERATIVE  
INSTITUTE FOR  
METEOROLOGICAL  
SATELLITE  
STUDIES



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A Report to the

Naval Oceanographic and Atmospheric Research Laboratory  
(NOARL), Monterey, CA

Under contract # N00014-93-C-6012

by the

Cooperative Institute for Meteorological Satellite Studies  
Space Science and Engineering Center  
University of Wisconsin-Madison  
1225 W. Dayton St.  
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September 1994

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## **I. OVERVIEW**

This final report summarizes the activities of the University of Wisconsin Cooperative Institute for Meteorological Satellite Studies (UW CIMSS) under contract N00014-93-C-6012 for the continued development of atmospheric thermodynamic sounding algorithms relevant to a shipboard interferometer sounder. The scope of the research effort was extended to make use of an instrument recently developed at UW CIMSS for the passive remote sensing of meteorological state parameters. This interferometer sounding system was deployed aboard the ship Point Sur as part of an experiment conducted by the Naval Post-Graduate School (NPGS), Monterey, California in May 1992. The objective of this deployment was the observation of atmospheric conditions leading to anomalous propagation of radar waves. The Pt Sur '92 experiment provided an excellent testbed for the latest hardware and software modifications to the CIMSS interferometer sounder.

Analysis of the passive infrared observations collected during the field program activities supported by this contract demonstrate the ability of the interferometer sounder to measure vertical gradients in atmospheric refractivity necessary for the detection of radar ducting under maritime conditions.

## **II. BACKGROUND**

The UW CIMSS has a long history of research and development in the use of passive infrared observations for the remote sensing of atmospheric state parameters. This section briefly reviews aspects of this history relevant to the shipboard interferometer sounder project.

### **A. HIS Program**

The High-resolution Interferometer Sounder (HIS) program at UW CIMSS

has demonstrated the instrument capability and data analysis techniques required for the inference of temperature and water vapor vertical profiles from high altitude aircraft with application to future satellite based infrared (IR) sounders. An aircraft instrument (the HIS) was developed and flown aboard the NASA ER-2 high altitude research aircraft [Revercomb 1987, 1988, 1989, 1990]. Techniques for sounding the atmosphere using the interferometric data were developed in close concert with the observing program [Smith 1987, 1988]. The success of the aircraft HIS measurements lead directly to the development of a ground based interferometer sounder, initially using the aircraft instrument in a ground based configuration [Smith 1990].

#### **B. Pt Sur '91**

The forerunner to the previously mentioned Pt Sur '92 experiment was a similar experiment conducted in 1991. The initial design of the Ground Based High resolution Interferometer Sounder (GB-HIS), developed at the UW CIMSS with the assistance of BOMEM, Inc., was deployed on the ship Pt Sur during an oceanographic survey cruise 7-10 May 1991 [Knuteson 1991]. The successful operation of this prototype interferometer sounder on the 1991 cruise out of Moss Landing, California motivated the activities discussed in this report. A summary of the results from the 1991 Pt Sur cruise can be found in a thesis of the Naval Post Graduate School (NPGS) [Rugg 1992].

#### **C. AERI for ARM**

The Department of Energy Atmospheric Radiation Measurement (DOE-ARM) program has funded the development of a groundbased instrument for the continuous accurate observation of downwelling infrared radiance to contribute to our understanding of global climate change. An Atmospheric Emitted

Radiance Interferometer (AERI) prototype, developed at the UW CIMSS, was available for use during the time frame of the Pt Sur '92 experiment [Revercomb 1991, 1992, 1993]. Techniques to use the AERI radiance observations for sounding the thermodynamic properties of the atmosphere were also developed during this time [Smith 1993]. The AERI prototype has since been installed at the ARM Southern Great Plains Cloud And Radiation Testbed (SGP CART) since March 1993, where it is routinely collecting downwelling radiance data.

### **III. FIELD EXPERIMENT**

The NPGS organized an experiment dedicated to the study of meteorological conditions off the California coast in May 1992 (Pt Sur '92). A summary of the synoptic situation for the 1992 cruise can be found in a NPGS Master's thesis [Rugg, 1992]. The experimental focus of this research was a demonstration of the new UW AERI sounder, from a shipborne platform. This section describes the deployment of AERI aboard the ship Point Sur, the complement of supporting instrumentation, and the data collected during the research cruise.

#### **A. Interferometer Sounder Deployment**

A surface based interferometer sounder, the AERI prototype instrument, was made ready at the UW for deployment aboard the ship Pt Sur. The AERI prototype consists of a BOMEM MB100 interferometer, calibration blackbodies, and control and monitoring electronics (Figure 1). In preparation for the ship deployment the support structure of the instrument was reinforced to allow it to be lashed to the railing of an upper deck (Figure 2). No significant modifications were required in either the hardware or software to accommodate the ship

environment. A local area network was run between the instrument on an exposed upper deck to the lab in the lower part of the ship. In the lab, the instrument performance was continuously monitored, real-time thermodynamic analyses were produced, and the data was archived.

The interferometer system was wrapped in a waterproof tarp with an open hole to the sky. The system operated in a fully automatic data collection mode with the exception of a required refilling of a liquid nitrogen cryogenic detector dewar every eight hours. The need for cryogen has since been removed through use of a mechanical stirling cycle cooler for maintaining the IR detectors at the desired operating temperature (77K).

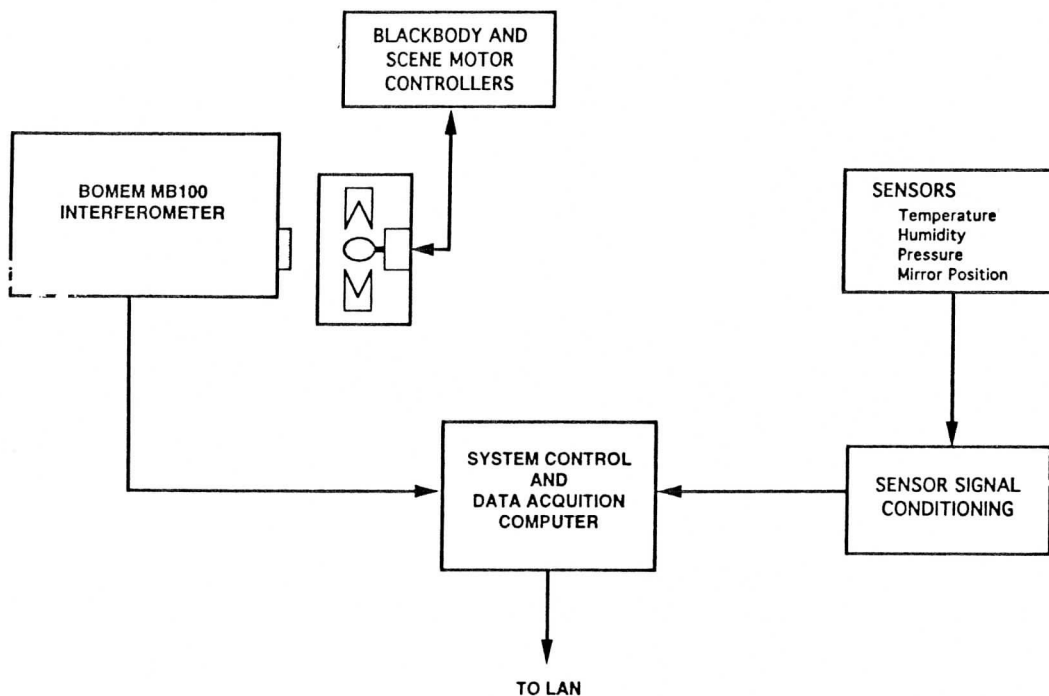


Figure 1. Interferometer Sounder (AERI) block diagram

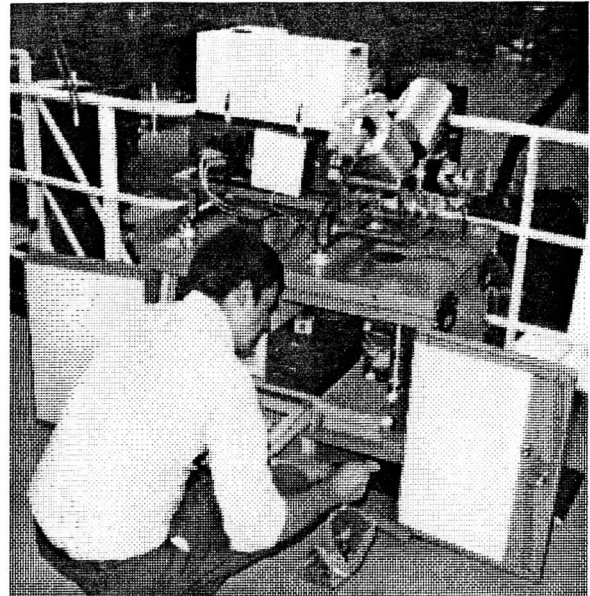


Figure 2a. Sounder during loading (left) and initial checkout (right).

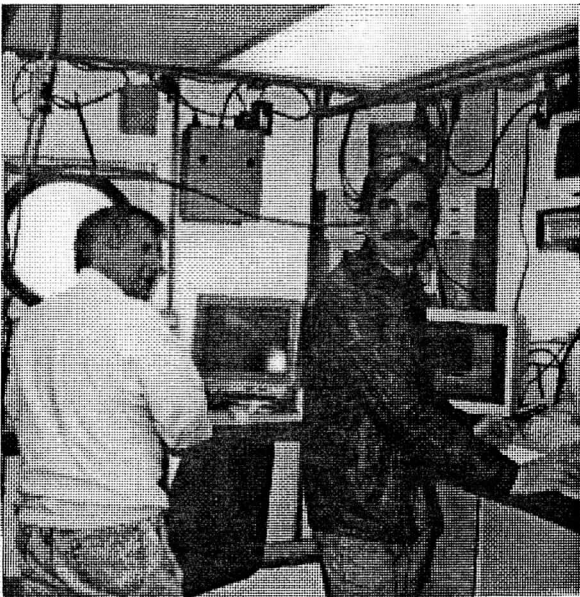


Figure 2b. Dry lab workstations (left) and instrument final configuration (right).

## B. Supporting Instrumentation

Complementary measurements made during the cruise included balloon launches at three hour intervals for the measurement of air temperature and



water vapor concentration, a cloud lidar to determine cloud base height, a collection system for near surface aerosols, water temperature bulk measurements, and wind speed and direction. Figure 3 shows the cloud base laser ceilometer and the balloon launch facility.

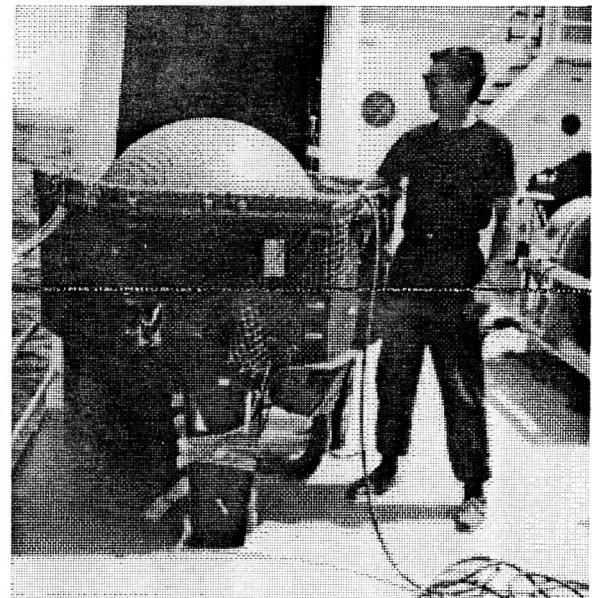
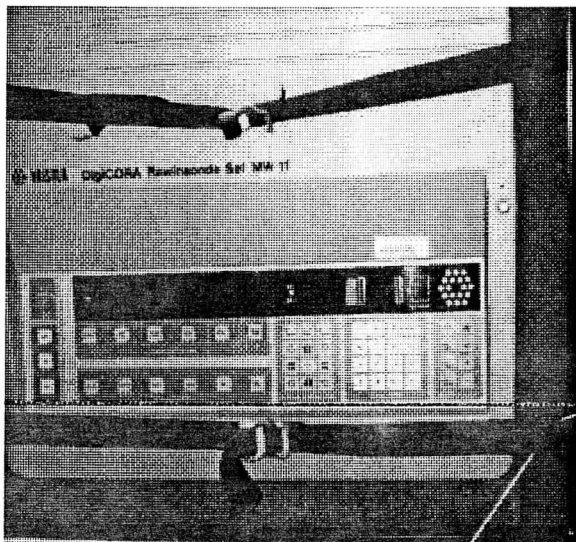
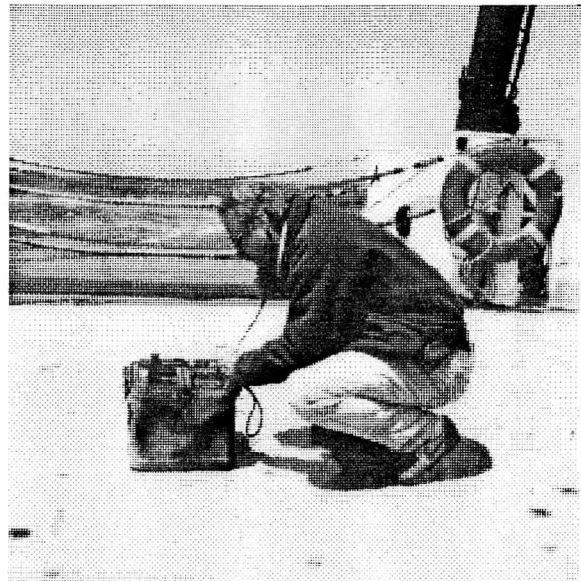
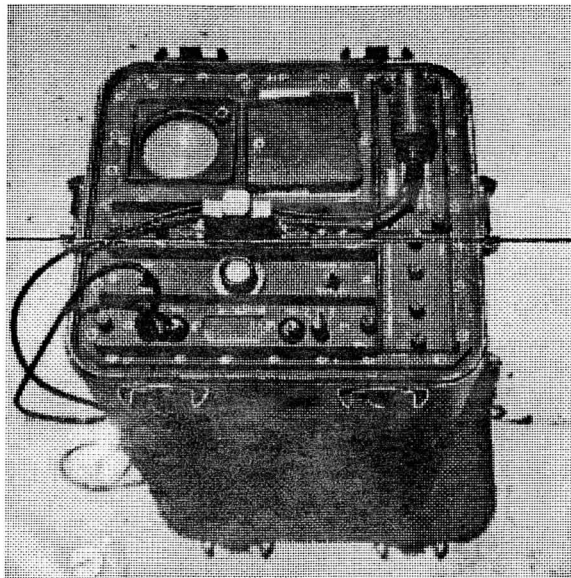


Figure 3. Laser ceilometer (upper) and Vaisala balloon launch system (lower).

### C. Observation Summary

Radiance data from the AERI system was collected for the duration of the cruise beginning at 04:00 UT on 8 May 1992 and continuing on a continuous basis through the end of the cruise at 18:00 UT on 11 May 1992. The ship track, beginning at Moss Landing in Monterey Bay CA, (Figure 4) was motivated by the desire to move offshore, away from a persistent low status cloud deck and into a region of clear sky. Though the sea state on these four days was quite rough, the interferometer sounder was essentially unaffected by the pitch, roll, and vibration of the shipboard environment. Figure 5 provides a summary of the interferometer sounder data collected on each day. The IR window channel clearly shows the periods of low overcast (warm temperatures) and clear (uniform low temperatures). Figure 6 shows one of the hundreds of downwelling infrared spectra collected at ten minutes intervals during the cruise.

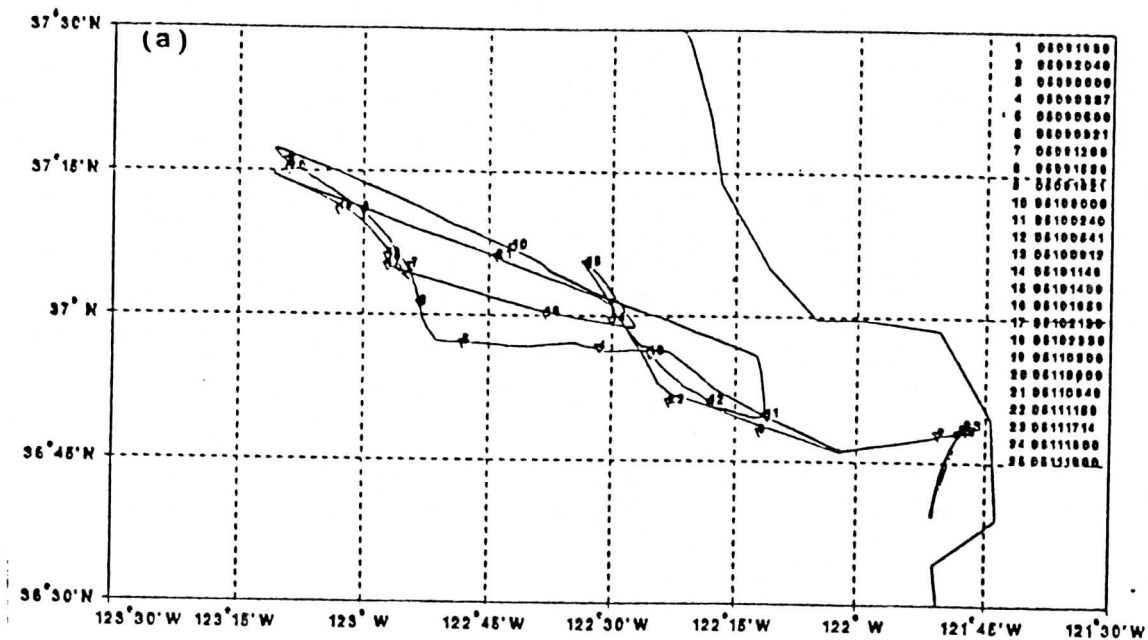


Figure 4. Ship track during the Pt Sur '92 research cruise. [Rugg 1992]



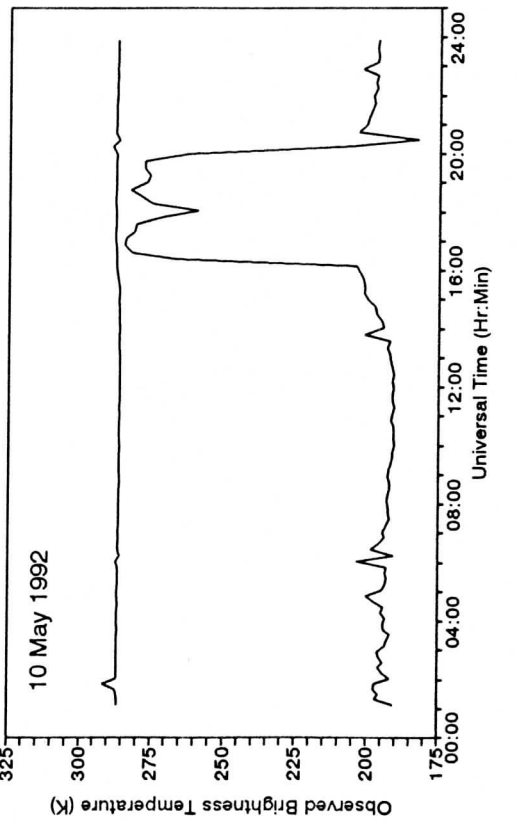
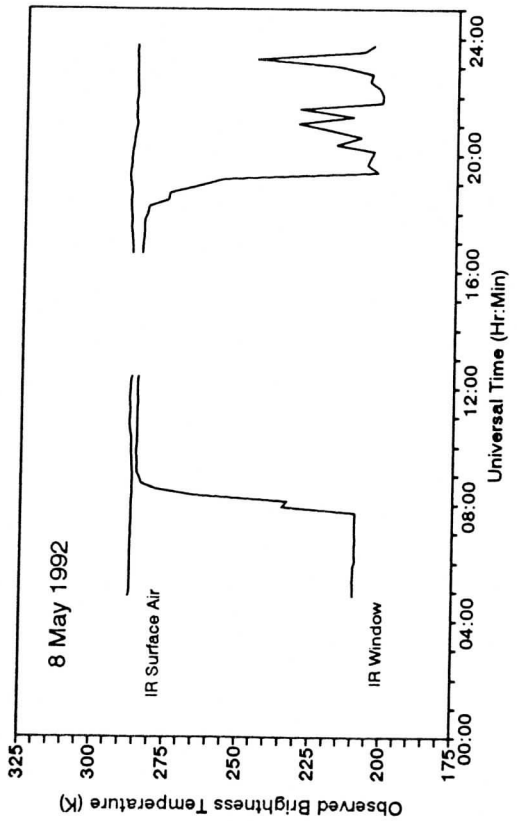
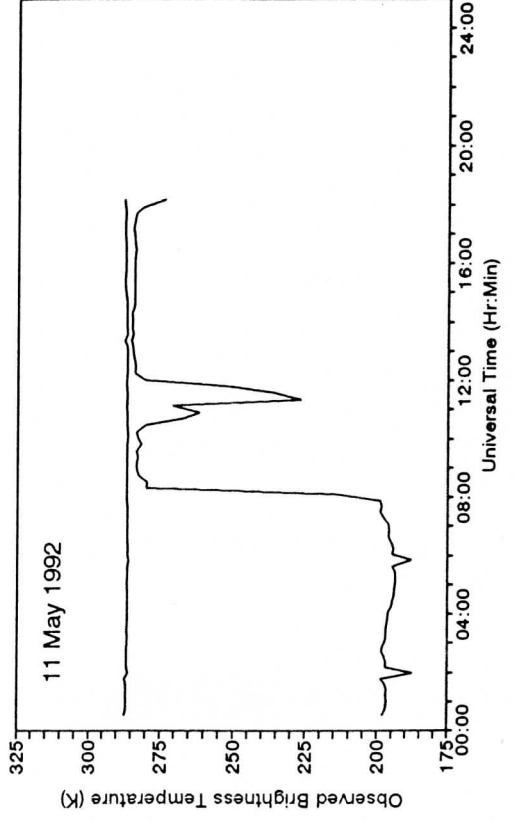
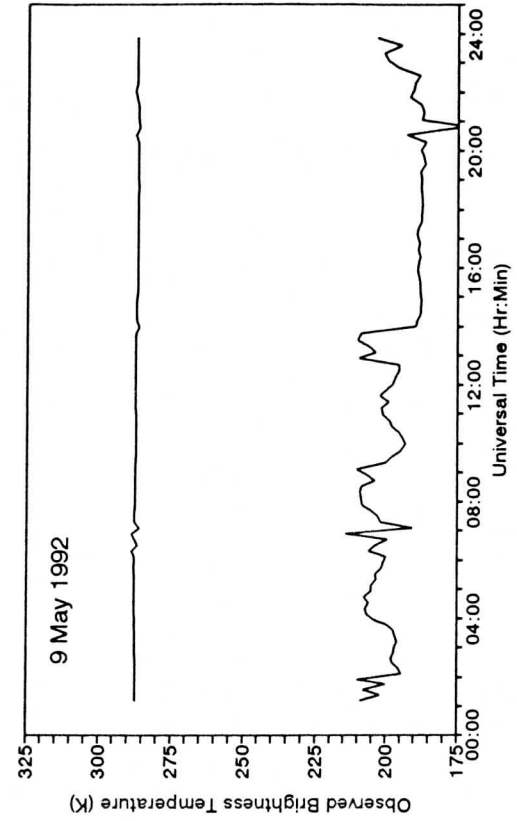


Figure 5. Summary plots from the interferometer sounder showing IR brightness temperatures for opaque and window channels during the four day deployment aboard the Pt Sur. Conditions of low overcast, cirrus, and clear are apparent.

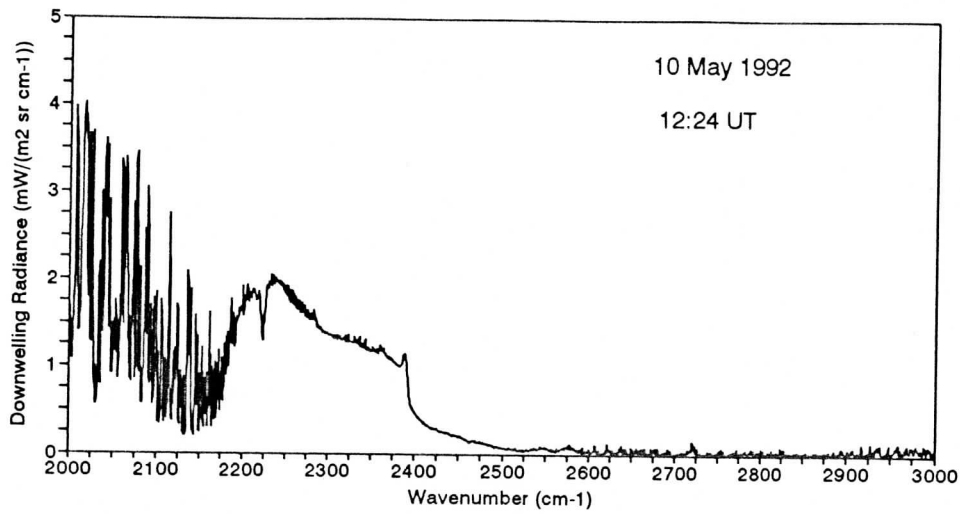
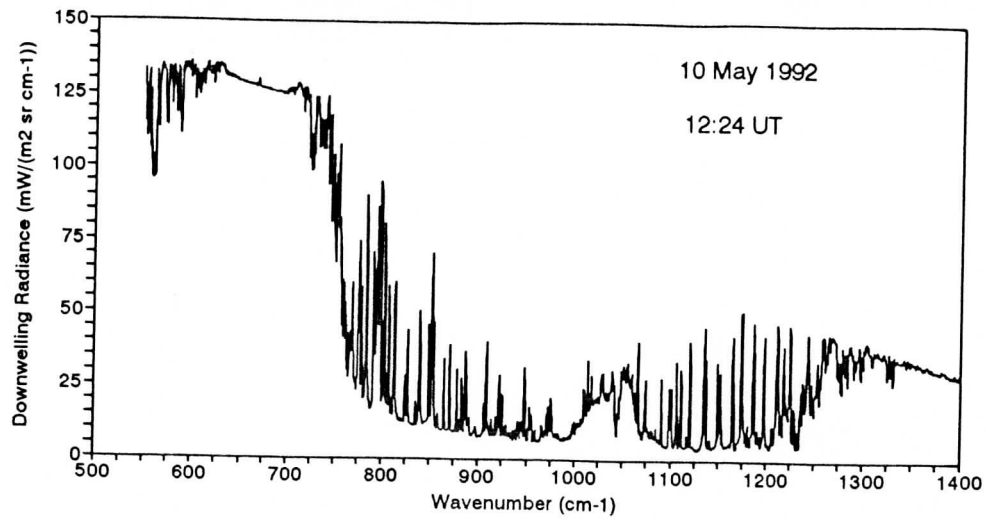


Figure 6a. Typical downwelling radiance spectra observed by the interferometer sounder during Pt Sur '92.

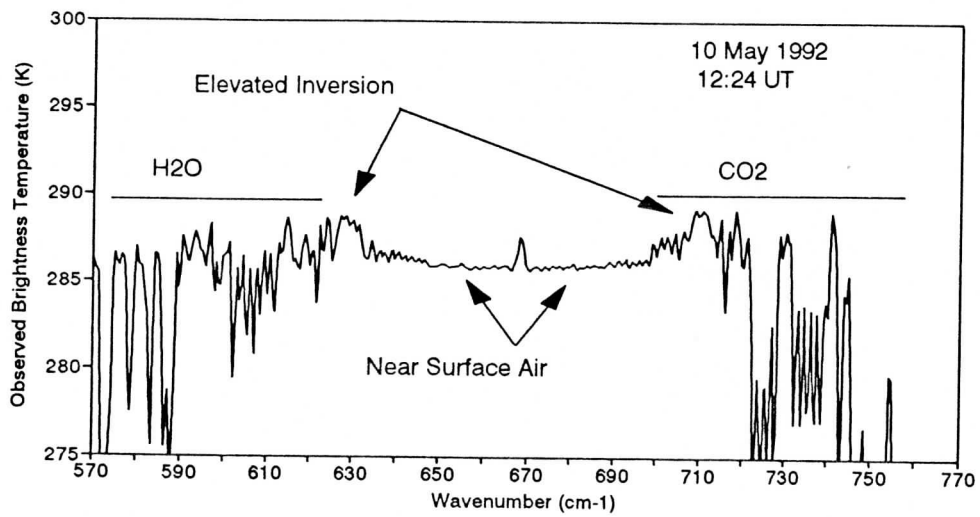


Figure 6b. Expanded region shown in equivalent brightness temperature.

## **IV. RESULTS**

As previously discussed, the AERI directly observes the downwelling infrared emission spectrum at the surface at relatively high spectral resolution. The infrared spectrum is itself a function of the vertical distribution of temperature, water vapor (and other minor atmospheric constituents), aerosol and cloud. This section describes an analysis technique to retrieve the atmospheric state parameters from a mathematical inversion of the infrared data. The resulting profiles of temperature and water vapor can be used to compute a representation of the refractive index of the atmosphere and thereby detect the presence or absence of a radar ducting situation.

### **A. Retrieval Technique**

The technique used to retrieve atmospheric state parameters from a downwelling infrared spectrum has been summarized in a UW Master's thesis, which was partially supported by this contract [Feltz 1994]. The basis of the retrieval technique is the formulation of a linearized form of the radiative transfer equation. The technique uses an analytic formulation of the linear perturbation of radiance due to a perturbation of atmospheric profile about a reference (or guess) state. A recursive method is used which has been "optimized" for the unique conditions encountered in infrared sounding of the atmosphere from the surface. The result is a vertical profile of temperature and water vapor with relatively high vertical resolving power near the surface that degrades in both vertical resolution and absolute accuracy above the boundary layer (0-2 km). Since the passive infrared spectra are obtained every ten minutes, the result of automatic operation of the AERI during Pt Sur '92 is a time continuous measurement of the thermodynamic characteristics of the constantly evolving marine boundary layer.

## B. Temperature and Water Vapor Profiles

The results of the retrieval algorithm for 9 - 10 May 1992 are shown in Figures 7-11. Figure 7 is a line plot showing an example retrieval of temperature and water vapor vertical profiles using the AERI compared to coincident radiosonde observations. Figures 8 and 10 are contour plots of the temperature fields on 9-10 May 1992 derived from the interferometer sounder radiance observations (10 minute intervals) compared with a similar plot obtained by linear interpolation of the radiosonde observations (3 hour intervals). Figures 9 and 11 display similar plots for May 9-10, 1992, comparing water vapor mixing ratio as a function of time and height. With the addition of a second IR spectral band recorded by the AERI instrument, information from both longwave (15  $\mu\text{m}$ ) and midwave (5  $\mu\text{m}$ ) infrared spectral regions in a new two band retrieval algorithm, indicate better temperature and water vapor retrieval results [Rugg 1992, Feltz 1994].

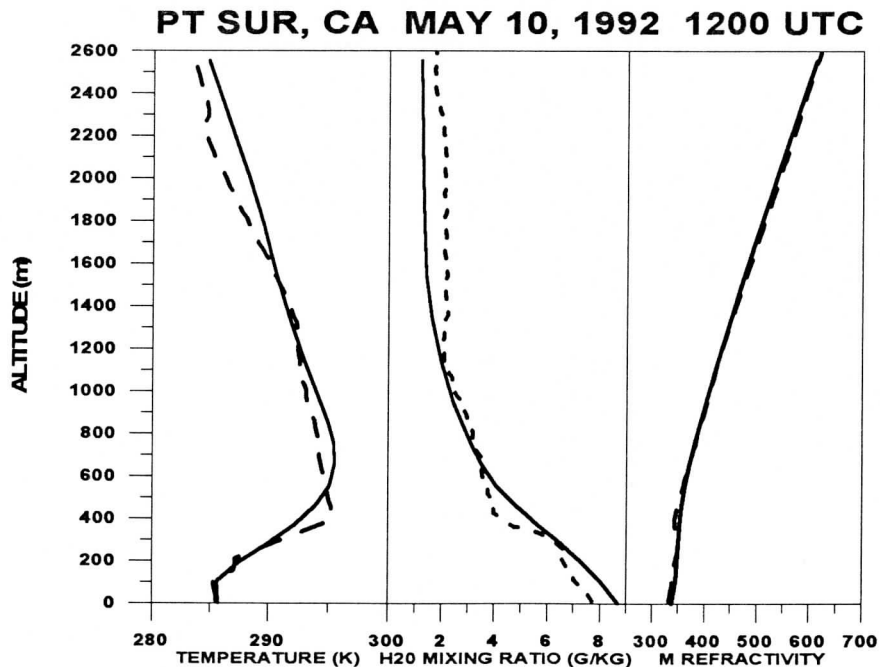


Figure 7. Comparison of interferometer sounder retrieved profiles (solid) to radiosonde observations (dashed).

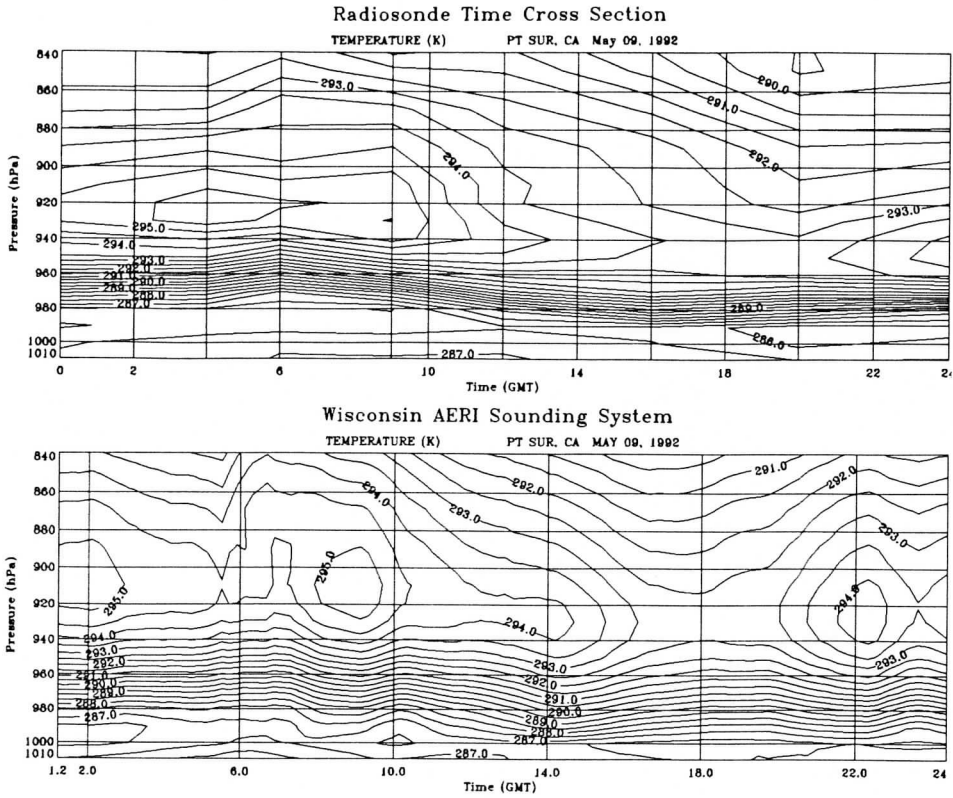


Figure 8. Interferometer sounder derived temperature field compared to interpolated radiosonde for May 09, 1992.

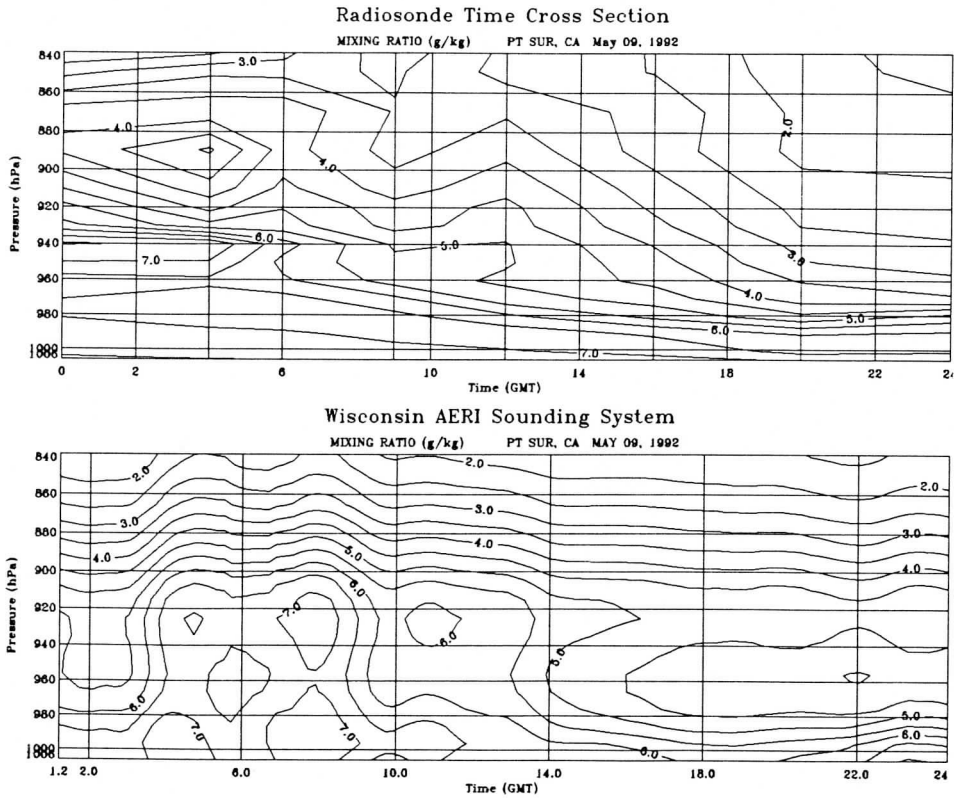


Figure 9. Same as above for the water vapor mixing ratio.

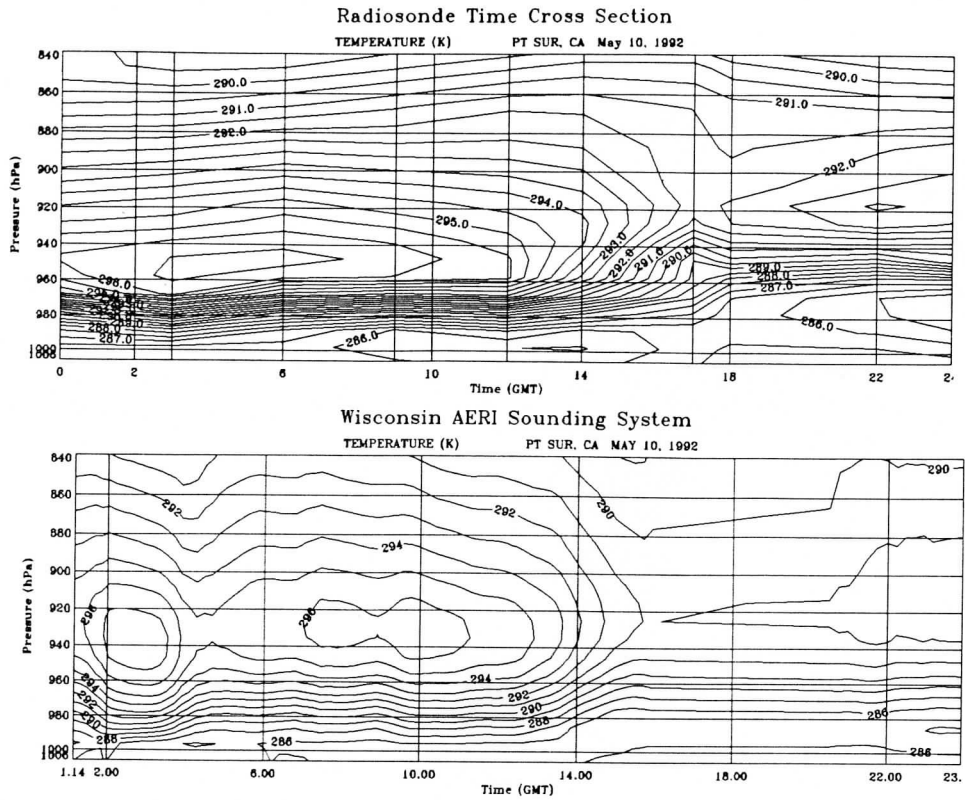


FIGURE 10. Interferometer sounder derived time cross section of temperature compared to interpolated radiosonde for May 10, 1992.

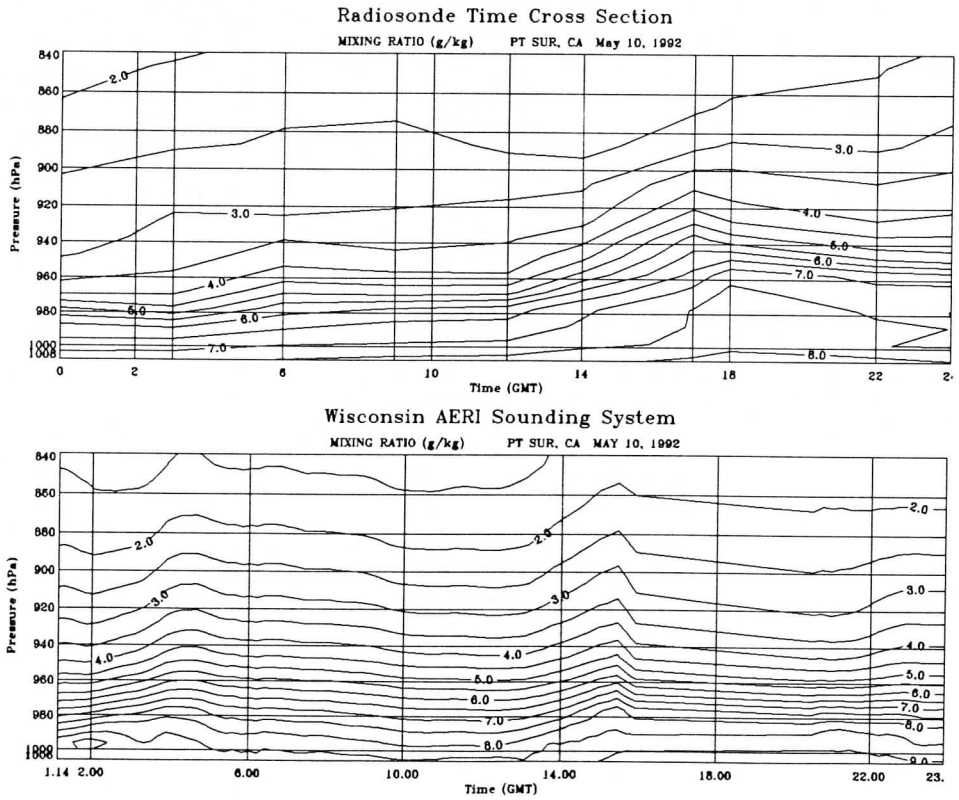


Figure 11. Same as above for the water vapor mixing ratio.

### C. Radar Ducting Detection

The computation of atmospheric refractive index at radar wavelengths takes the semi-empirical form (Doviak 1984):

$$N = (n-1) * 10^6 \quad \text{(definition)}$$

$$N = (P/T)*(77.6 + 3.73E5*q/(0.622*T)) \quad \text{(approximation)}$$

where  $N$  is the refractive index,  $P$  is the atmospheric pressure,  $T=T(P)$  is the vertical profile of air temperature, and  $q=q(P)$  is the water vapor concentration vertical profile. The modified index of refraction, which takes into account the curvature of the earth, is given by

$$M = N + 0.157*Z$$

where  $Z$  is the height above the surface.

Using these relations one can compute the vertical derivative of the modified index of refraction,  $dM/dz$ . The various conditions relevant to radar refraction are summarized as follows:

$dM/dz < 0;$	trapping layer
$0 < dM/dz < 0.079$	super refractive
$0.079 < dM/dz < 0.157$	normal refractivity
$0.157 < dM/dz$	sub refractive

The primary role of the AERI with respect to radar refractivity is the detection of the tendency toward a ducting condition during day or night. Figure 12 shows a comparison of super refractive conditions indicated by the interferometer sounder compared to a similar plot generated from radiosonde data.



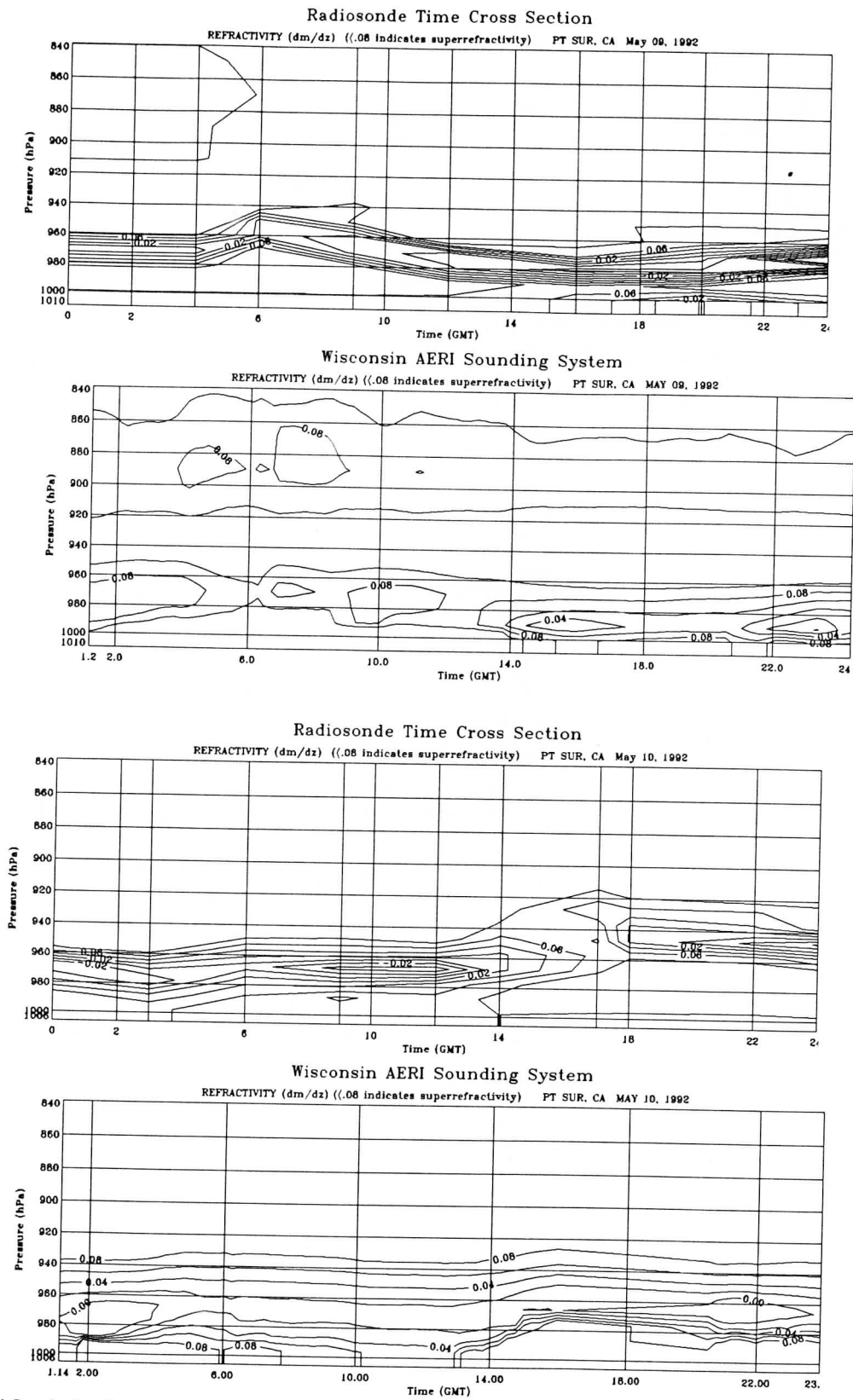


Figure 12. Interferometer sounder plot of super refractivity compared to radiosonde observation for 9 May 1992 (upper) and 10 May 1992 (lower).

## **V. CONCLUSIONS**

The results of the Pt. Sur 1992 experiment clearly show the ability of the interferometer to detect the temperature and moisture profile conditions responsible for ducting. Because the vertical resolution of the system is limited, some instances of weak ducting may be missed by the radiometric method. However, moderate to strong ducting conditions are detected. The system has the advantage of being continuous, passive, and fully automatic.

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