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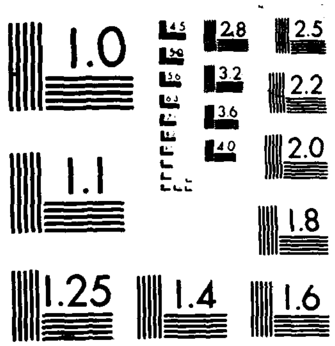


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# Intercomparisons of Radiosondes and an Airborne Refractometer for Measuring Radio Ducts

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3 July 1986







ATMOSPHERIC SCIENCES DIVISION PROJECT 6670
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The capabilities of two types of radiosondes and an aircraft refractometer to measure radio ducting conditions were compared in a series of flights in September 1985 at Chatham, MA., on Cape Cod. The tests were part of a program studying radio propagation on Air Force communication links. The intercomparisons were made between data from a refractometer mounted on a small single engine aircraft (Cessna 172), data from a portable radiosonde system used in Air Force radio link tests, and data from an operational NWS synoptic sounding system. The synoptic sonde and the portable sonde were often on the same balloon train. The comparisons show that the aircraft refractometer data indicate the highest number of ducts and the synoptic data the least number of ducts.

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## Preface

We thank the observers and staff at the National Weather Service Chatham facility for their assistance. They were extremely cooperative in giving whatever assistance we needed, provided it did not impact their operational responsibilities. We acknowledge the support of F. Mahler of the National Telecommunications and Information Sciences Laboratory who flew the aircraft and has been responsible for much of the refractometer improvements in the last several years. We also thank S. Sheets and TSgt K. Wolfe for technical support, and Mrs. Helen Connell for manuscript preparation.

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## Illustrations



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# Intercomparisons of Radiosondes and an Airborne Refractometer for Measuring Radio Ducts

## 1. INTRODUCTION

In September 1985, a series of field tests was undertaken at Chatham, MA as part of an in house program to study atmospheric effects on Air Force microwave communication systems. Part of this study used refractive index (N) profile data from three sources: an aircraft refractometer, a portable radiosonde, and a synoptic NWS rawinsonde. The primary purpose of this series of tests was to measure the refractive index structure function ($C_N^2$) in and near atmospheric inversion layers. The secondary purpose was to compare refractive index profile data from all three sources. This report presents only those data pertaining to the secondary purpose. Some of the shortcomings of the data base, such as incomplete aircraft profiles, are due to the precedence of the $C_N^2$ measurements in flight planning.

Chatham is located on the southeastern tip of Cape Cod. It was chosen because of the presence of a National Weather Service upper air station, its proximity to our work location, its proximity to the ocean, and the presence of an airport.

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## 2. DESCRIPTION

Three methods were used to obtain vertical profiles of the microwave refractive index. Two of these are radiosonde systems that measure temperature, pressure, and humidity, and the third is a refractometer that measures index of refraction directly.

The first radiosonde system is called the Atmospheric Data Acquisition System (ADAS). It consists of a ground receiver and data processor, a cassette tape recorder, a printer, and the radiosonde, as shown in Figure 1. The radiosonde itself consists of a bead thermistor to measure the temperature, a capacitively sensed aneroid cell to measure the pressure, and a carbon hygristor to measure the humidity. The sonde time-commutates the data from these sensors and uses it to modulate a crystal controlled transmitter at 403.5 MHz. The commutation provides a complete frame (T, P, H) about every 5 sec. All of these data were recorded/printed and were available for analysis.

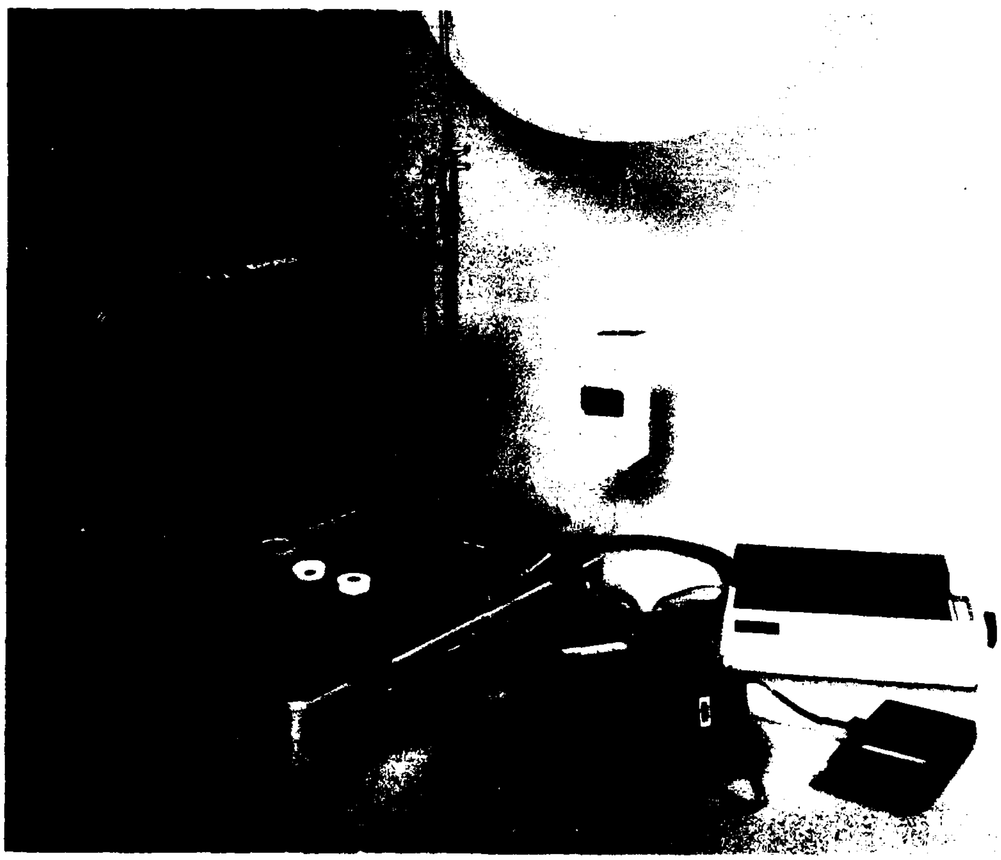

Figure 1. Portable Radiosonde System - Automatic Data Acquisition System (ADAS) - Manufactured by AIR Inc., Boulder, CO

The second radiosonde system is used at synoptic upper air stations in the U.S.[1] The radiosonde (VIZ mfg. No. 1392-510) consists of a rod thermistor to measure temperature, an aneroid cell to measure pressure, and the same carbon hygristor to measure humidity. This radiosonde commutates the temperature and humidity data along with references and send them to the ground station as modulation on a 1680 MHz carrier frequency. A principal difference between the sondes is that the aneroid cell drives a mechanical commutator in the synoptic instrument. Consequently, the position of the commutator, or contact number, contains the pressure information. The commutation rate for the synoptic sonde is thus determined by the rise rate, and is slower than the commutation rate for the ADAS sonde. The time for each contact averages about 20 sec in the lower atmosphere and the cycle is THTHTHTHTRTHTHTHTHTRT ... where T is temperature, H is relative humidity, and R is reference. This results in a time between adjacent humidity values of 20 to 30 sec, and when a reference intervenes, of about 50 sec.

The refractometer used was developed at the National Telecommunications and Information Sciences (NTIS) Laboratory at Boulder, CO.[2] It is a single cavity Birnbaum type. The cavity is not the frequency determining element, but is excited with a signal, centered on the resonant frequency, that has a sawtooth frequency modulation. An error signal that detects when the resonance is not centered is used to adjust the excitation. The refractometer relies on the relationship

$$\Delta N = - \frac{\Delta f}{f} \cdot 10^6 \qquad (1)$$

so that the resonant frequency (f) of the cavity depends on the refractive index (N) of the air that is continuously flushed through it. The refractometer is mounted on the strut below the wing of a single engine aircraft, as shown in Figure 2. The refractive index, together with the air temperature from a bead thermistor and atmospheric pressure from a laboratory aneroid cell, are recorded twice a second on magnetic tape. Although recorded twice a second, the refractive index from the refractometer is updated only once a second. The aircraft recording is controlled by a computer system that digitizes the data (12 bit) prior to recording it, and also allows the operator to insert comments on atmospheric conditions and the type of test. For the $C_N^2$ measurements, additional data are recorded at high speed (64 samples/sec) from a second channel of the refractometer.

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1. Federal Meteorological Handbook No. 3 (1971) Radiosonde Observations - Superintendent of Documents, U.S. Gov't Printing Office, Washington, D.C.

2. Thompson, M.C., Marler, F.E., and Allen, K.L. (1980) Measurement of the microwave structure constant profile, IEEE Trans. Antennas Propag., AP-28(No. 2).

Figure 2. Aircraft Refractometer Configuration - Insert Shows Internal Electronic Equipment

## 3. TESTS

All radiosonde tests were performed at the NWS upper air station at Chatham, MA. The station is located on a bluff 16 meters above the ocean. There were two types of soundings, those involving both the synoptic radiosonde and the ADAS sonde, and those involving only the ADAS sonde. In the double sounding case the ADAS sonde was piggy-backed on what is the normal synoptic sounding. The synoptic times are 0000 and 1200 GMT but balloons were released earlier than this, usually 0630 and 1830 ETD. The ADAS sonde was hung about 5 m below the synoptic sonde and they were carried aloft by 1200 g balloons with a vertical ascent rate of approximately 5 m/sec. At non-synoptic times, only the ADAS sonde was used, and was carried aloft by a 100 g balloon with a vertical ascent rate of approximately 3 m/sec.

The aircraft profiles were obtained by having the aircraft [illegible] cal speed of approximately 3 m/sec. The profile was taken as close as possible in space and time to the balloon releases. The time factor for synoptic releases was sometimes larger than desired because the balloon could not be delayed. A total of 17 runs was made over a 10 day period. The times are given as Eastern Daylight Time (EDT). Table 1 lists the dates and times of the various runs.

Table 1. Schedule of Events

| Event No. | Date | Acft | ADAS | NWS |
|---|---|---|---|---|
| 1 | 9/17 | | 0653-0705 | 0653-0705 |
| 2 | 9/18 | 0659-0727 | 0649-0700 | 0649-0700 |
| 3 | 9/18 | 1452-1521 | 1510-1529 | |
| 4 | 9/19 | 0643-0714 | 0648-0659 | 0648-0659 |
| 5 | 9/20 | 0701-0735 | 0636-0647 | 0636-0647 |
| 6 | 9/20 | 1052-1107 | 0934-0955 | |
| 7 | 9/21 | 0724-0742 | 0630-0641 | 0630-0641 |
| 8 | 9/23 | | 0632-0644 | 0632-0644 |
| 9 | 9/24 | 0710-0725 | 0626-0637 | |
| 10 | 9/25 | 0642-0648 | 0636-0645 | 0636-0645 |
| 11 | 9/25 | 0932-0955 | 0930-0947 | |
| 12 | 9/25 | 1606-1623 | 1526-1544 | |
| 13 | 9/25 | | 1906-1917 | 1906-1917 |
| 14 | 9/26 | 0631-0648 | 0638-0650 | 0638-0650 |
| 15 | 9/26 | 0853-0903 | 0811-0830 | |
| 16 | 9/26 | 1407-1423 | 1435-1452 | |
| 17 | 9/26 | | 1833-1844 | 1833-1844 |

## 4. DATA

Both radiosondes measure pressure (P), temperature (T), and relative humidity (RH) as commutated functions of time. As mentioned earlier, the rate of commutation for the two sondes is different. The height to which these measurements are assigned is computed using the surface height and the hydrostatic equation

$$dP = \rho g dz \tag{2}$$

where

$\rho$ is air density,

g is acceleration due to gravity, and

z is altitude.

The index of refraction is computed from

$$N = \frac{77.6}{T} \left(P + \frac{4810\, e_w}{T}\right) \tag{3}$$

where

T is temperature in degrees Kelvin,

P is total atmosphere pressure in mb,

$e_w$ is partial pressure of water vapor in mb,

and $e_w$ is calculated using the empirical relationship

$$e_w = 6.1078 \times \mathrm{R.H.} \times 10 \exp\left(\frac{7.63\,T}{241.9 + T}\right). \tag{4}$$

The modified refractive index is then calculated from

$$M = N + 0.157\, Z \tag{5}$$

where Z is in meters.

In performing these calculations, all of the data from the ADAS sonde were available to us while only the "significant" data from the synoptic soundings were used. This was partly by choice since in our field experiments on propagation paths, only these data would be available.

Figure 3 shows the air temperature and dew point temperature from a representative sounding taken on 26 September at 0630 LDST. Dew point temperature is calculated from

$$T_D = \frac{241.9 \times \log_{10}(e_w/6.1078)}{7.63 - \log_{10}(e_w/6.1078)}. \tag{6}$$

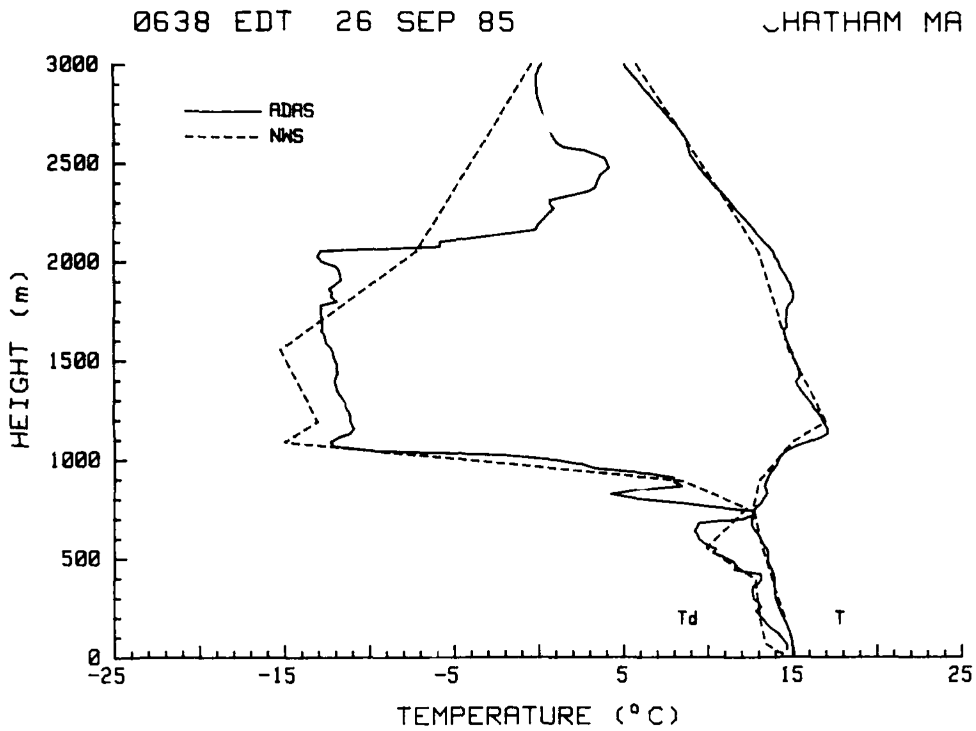


Figure 3. Atmospheric Temperature (T) and Dew Point Temperature ($T_D$) From Dual Radiosonde Flight 0638, 26 September 1985

Figure 4 shows the N and M profiles for this same sounding. Since the refractometer reads out directly in refractive index, all that is required is the conversion of the reading to M units, using Eq. (5). Figure 5 shows the aircraft sounding taken closest in time to the balloon sounding of Figure 4. The balloon sounding data are included in the figure and the profiles are offset from each other by 40 M units to avoid confusion. A radio duct is indicated in this figure. It is quite apparent that the modified refractive index (M) is a much better indicator of ducting than N. Also shown by way of definition are the duct thickness, the ducting layer ($dM/dZ < 0$) and the $\Delta M$.

Because ducting situations are very important to radio propagation and they form a convenient means of comparing the products from the various systems, we have shown all the data as M profiles. Figures 6, 7, and 8 show all of the comparisons; 6 of these are three-way comparisons while 11 are comparisons between only two techniques. These figures show the profiles with varying M offsets between intercomparisons to avoid confusion. The numbers refer to the event numbers in the table of events.

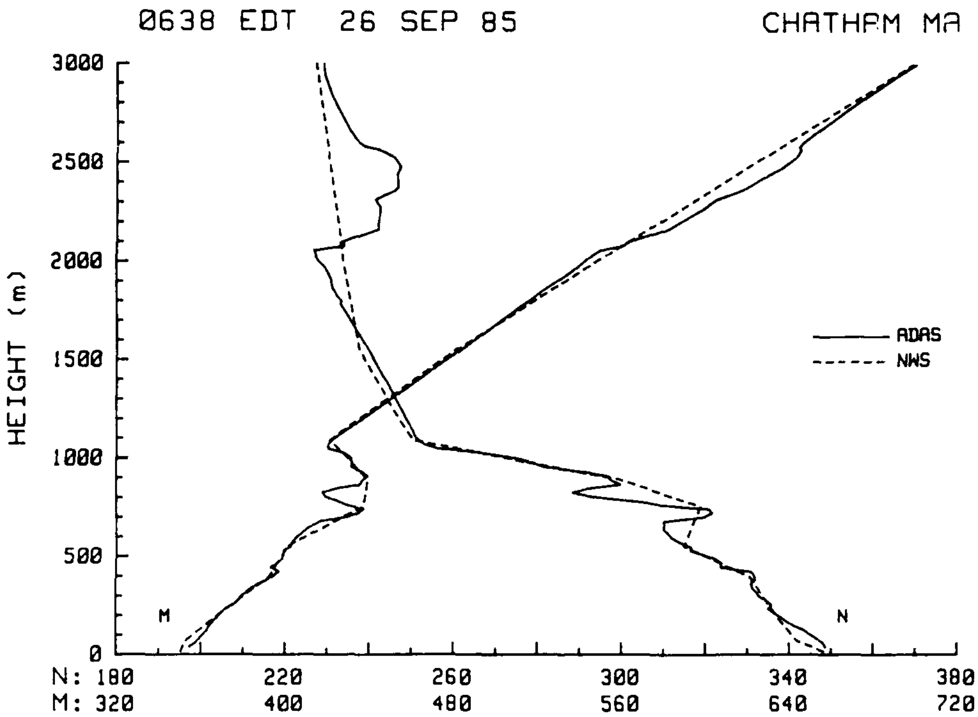


Figure 4. Index of Refraction (N) and Modified Index of Refraction (M) Profiles for Balloon Data of 0638, 26 September 1985

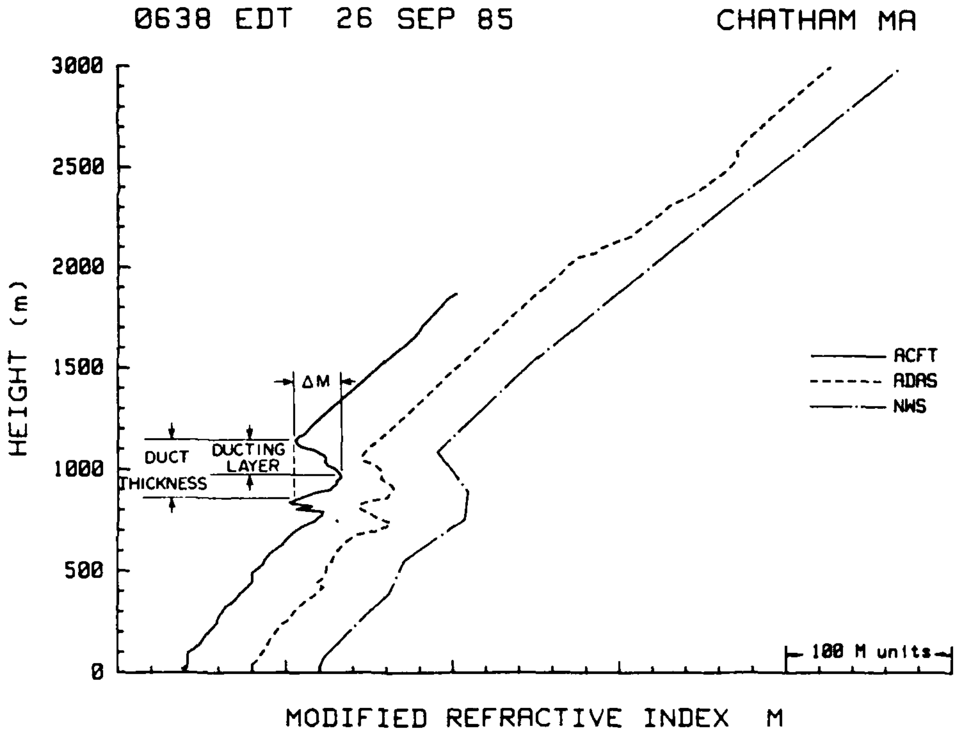


Figure 5. Modified Refractive Index (M) Profiles for Refractometer and Balloon Data of 0638, 26 September 1985

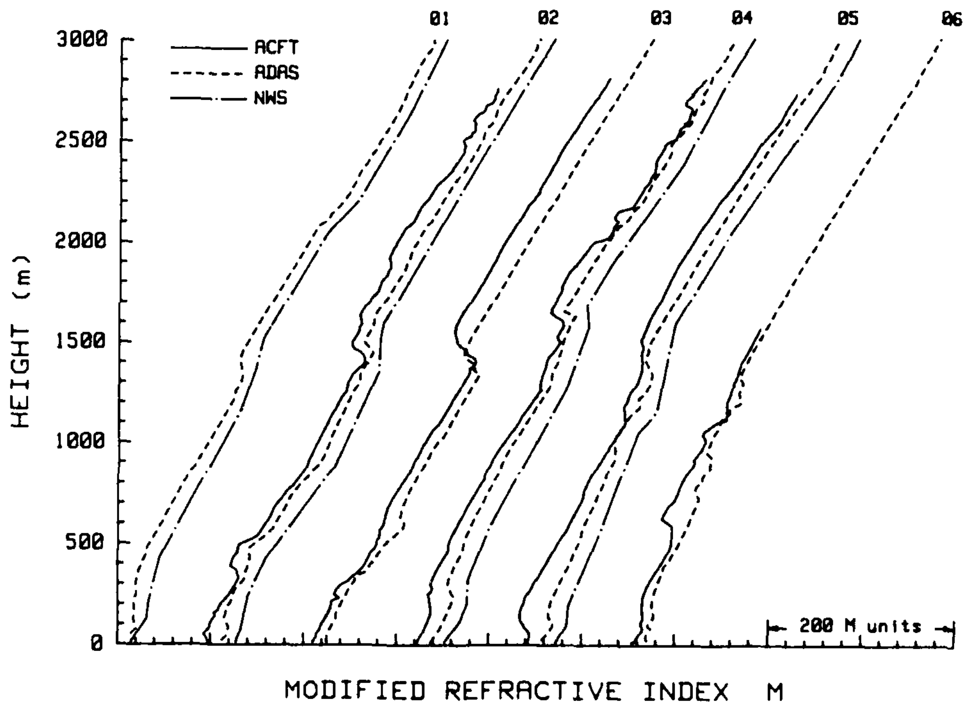


Figure 6. Modified Refractive Index (M) Profiles for Events 1 Through 6 - September 1985

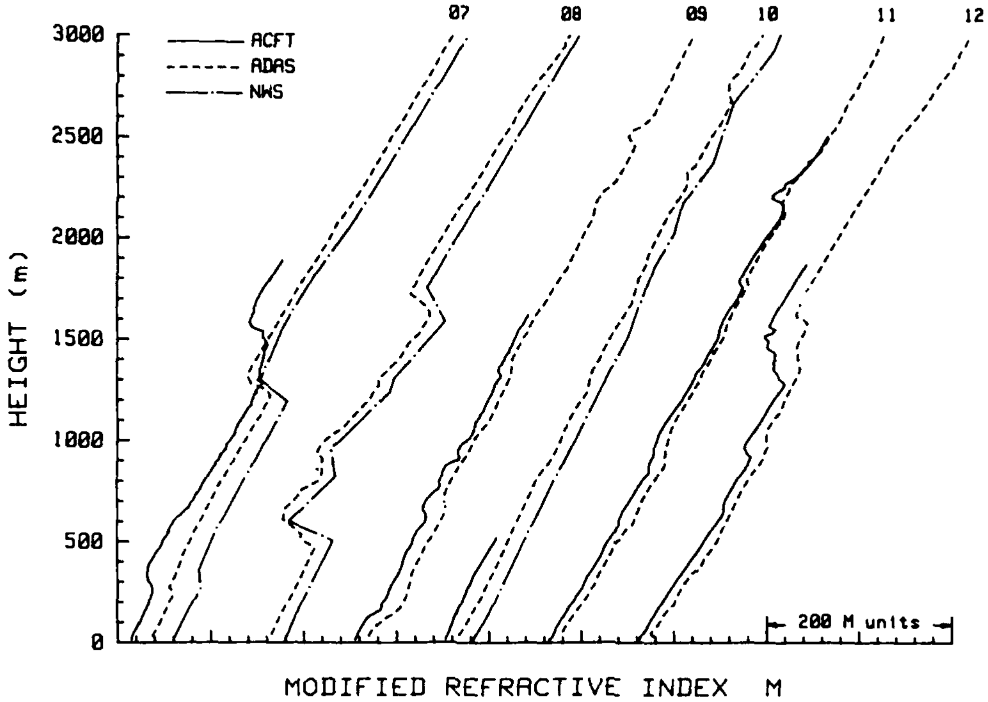


Figure 7. Modified Refractive Index (M) Profiles for Events 7 Through 12 September 1985

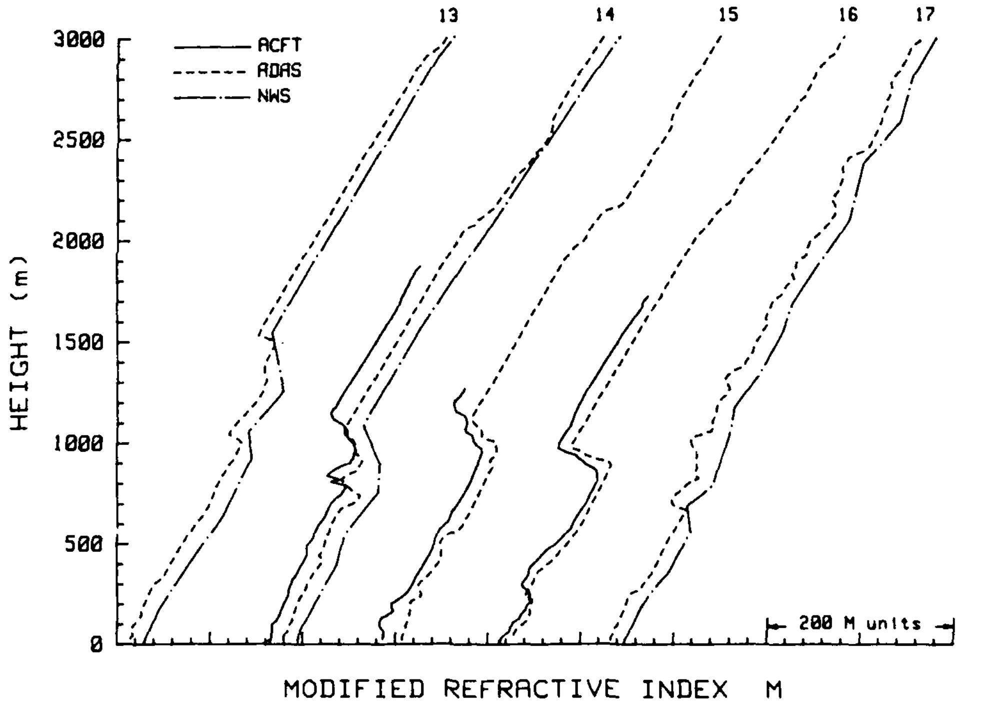


Figure 8. Modified Refractive Index (M) Profiles for Events 13 Through 17 - September 1985

## 5. DISCUSSION

In comparing the two types of radiosonde soundings, it was our intent to understand the products of the two as we might use them. Our interest is in the refractive index profiles for use in studying propagation paths. When we use data from the ADAS system, we have access to all the data. When we use data from the synoptic NWS radiosonde we are privy to only the transmitted "significant level" data. The results should not be construed as implying anything about the synoptic usefulness of either instrument.

In general, the agreement between the two radiosonde data bases is excellent. When the two sets of atmospheric temperatures are compared at the significant levels as reported from the synoptic sonde, the mean difference is found to be 0.033°C and the standard deviation of the differences, 0.44°C. When the sets of dew point temperatures are similarly compared, the mean difference is found to be 0.123°C and the standard deviation of the differences, 1.85°C. In this second comparison, data were omitted when both dew point depressions were greater than 20°C or when the synoptic radiosonde reported a 30°C depression. Dew point temperature difference in these dry conditions is not important to refractive index. One would expect good agreement since both sounders use the same humidity sensor, a carbon humidity element (VIZ Mfg. No. 1286-162), and the same temperature measuring technique, a thermistor with a white paint coating exposed directly to the air. The agreement is visible in Figure 3 where temperature and dew point temperature are plotted as functions of altitude. In addition to the vertical profiles of temperature from the radiosondes, a vertical profile of temperature from the aircraft was also available and can be seen to agree with the radiosonde data to better than 0.5°C (Figure 9). An aerodynamic heating correction of 1.0°C was made to the aircraft measurement.

Since we use the data to determine atmospheric effects on microwave communication systems, it is important to compare the refractive index and refractive index gradients as measured or derived from these systems. To do this we will use the modified refractive index (M) profiles since this allows easy visual identification of radio ducting situations, $dM/dZ < 0$. The plots of M vs Z for cases including aircraft flights show that aircraft data indicate the greatest number of ducting situations and the NWS sonde the least number. If we ignore the first 50 m above the surface, there is only one instance where a duct thicker than 50 m is indicated in the ADAS sonde data and not in the aircraft data. This appears in the 18 September 1452 flight, as shown in Figure 6 as event No. 3, at an altitude of 600 m. The duct is only 80 m thick and the soundings are 18 min apart. Therefore the discrepancy is probably atmospheric and not instrumental in origin.

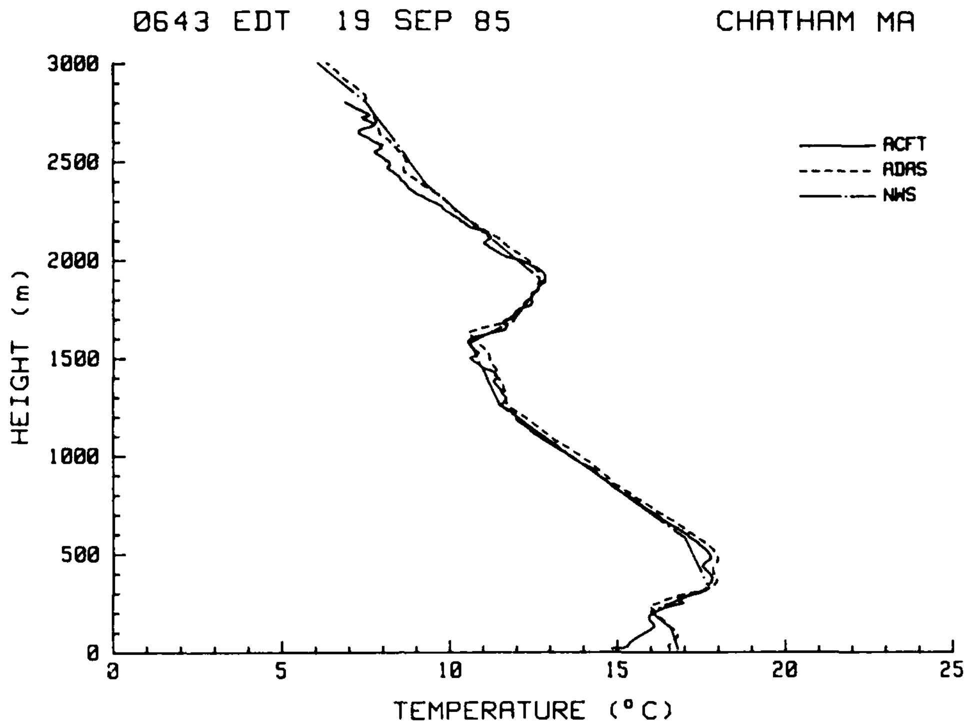


Figure 9. Atmospheric Temperature Profiles for Aircraft and Radiosondes for 19 September 1985 Event No. 2

In examining the events where the refractometer and the ADAS sonde are less than 20 min apart we found four instances where the aircraft data showed a duct greater than 50 m thick that was not indicated by the radiosonde. Two additional ducts, although indicated by the ADAS sonde, were indicated as less than 50 m thick. In no case was a duct thicker than 60 m indicated by the aircraft and not indicated by the ADAS. Of the 11 ducts indicated by both the refractometer and the ADAS, the refractometer shows a larger $\Delta M$ in 8 cases and the ADAS $\Delta M$ is larger in 2 cases.

The M profile data from the NWS sonde does not show ducting in several instances where both the aircraft and ADAS data indicate the ducting criterion has been satisfied. Two of the most notable occurrences are in event No. 14, shown in Figure 8, and event No. 2, shown in Figure 6, at altitudes of 800 m and 500 m, respectively. When there are just balloon releases, there are additional instances where ducting is indicated by the ADAS data and not by the NWS data. One of the most dramatic cases was event No. 17 (Figure 8) on 26 September 1985 at 1833. The ADAS instrument shows a strong duct between 600 and 700 m, a second strong duct between 800 and 1050 m, and a third weaker duct near 1300 m. The synoptic data show only the first of these. The temperatures and dew point temperatures for this flight, illustrated in Figure 10, show that the synoptic data do not indicate the two tongues of dry air that caused the ducting. The layer at 1000 m, at least, was missed because of the way the data are commutated in the NWS sonde. The dry layer occurred where the reference contact caused the humidity contacts to be about 60 sec apart.

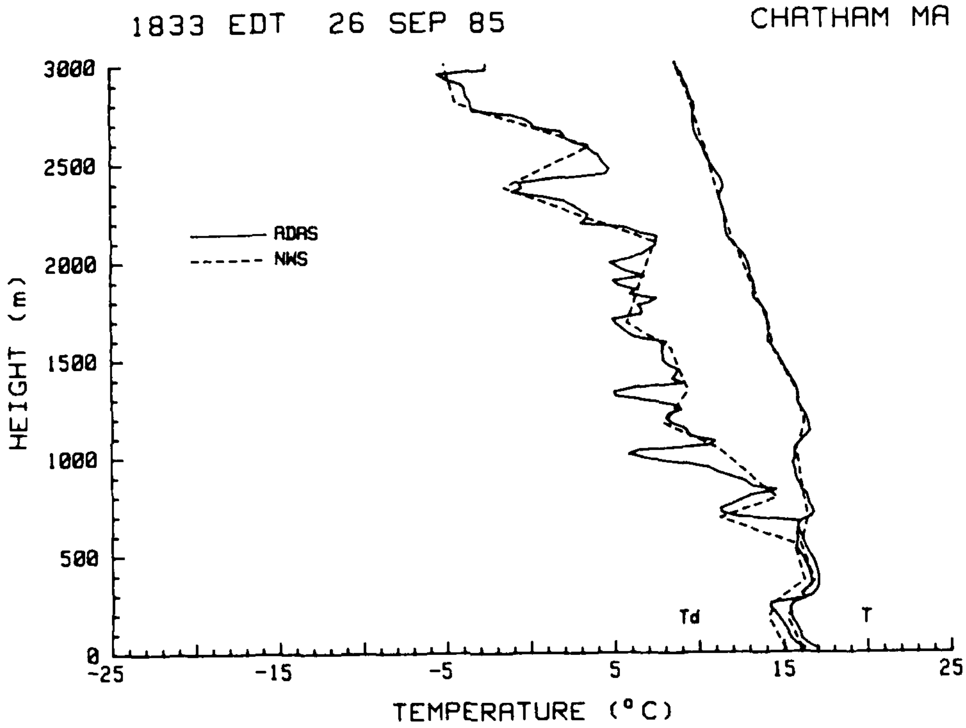


Figure 10. Atmospheric Temperature (T) and Dew Point Temperature ($T_D$) for Balloon Sounding of 1833, 26 September 1985

Examination of all the events involving both the ADAS and the synoptic sonde reveals 11 instances where the ADAS showed a duct greater than 50 m thick and the synoptic data did not indicate ducting. Of these, 7 were greater than 100 m and only 1 was greater than 150 m. In the 10 instances where both the ADAS and the synoptic sonde show ducting, the ADAS sonde indicated a larger value of $\Delta M$ in 8 cases.

## 6. CONCLUSIONS

The higher commutation rate of the ADAS instrument makes it possible to detect all ducts more than 60 m thick when used on balloons with ascent rates of 6 m/sec in the first few kilometers. In one case, the data from the synoptic sonde failed to indicate a duct 205 m thick, (event No. 17). In general, the synoptic data will detect all ducts more than 250 m thick and only rarely miss ducts more than 150 m thick. When all data are available from an instrument with a higher commutation rate (5 sec frame rate), any duct more than 60 m thick should be detected. In our propagation experiments we have used ADAS instruments and rise rates of 2.5 m/sec, so that ducts as thin as 30 m are detectable.

The aircraft data is limited by the update rate of the refractive channel, 1 sec, and the rise rate of the aircraft, in our tests about 3 m/sec. This results in resolution of about 6 m ducts.

In addition to missing some of the thinner ducts, both radiosonde instruments underestimate the change in M in the ducts relative to the aircraft refractometer. This has two types of effects; the duct thickness is less, and the critical angle necessary for a radio wave to escape is greater. There is no indication of either instrument indicating ducting erroneously.

These tests would indicate that any study of the frequency of occurrence and strength of radio ducting based on synoptic data will underestimate the frequency for ducts with thicknesses less than 300 m and will underestimate the strength of the ducts in general. The limited amount of our testing is not sufficient to make quantitative estimates of this deficiency.

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