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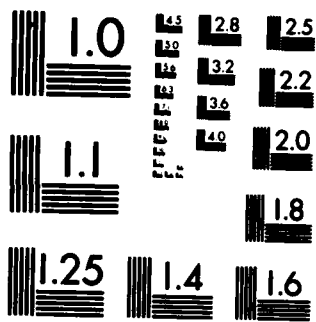
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GUIDELINES FOR CORRECTION OF RADIOSONDE-DERIVED REFRACTIVE PROFILES AND CLEMATOLOGIES

**PREPARED FOR REFRACTIVE ATMOSPHERIC EFFECTS ASSESSMENT
BLOCK POLARON, NAVAL OCEAN SYSTEMS CENTER**

by
R. A. MELVEY
Geophysics Division

20 November 1982

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20. ABSTRACT (Concluded)

This report discusses these factors, and presents recommendations both for revision of existing refractive statistics, and modifications to radiosonde observation and reduction procedures which should lead to substantial improvement in data for operational and climatological applications.

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**GUIDELINES FOR CORRECTION OF RADIOSONDE-DERIVED REFRACTIVE
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**PREPARED FOR REFRACTIVE ATMOSPHERIC EFFECTS ASSESSMENT BLOCK PROGRAM,
NAVAL OCEAN SYSTEMS CENTER**

By

R. A. Helvey

SUMMARY

Substantially more frequent occurrences of surface-based superrefractive and trapping layers are noted in daytime than in nighttime refractive data derived from standard American radiosondes (military and civilian). Evidence indicates that this diurnal bias is largely or entirely fictitious. Estimates of electromagnetic propagation based on these data will be correspondingly compromised or invalidated.

Several factors contribute to this bias, including sensor and sonde characteristics, exposure prior to release, and sampling and reduction procedures. The problem is fundamentally a consequence of hygistor (carbon or earlier lithium chloride) vulnerability to temperature effects. It has been known for some years that hygistor thermal lag and temperature excess due to sonde and solar heating have been responsible for a daytime deficit in indicated relative humidities aloft. Because standard procedures specify use of psychrometric data for the surface point — which is not subject to the same errors — an unrealistic tendency for decreasing humidity and refractivity through the lowest layer results. Although these effects should have decreased with the introduction of an improved sonde in the early 1970s, conditions still occur which continue the daytime bias.

Hygistor thermal lag contribution to the humidity/refractive deficit during and some distance above the daytime superadiabatic layer is often significantly magnified by heating of the sensor during pre-release preparations, due to solar radiation and inadequate ventilation. Because the single data channel is shared sequentially by temperature, humidity and reference, humidity data is frequently lacking at the first reporting point from the sonde (typically the top of the superadiabatic layer or the mandatory 1000 mb level). In this event an interpolated value is obtained, which unfortunately consistently underestimates humidity and thus still tends to yield spurious surface-based ducts.

It has recently been noted that at a number of sites exposure of the sonde to an air-conditioned environment before release results in an initially cool hygistor, which although not used for the surface point nevertheless may contribute to an excess of subrefractive surface layers when the layer top is near enough to the surface so that the effect of initial conditions at time of release is more important than subsequent bias due to lag.

A number of recommendations designed to reduce these various errors have been presented.

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INTRODUCTION

In a previous report (Helvey, 1979¹) evidence was presented indicating a large bias towards daytime occurrences of spurious surface-based ducts in data derived from radiosondes manufactured in the United States. Serious errors in estimates of electromagnetic propagation conditions can result from straight-forward application of these data. A discussion of the nature and origin of the deficiencies in the data is given in this report, followed by suggestions for modifications in the measurement and reduction process to improve the quality of the data for refractive applications.

SOURCES OF ERROR

Inaccuracies in radiosonde data arise from various factors, including sensor characteristics, sonde design and materials, handling prior to release, and reduction procedures. Pressure, temperature, and humidity from the sonde are required for computation of microwave refractive index, with humidity the most critical parameter. A redesigned sonde introduced in the early 1970s brought significant improvement in accuracies of the humidities aloft. Nevertheless, problems associated with pre-release exposure of the sonde, sampling limitations, and reduction procedures have continued to adversely affect measurements, particularly within the first few hundred feet of ascent — precisely the region of greatest concern for naval operations.

Sensor Lags

We are concerned here with impact of measurement errors on appraisal of communication/detection systems performance, rather than accuracy of ranging determinations. The former requires a knowledge of the rate of change of refractivity with altitude, or vertical refractive gradient. For this reason, the relative accuracy of adjacent data points within individual sounding profiles is of practical relevance, rather than their absolute accuracy. Sensor lags alter the apparent altitude and amplitude of vertical refractive gradient features computed from the observed temperature and humidity profiles. The lags are a consequence of the inability of sensor and nearby sonde structures to respond instantaneously to variations in ambient atmospheric conditions. They are most significant where temperature and relative humidity gradients are largest: in temperature inversions, or the superadiabatic layer which typically develops over land during daytime hours.

Temperature and humidity are measured in the standard U.S. civilian and military radiosondes by electrical resistance of their sensors, a thermistor, and hygistor, respectively. Response of the thermistor to temperature changes is fairly good at lower altitudes, with time constant around 2 to 4 seconds (Sion, 1955²). In the warm temperatures typical of low altitudes in temperate and tropical conditions, the hygistor humidity response is even better, with time constant less than 1 second (Marchgraber and Grote, 1968³). But the temperature of the hygistor is required in order to convert its measurements to relative humidity: a small correction in the resistance-to-humidity relationship, and a much more important role in determining saturation vapor pressure at the sensor surface. Unfortunately, hygistor *thermal* lag is considerable, being approximately 13 seconds near sea level for the element and

¹ Helvey, R. A. "Preliminary Assessment of Temperature Induced Radiosonde Humidity Errors and Effects on Apparent Low-Level Refractive Structures" in *Proceedings of the Conference on Atmospheric Refractive Effects Assessment*, Naval Ocean Systems Center, June 1979. UNCLASSIFIED

² Sion, E. "Time Constants of Radiosonde Thermistors." *Bull. Amer. Meteor. Soc.*, V. 36, 1955. pp. 16-21. UNCLASSIFIED

³ Marchgraber, R. M. and H. H. Grote. "The Dynamic Behavior of the Carbon Humidity Element ML-476" in *Humidity and Moisture*, Reinhold Publishing Co., 1968. pp. 331-345. UNCLASSIFIED

sonde type in current general use (Brousaides and Morrissey, 1974⁴). In the various U.S. sondes employed prior to about 1973, including the models before the early 1960s using the lithium chloride element, hygistor thermal lag could reach 30 to 40 seconds or more in the lower troposphere (and still worse at higher altitudes) because of poor ventilation. Since the temperature needed for computing relative humidity is obtained from the thermistor, the mismatch in thermal lag between the two can result in a sizeable humidity error. Relative humidities and corresponding refractivities tend to become too small when the sonde ascends through decreasing temperatures, particularly in the daytime surface-based superrefractive layer; on the other hand these parameters become too large during sonde transit through temperature inversions.

Although heating of the hygistor due to solar radiation or dissipation of heat from sonde electronic components will contribute to humidity error, except in the circumstances described below this should be in the form of a slowly changing bias with altitude, and thus not significantly affect apparent vertical refractive gradients.

Surface Conditions

Sonde handling before release can result in substantial additional error. Inadequate natural ventilation leads to accumulation of a temperature excess in the instrument and hygistor. Based on tests at PACMISTESTCEN, in worst cases hygistor temperature exposed in the sun can reach 8°C or greater above that of the ambient atmosphere, producing a relative humidity deficit approaching 30 percent, and a corresponding refractivity deficit of 25 to 30 N-units. Similar consequences will attend introduction of a sonde into a relatively cool outdoor environment after preparation inside a warm enclosure. Because of hygistor thermal lag, the effects of any initial temperature excess at time of release will persist up to several hundred feet above the surface, prolonging and increasing the magnitude of the daytime refractive deficit aloft associated with the near-surface superadiabatic conditions.

Recently, we have discovered evidence for an initial error in the *opposite* direction at a number of sites in the tropical Pacific (U.S. Trust Territories). According to information from personnel familiar with facilities at these sites, the sondes are prepared in air-conditioned offices (a practice since at least the mid-1960s). They are apparently often released before becoming fully acclimatized to the prevailing warm, moist outdoor environment. By implication, this situation could exist at other sites in similar climatic regimes.

Surface Data Source

The ultimate effect of these initial and lag errors on the final refractive profile data depends on additional factors. Although aloft the errors in refractive gradient are typically most strongly related to vertical variations in sonde humidity error, for the near-surface layer a special situation exists. Because standard procedures given by the Federal Meteorological Handbook for Radiosonde Observations (FMH-3) specify use of psychrometric data for the surface point, the relative accuracy between sonde and psychrometer becomes a determining factor. Several alternative situations are depicted schematically in figures 1a-b and 2a-b. An idealized daytime atmospheric temperature profile (labeled "T") is plotted in figure 1a. The dashed curve marked "C" represents hygistor thermal response to that ambient temperature as the sonde is borne aloft, starting from an assumed initial negative offset caused by recent exposure to a cooler environment. The curve marked "W" represents temperature of a hygistor with an initial positive offset such as might be caused by overexposure to solar heating prior to release. In figure 1b are shown the corresponding curves for humidity or refractivity error with height. Regardless of the actual atmospheric humidity profile, the errors due to thermal lag would tend to cause the same relative departures from true conditions. Note that the variation between the psychrometer surface values and points selected from the radiosonde at some level below the altitude where the "cold" hygistor and ambient temperature curves cross suggests a bias towards subrefractive surface-layer gradients when the hygistor is initially cold, and superrefractive when it is too warm. This is exactly the opposite of that which might be inferred from consideration of the sonde data alone. An idealized nighttime temperature profile is indicated in figure 2a with hygistor thermal response shown in the same

⁴Brousaides, F. J. and J. F. Morrissey. "Residual Temperature-Induced Humidity Errors" in *National Weather Service Radiosonde, Final Report*, Air Force Cambridge Research Laboratories, L. G. Hanscom AFB, MA, 28 February 1974. (AFCRL-TR-74-0111). UNCLASSIFIED

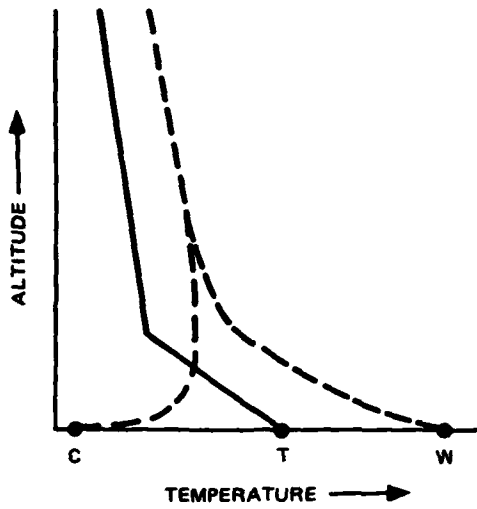


Figure 1(a).

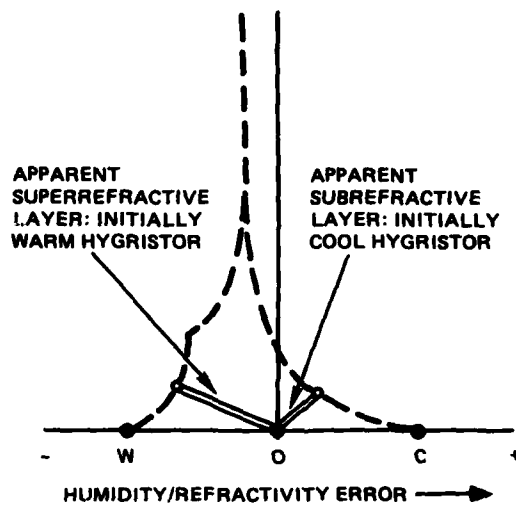


Figure 1(b).

Figure 1. Schematic Daytime Temperature Profile (T) With Superadiabatic Surface Layer; Hygristor Temperature Curves for Initially Warm (W) and Cool (C) Sensors, and Corresponding Humidity/Refractive Error Profiles.

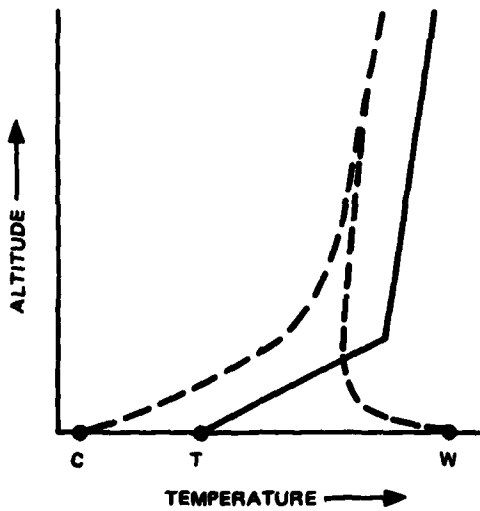


Figure 2(a).

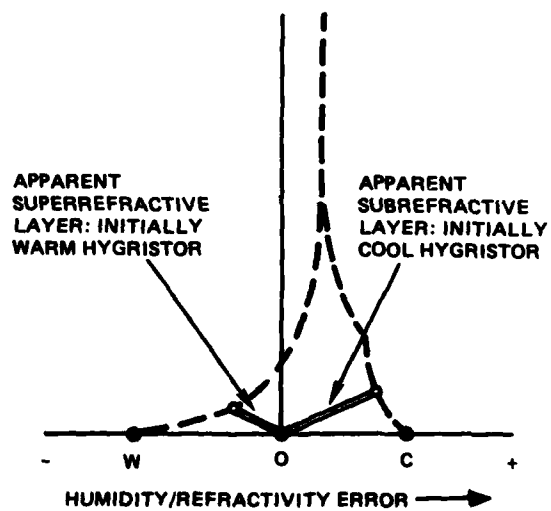


Figure 2(b).

Figure 2. Schematic Nighttime Temperature Profile (T) With Surface Inversion Layer; Other Curves as in Figure 1.

manner as in the preceding figure. The corresponding humidity/refractive error curves given in the adjacent plot demonstrate that near the surface the sign of the apparent refractive gradient is controlled by the initial hygistor temperature offset from the psychrometric value; at some higher altitude, the direction of slope of the ambient temperature profile determines whether the refractive gradient between the surface psychrometric and the upper value appears to be subrefractive or superrefractive.

Sampling and Reduction Procedures

A single telemetry channel at 403 MHz or 1680 MHz is shared by the several sonde parameters in sequence. Temperature and humidity are transmitted alternately at a rate determined by the change of pressure with altitude in the baroswitch type of sonde which has been used most widely; in the less common "ranging" instruments, a clock causes cyclic switching between these parameters. Apart from errors due to inaccuracies in manually selecting, reading, and transcribing values from the analog recorder chart, the intermittent and non-concurrent nature of the temperature and humidity samples ("contacts") and necessity for limiting the number of reduced data points are major factors in misrepresentation of actual atmospheric refractive structure.

For various reasons, the first point selected from the sonde data is generally at a level well within the surface region most susceptible to lag and initial error. In the event a humidity contact happens to be present at that level, it will tend to yield a spurious refractive gradient as previously explained. But, because of the interruptions in the trace due to switching between parameters, it will often be necessary for the operator to approximate the missing value. Whether this is accomplished by linear interpolation between the surface psychrometer point and the next available humidity contact, or by adopting the value of an adjacent contact, the resulting humidity is liable to uncertainty. In particular, linear interpolation (actually carried out in terms of recorder chart ordinate values) consistently underestimates the humidity when the missing point is at the top of the daytime surface superadiabatic layer (or mandatory 1000 mb reporting level), because it does not take into account the rapid increase in relative humidity one would normally expect with the rapid decrease in temperature through the layer.

RECOMMENDATIONS

To correctly obtain radiosonde measurements and reduced data suitable for Navy refractive assessment applications, the following recommendations are submitted. These should substantially reduce most of the radiosonde-derived errors that result in erroneous refractive structure, although it now appears little can be done to recover reliable estimates of surface layers from data bases already compiled.

Radiosonde Handling and Reduction

To minimize errors in low-level refractive features and improve detection of significant layers:

1. Avoid exposing the sonde to any environment other than ambient outdoor conditions for 5 minutes prior to release.
2. Use a portable aspirator to ventilate the sonde up to the moment of release. This will avoid troublesome heating/cooling errors. A prototype is planned to be built and tested at PACMISTESTCEN.
3. If the above is not available, use an aspirated thermoscreen. Choose a well exposed but shaded location away from paved surfaces. On board ship, avoid proximity to large superstructures.
4. Obtain the surface data point for the sounding from the aspirated sonde itself (not a psychrometer) to avoid instrumental differences. Allow sufficient time to get a stable "average" surface point. This can also be used for the baseline determination when the "ACCULOK" hygistor is not available as is the case for Navy sites.

5. Use a "rapid switch" (PACMISTESTCEN or equivalent) to improve the resolution of important humidity and temperature features needed to determine refractive layers. This is used to eliminate all reference contacts except the 10th, 15th, 20th, etc., thus providing more contacts for humidity and temperature. Intervening pressures can be estimated by linear interpolation.
6. Reduce *every* contact up to the top of the region of refractive interest (unless the points are aligned along a nearly straight line).
7. Apply lag corrections if at all possible. To facilitate this step, PACMISTESTCEN will be providing algorithms to be considered for insertion into IREPS radiosonde reduction software.
8. Select final "significant levels" based on deviations in humidity of 3 percent and in temperature of 0.5°C. Preserve regions of strong gradient in either humidity or temperature.
9. If a point must be selected within the first 500 feet above the surface, particularly at the top of the daytime superadiabatic layer (or top of a strong surface radiation inversion), provide a relative humidity for that level by computing *mixing ratio* or *dewpoint* from the surface point and the first available humidity contact above 500 feet, performing a linear interpolation in that parameter, and converting back to relative humidity.

Recommendations for Climatological/Historical Data

For refractive/duct climatologies and historical data from American sondes at least through 1974, it appears necessary to ignore surface layers or gradients with upper levels less than 500 feet altitude above the surface, with only cautious acceptance of such layers up to 1,000 feet. This proscription does not apply to "elevated-surface" or elevated layers (or evaporative ducts). Recovery of true conditions for the surface layer does not seem feasible, either day or night for affected sites, because of the uncertain initial state of the sonde.

Until a satisfactory estimate of surface layers can be compiled from non-contaminated data, some guidance as to their occurrence may be obtained by downward extrapolation of statistics for elevated and elevated-surface layers. This is liable to be unreliable when formation of surface layers through advective processes is significant, but it would be difficult to distinguish such layers from the fictitious layers resulting from radiosonde errors.

In order to remedy this major deficiency in current refractive knowledge, a thorough examination of radiosonde data from all the more common types of instruments employed by various weather service around the world should be undertaken, with particular attention to diurnal differences, and relevant sonde and procedural characteristics.

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