MIDDLE
ATMOSPHERE
PROGRAM

HANDBOOK FOR MAP
VOLUME 2

Extended Abstracts from
International Symposium on
Middle Atmosphere Dynamics
and Transport
July 28 - August 1, 1980
Urbana, Illinois

Edited by

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June 1981

Copies available from SCOSTEP Secretariat, University of
Illinois, 1406 W. Green Street, Urbana, Illinois 61801

MEASUREMENTS OF STRUCTURAL FEATURES IN PROFILES OF MESOSPHERIC DENSITY

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ABSTRACT

Recent measurements using a higher sensitive piezoelectric accelerometer in a falling sphere have been examined to study the detail structure features in vertical profiles of the mesospheric density. The measurements have a vertical resolution of about 100 meters through the mesosphere. Features with scale sizes of 500 meters or larger and amplitudes greater than 1% could be perceived in the data. The minimum structure scale size observed in the 60 km region has been about 1.5 km and in the 90 km region about 3 km. The vertical scales of the atmospheric density structures have been examined for consistency with those expected for gravity waves and tidal features in the region between 50 and 120 km. The measurements have also been examined to define those regions that would be statically unstable based on the logarithmic density gradient being less than the density adiabat. In the few sets of high resolution measurements obtained to date, all have exhibited regions of static instability which are probably associated with layers of intense turbulence in the mesosphere.

INTRODUCTION

The measurements of the dynamical properties in the middle and upper atmosphere are basic for making the next major advances in understanding and modeling of the atmosphere. Several techniques for ground-based monitoring of features associated with atmospheric dynamics using radars, *Gage and Balsley* [1978], *Röttger et al.* [1979], *Gibbs and Bowhill* [1979], and LIDAR techniques, *Juramy et al.* [1980] and *Richter and Sechrist* [1978], are just now beginning to provide major contributions to this problem. In order to place the ground-based measurements on a firm foundation for interpretation of various parameters that describe the dynamical state, it is necessary that high resolution *in situ* measurements be performed. The techniques which have been used to analyze high resolution measurements of the electron and ion density, *Thrane and Grandal* [1980], and chemical releases, *Zimmerman et al.* [1978], will be important to developing the understanding. However, a recently developed technique for measuring the small scale structure in the neutral density, temperature and wind should also be important for determining the *in situ* dynamic properties.

The results from a recently developed high resolution piezoelectric accelerometer technique will be briefly described in this report. The experiment technique has been described previously, *Philbrick et al.* [1978a]. The experiment consists of an accelerometer with three concentric proof masses suspended in cantilever fashion at the center of a 25 cm diameter sphere. The sphere containing all of the electronics, telemetry and tracking systems is released from a rocket payload at an altitude of approximately 70 km and measurements are made to altitudes between 40 and 50 km on downleg of the trajectory. The sensitivity of the instrument is sufficient that quality measurements can be obtained to altitudes in excess of 160 km. The mass distribution within the sphere is adjusted so that it is highly stable at the 6 RPS spin rate. The spin plane accelerometer axes experience very little drag acceleration associated with the vertical velocity of the payload on upleg of the flight. However, the upleg measurements are very sensitive to the horizontal wind and the horizontal rocket velocity. By assuming that the wind and density field is uniform over the ∿ 30 km distance between upleg and downleg, it is possible to derive unique profiles for the density and wind components. The density profile can be used to derive a temperature profile under the assumption of hydrostatic equilibrium and the ideal gas law. The vertical resolution of the measurements is about 100 meters in the mesosphere.

The density is determined from the drag acceleration through the relationship,

$$\rho = \frac{2\, a_D m}{V^2 C_D A}$$

where the mass, m, and the cross section area, A, are accurately known and the velocity, V, is determined from the trajectory. The largest sources of error in the density determination are associated with the drag coefficient, C_D, which is known to about 3% in the mesosphere and about 5% in the thermosphere; the determination of the spin axis direction in space, ∿ 1° which translates to 2%; and the altitude assignment given to the measurement points, a 60 meter error translates to ∿ 1% error. The absolute accuracy of the density measurements should be of the order of 5% in the mesosphere and the relative profile should be accurate to a fraction of a percent for observations of structure over distances of several kilometers.

MEASUREMENT RESULTS AND ANALYSIS

A set of measurements was obtained at Red Lake, Canada as part of the Solar Eclipse Program on 26 February 1979. The preliminary results from those measurements of density and temperature are shown in Figures 1 and 2. Figure 1(a) shows the measured density profile compared to the USSA 76 model and 1(b) the corresponding temperature profile. In Figure 1(c) the density measurements are given as a ratio to the model values in order to observe the detail structure. Each point represents a unique determination of density calculated for each half spin cycle of the

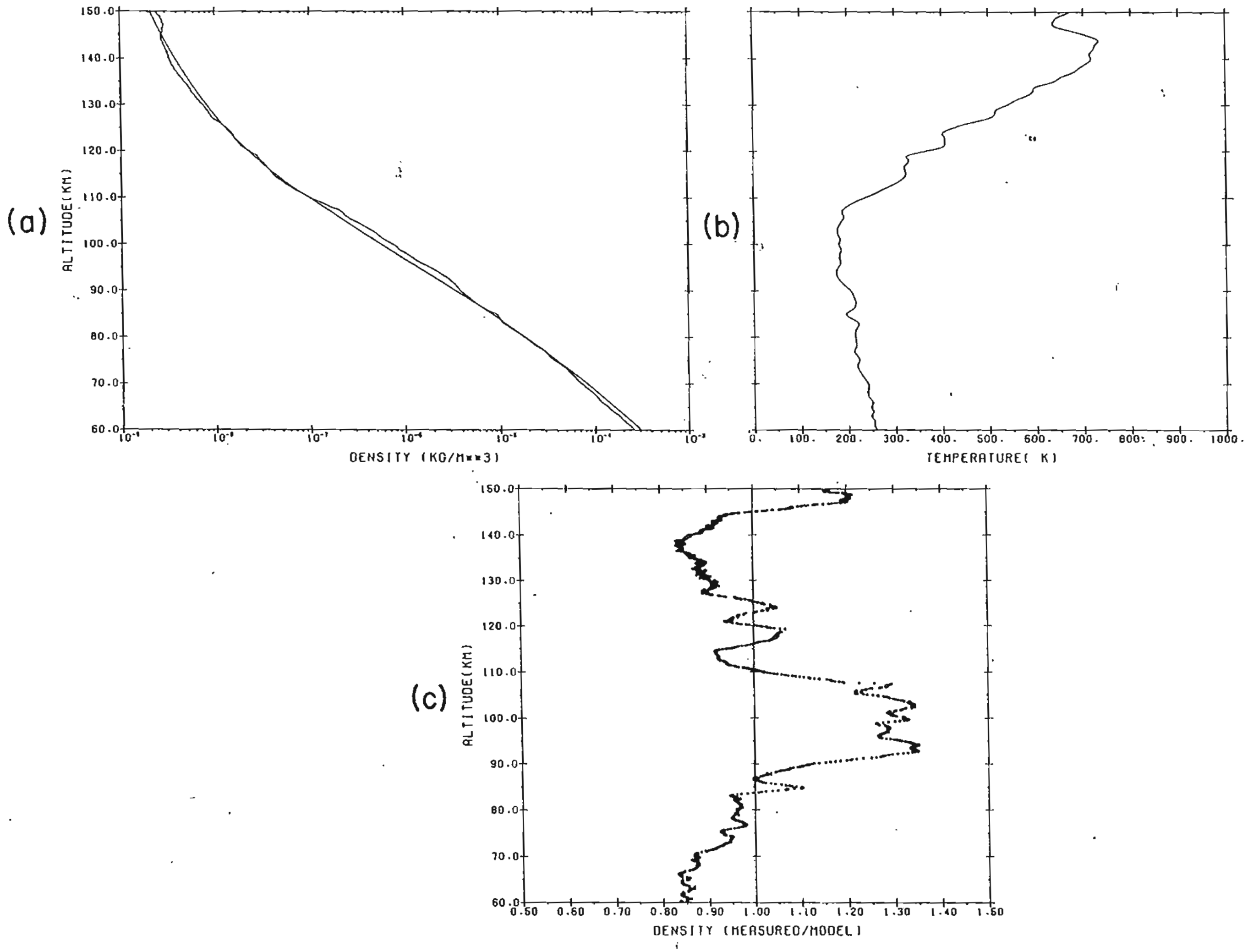

Figure 1. (a) Density measurements during the solar eclipse program, 26 February 1979, Red Lake, Canada, compared to USSA 76 model. (b) Temperature profile derived from density measurements of (a). (c) Density measurements of (a) ratio to USSA 76 model.

sphere. Figure 2 shows the measurements of the wind speed and direction and calculations of the Richardson number. The very high wind speeds are probably associated with the effects of the strong geomagnetic storm which was in progress. The wind direction is shown relative to the plane of the trajectory and 157° would correspond to a Northward wind vector. The Richardson numbers were calculated from the temperature and wind measurements to identify those regions where turbulence is likely to exist, the regions where $R_i \leq \frac{1}{4}$.

Figure 3 indicates a way in which statically unstable regions can be identified from density profiles. The mean density gradient described by the USSA 76 model is between the 12 and 18% per kilometer. If the logarithmetic density gradient is less than g/C^2, where g is the acceleration of gravity and C is the speed of sound, then the region would be expected to be statically unstable, i.e. unstable from the density gradient alone and independent of the wind field [*Philbrick et al.*, 1980]. The difference between the mean density gradient and the statically unstable condition is between 3 and 4% per kilometer through the mesosphere. Thus, in a profile such as Figure 1(c), it is possible to identify those regions with positive slopes greater than about 4% per kilometer as unstable layers. This would be the case in the regions 83 to 85 km, 87 to 92 km and 98 to 100 km. Indeed when a comparison is made with Figure 2(c), the regions centered at 90 and 99 km exhibit a low Richardson number and correspond to statically unstable regions. The layer centered at 96 km in Figure 2(c) corresponds to a wind shear region (see Figure 2(b), and is associated with a region of dynamic instability.

The altitude resolution available with current techniques allows an examination of the gravity wave structure that may be present in the data. Figure 4 shows an analysis [*Philbrick et al.*, 1978] of the scale sizes of gravity wave structures that may be expected in the mesosphere, following the work of *Hines* [1974]. The curves indicate the region of expected scale sizes and periods, where a reasonable eddy diffusion profile [*Philbrick et al.*, 1973] has been considered. The minimum vertical scale size at 60 km would be about 1 km and at 110 km about 3 km. In Figure 5, three cases of high resolution measurements are considered. Figure 5(a) shows the results of an earlier accelerometer measurement [*Philbrick et al.*, 1978a]. Figure 5(b) shows the density profile derived from radar tracking of the hypersonic sphere [*Philbrick et al.*, 1978b]. Figure 5(c) shows an expanded plot of the data shown in Figure 1 but relative to a mean of the measurements rather than a model. In each of the cases of Figure 5, the vertical resolution was sufficient to observe structure scales of about 0.5 km. However, the minimum scale size observed near 60 km was about 1.5 km and near 100 km was about 3 km, consistent with the analysis of Figure 4.

The results which have been shown indicate the advances recently made in making *in situ* measurements of the structure and dynamical properties in the middle and upper atmosphere. The combination of the

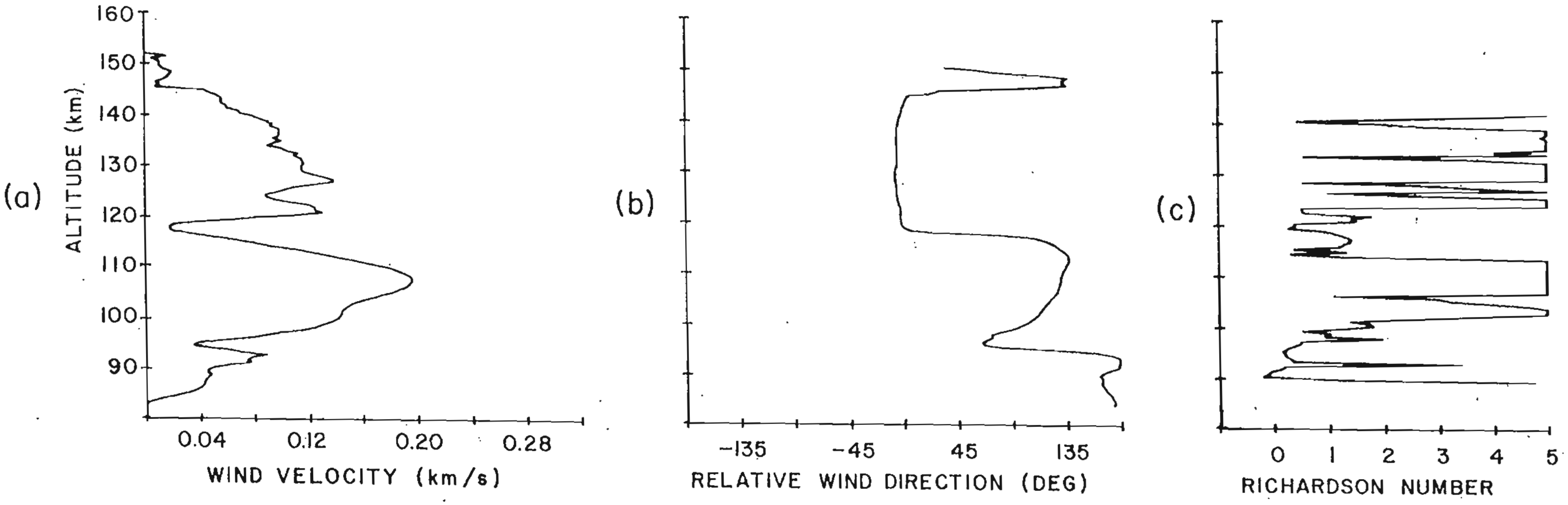

Figure 2. (a) Wind speed derived from accelerometer measurements during the solar eclipse program. (b) Wind direction measurements corresponding to (a), north corresponds to 150°. (c) Richardson numbers calculated based on the temperature and wind profiles of Figures 1(b), 2(a) and 2(b).

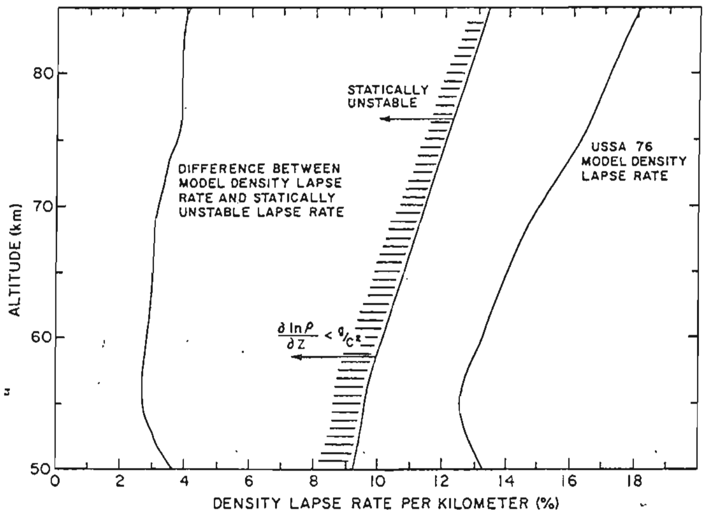

Figure 3. Density gradients for the USSA 76 model, static instability condition and difference.

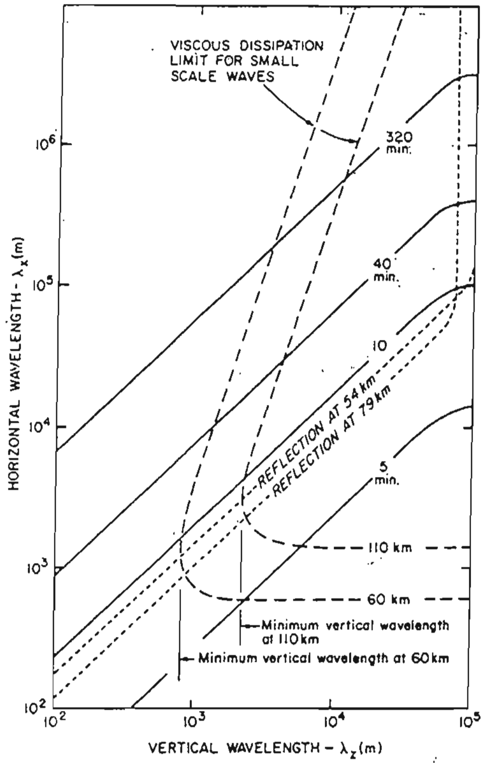

Figure 4. Wavelengths of propagating modes expected in the mesosphere and lower thermosphere after the analysis of *Hines* [1974]. The dashed lines represent the viscous dissipation limit for small-scale waves and the limits of scales for waves reflected back toward the ground. The range of permitted wavelengths lies in the upper right portion of the figure [*Philbrick et al.*, 1978b].

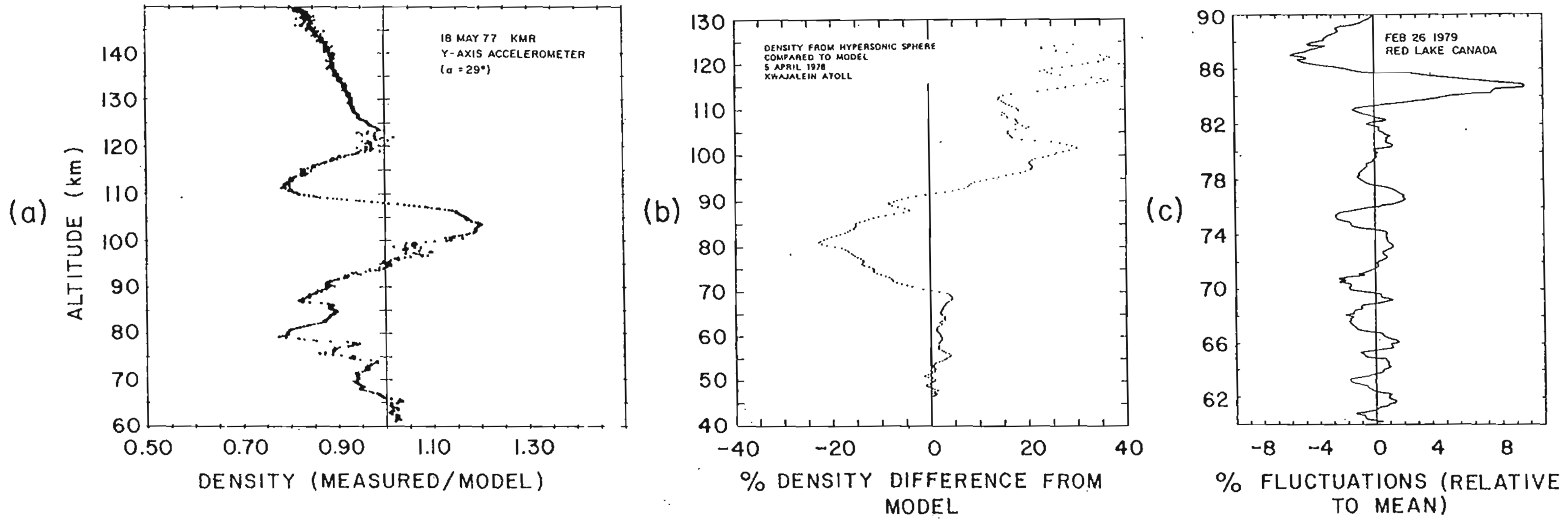

Figure 5. Accelerometer measurements of density show wave structure on 18 May 1977 at Kwajalein Atoll [*Philbrick et al.*, 1978a]. (b) Wave structure with increasing wavelength as a function of altitude measured by a hypersonic sphere [*Philbrick et al.*, 1978b]. (c) Wave structure in the data of the lower part of Figure 1 relative to a mean profile.

in situ measurements together with the continuous soundings of ground base measurements should add substantially to our understanding of the atmospheric dynamics during the period of the MAP operations.

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