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MESOSPHERIC DENSITY VARIABILITY

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ABSTRACT

Several sets of measurements of atmospheric density, temperature and winds in the mesosphere were obtained at Kwajalein Atoll, Marshall Islands, during the period 1976-1978. The measurements were made with inflatable passive spheres and accelerometer instrumented falling spheres. Comparisons of sets of measurements obtained over a period of a few hours frequently show relatively large density variability in one or more altitude regions of a few kilometers thickness. Richardson numbers, calculated from the wind and temperature data, have been used to indicate those regions where turbulent layers would be expected. The regions that exhibit a large variability between the density profiles correspond to the turbulent regions predicted by the stability calculations. The study indicates that the vertical thickness and persistence of the turbulent layers tend to increase with increasing altitude through the mesosphere.

INTRODUCTION

Measurements of the atmospheric density, temperature and winds in the mesosphere and lower thermosphere, 50 to 100 km, have historically shown a large variability when compared with either a model or a mean of several measurements (cf USSAS 1966 [1]). The available data in this region are limited because of the necessity of rocket probes to make in-situ measurements. In only a few cases have several measurements been made at time intervals of one to three hours in the same day. In examining several of these data sets, it has been found that changes in atmospheric density by as much as 20% may occur in periods of a few hours. These changes appear to occur in layers of a few kilometers in vertical thickness. An examination of several data sets has shown that the presence of large variability in density and temperature is also frequently correlated with regions of strong wind shears. The density structure and the wind shear act to destabilize the atmosphere and are likely to result in turbulent layers which gradually dissipate the structure features.

To examine the turbulent regions, the Richardson number (R_i) is calculated and values less than 1/4 are accepted as an indication of a turbulent regions. As will be shown, there are significant layers where R_i is negative, indicative of statically unstable regions of the atmosphere. These are differentiated from the dynamically unstable regions, where $0 < R_i \leq 0.25$, in the presence of significant wind shears. A statically unstable region occurs when the atmospheric lapse rate is negative and its magnitude is greater than the adiabatic lapse rate ($\Gamma = 9.8^{o}$K/km). When examining the density structure, this is also represented by the negative logarithmic density gradient ($\partial \ln\rho/\partial Z$) being smaller than the density adiabat (g/c^2), c being the speed of sound.

DISCUSSION

Atmospheric density measurements from two series of rocket flights at Kwajalein Missile Range ($\sim 10^{o}$N, 170^{o}E) are presented in Figures 1a and 2a. Most of these measurements were made using a one meter diameter inflated passive sphere (Robin sphere) which was tracked by radar to derive density, temperature and wind information in the 40 to 100 km region [2]. One of the profiles was obtained using an accelerometer instrumented falling sphere [3]. The density measurements are shown as a ratio to a monthly tropical reference atmosphere prepared by Cole and Kantor [4]. The profiles shown in Figure 1a exhibit a large density variability in the height regions 63 to 72 km, 77 to 82 km and 85 to 90 km. The density measurements near 80 km show a change of more than 20% during the 6 hour period. In Figure 2a, the density profiles obtained on 5 April 1978 are shown. These measurements show extremely small variation between 60 and 70 km. In the altitude region between 70 and 90 km, differences of up to 10% exist between the profiles, with the extremes mostly defined by the profiles identified as 2018 and 2021.

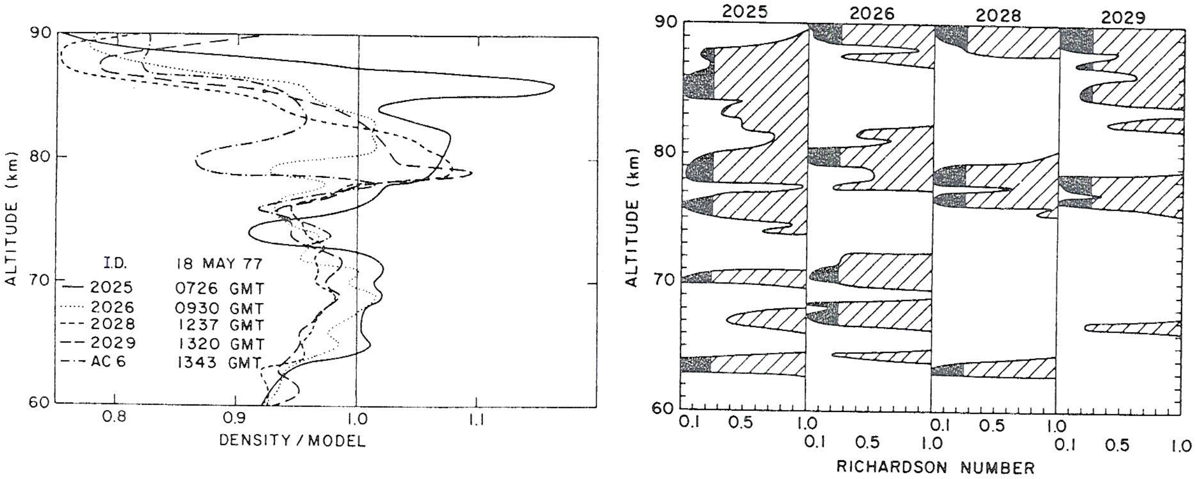

Fig. 1. Density measurements and Richardson numbers for falling sphere flights at Kwajalein Atoll on 18 May 1977. (a) The density measurements are shown as a ratio to the Cole and Kantor [4] tropical atmosphere for four Robin sphere flights and one accelerometer instrumented sphere (AC-6). (b) The Richardson numbers calculated from the temperature and wind measurements are shown for the range of values $0<R_i<1$ with the negative values ($R_i<0$) indicated at $R_i=0$.

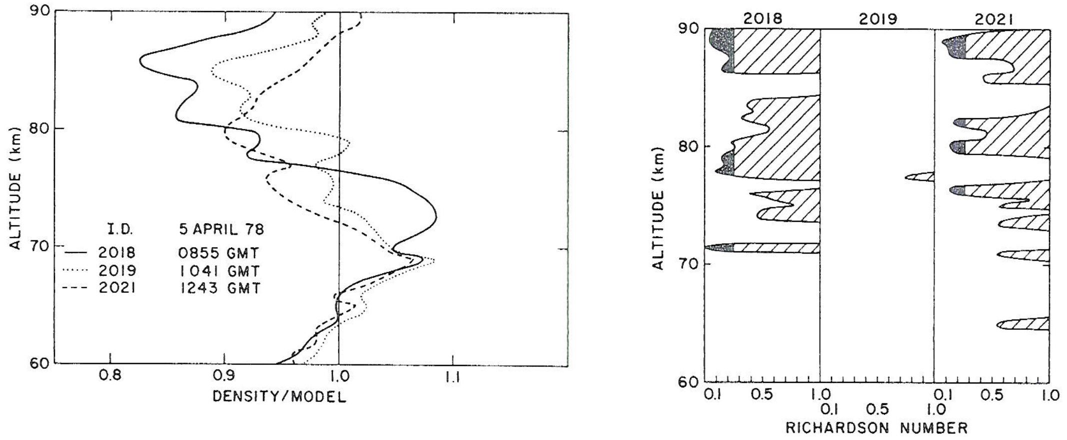

Fig. 2. The results obtained on 5 April 1978 are displayed as in Figure 1.

Corresponding to these density profiles, temperature profiles can be calculated by assuming hydrostatic equilibrium and the ideal gas law. The derived temperature profiles and the simultaneously measured wind profiles were used to calculate the Richardson number.

Figures 1b and 2b show the calculated Richardson numbers for the corresponding profiles. The calculated values are in the range from 0 to 1 with negative values indicated at zero. Those regions where the Richardson number is less than 1/4 are distinguished by shading. In Figure 1b, the height region between 63 and 72 km exhibits several layers with low Richardson numbers for the 2025 and 2026 measurements, and comparison to Figure 1a shows that those profiles are significantly different from the 2028 and 2029 profiles in this region. Note that the peaks of the turbulent layers, i.e. low Richardson numbers, correspond to regions where the 2025 and 2026 profiles are tending toward the later profiles which represent more stable conditions. The inference would be that between 0726 and 1237 GMT the turbulent layers worked to dissipate the large density structure, which resulted in a stable region between 63 and 72 km at later times. Between 78 and 82 km a persistent and intense layer of turbulence, which corresponds to the region of large density variability, would be indicted by the calculated negative Richardson numbers. Similar comparisons can be made by examining the measurements 2025 at 85 km and 2026, 2028 and 2029 in the region from 88 to 90 km. The turbulent layers indicated below 70 km correspond to regions where super adiabatic temperature lapse rates exist in each case. The region between 77 and 82 km contains both super adiabatic lapse rates and large wind shears (> 40 m/sec·km) in each of the flights. In the region from 85 to 90 km, a large wind shear exists coincident with each layer, and a few of these layers also contain large temperature lapse rates. In general, the temperature structure is most important for stability considerations below 70 km and both temperature structure and wind shear are important above 70 km.

Figure 2b indicates that the region of the atmosphere between 60 and 70 km should be stable and comparison with Figure 2a shows very small density variations. At higher altitudes several unstable regions are indicated but none are as intense as those of Figure 1b and, correspondingly, the density variations in Figure 2a are less than in Figure 1a. The region above 70 km shows density variations in the 2018 and 2021 profiles which are in general agreement with the indicated layers of turbulence. It is interesting to note that measurement 2019 would indicate a very stable atmospheric condition between the times of the 2018 and 2021 measurements and that the 2019 density profile generally represents a median of the two other measurements.

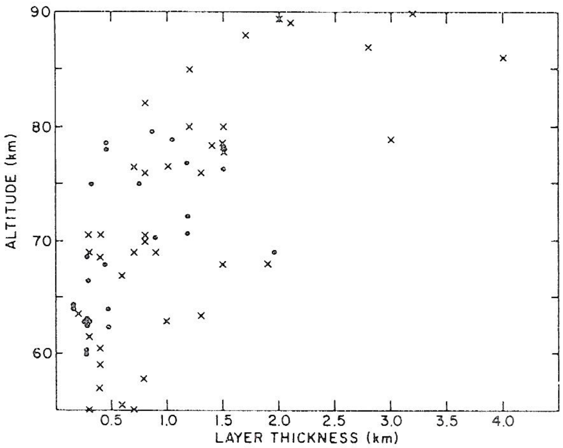

Fig. 3. The vertical thickness of turbulent layers observed in the mesosphere, from the Richardson numbers ($R_i \leq 1/4$) determined from falling sphere flights (X), and from VHF radar measurements (·) of Röttger and Rastogi [5].

The thickness of the turbulent layers, determined by the criterion $R_i \leq 1/4$, from these measurements are compared in Figure 3 with recent radar studies [5] obtained by the SOUSY-VHF Radar in West Germany during June 1978. The rocket probe and radar measurements of the turbulent layers agree well despite the coarsness of resolution of the rocket measurements. There is a definite tendency toward thicker layers of turbulence in the upper portion of the mesosphere. Typically the thickness is less than 1 km near 60 km but may increase to as much as 4 km at 90 km.

CONCLUSIONS

Altogether six sets of measurements have been examined, and the following conclusions have been reached. Regions which exhibit significant structural features in the density profile tend to show the largest variations when a sequence of measurements is made. Those regions also appear well correlated with either large temperature lapse rates and/or with large wind shears, thus implying a reduction in atmospheric stability. The instabilities most likely result in turbulent layers being formed, which tend to dissipate the density structure. The temperature lapse rates appear to be more important for stability conditions in the lower mesosphere, and the wind shears appear to be more important in the upper mesosphere. The thickness and the persistence of the turbulent layers tend to increase as the altitude increases through the mesosphere.

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