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16.Summary/Notes
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## Abstract

Lidar observations of the mesospheric sodium layer, made at São José dos Campos ($23^{o}S$, $46^{o}W$), show three distinct types of organized structure in the vertical distribution of sodium. Profiles averaged over several days show a smooth but assymmetrical distribution. A sequence of profiles for a given night normally shows a wavelike structure which descends through the layer with time. Very occasionally an extremely narrow peak is observed at a constant height for several hours. On one occasion a layer 2.5 Km wide, with scale heights of 700 m on the bottom-side and 900 m on the top-side, was observed to persist at a constant height for three hours. It is concluded that such a layer could neither be produced by neutral density perturbations nor by photochemical processes and therefore indicates a source of sodium in the mesosphere.

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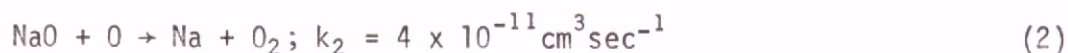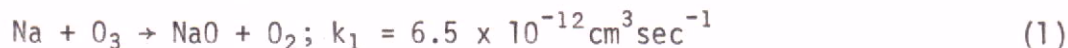12200 - São José dos Campos, SP, Brasil

## 1. Introduction

The source of the mesospheric sodium layer has been the subject of speculation ever since the existence of the layer was first determined from twilight spectroscopy. It is generally believed that the sodium is either extra-terrestrial in origin or comes from the surface of the sea, reaching mesospheric heights via meteorological processes. The possibility of a volcanic source has been rejected on the grounds that the very large long term variations in volcanic injection into the atmosphere, as evidenced by variations in the stratospheric aerosol burden, are not reflected in the sodium layer (Junge et al, 1962).

Independently of the origin of the sodium in the mesosphere, it appears that it reacts with other species, principally atomic oxygen and ozone, so that the vertical distribution of these species should influence the distribution of free sodium. Although a number of possible reaction schemes have been suggested, oxidation to NaO by ozone and reduction of the oxide by atomic oxygen, first suggested by Chapman (1939), seems to be the most probable one mainly because the estimated rates for other reactions are much too slow. Unfortunately the relevant reaction rates

have not been measured, but are estimated from the analogous hydrogen reactions. The reactions involved are the following:

$$Na + O_3 \rightarrow NaO + O_2; \quad k_1 = 6.5 \times 10^{-12} cm^3 sec^{-1} \tag{1}$$

$$NaO + O \rightarrow Na + O_2; \quad k_2 = 4 \times 10^{-11} cm^3 sec^{-1} \tag{2}$$

In equilibrium, therefore, we get

$$k_1 [Na] [O_3] = k_2 [NaO] [O] \tag{3}$$

Where the square brackets indicate number density. The rate coefficients are from Hunten (1967).

If we assume equilibrium conditions, with no sources or sinks in the mesosphere, then the mixing ratio, R, of total sodium, i.e. Na + NaO, should be independent of height, and therefore we may write

$$[Na] + [NaO] = R \rho \tag{4}$$

where $\rho$ is the atmospheric number density. In fact ionization may be important on the topside of the layer and other reactions, particularly with $O_2$, might be relevant below 80 Km, but equations 2 and 4 should at least give us a first approximation to the shape of the sodium layer.

Using summer midnight atomic oxygen and ozone profiles from Shimazaki and Laird (1972), and total density from the U.S. standard atmosphere supplements (1966), we calculate the height variation of sodium shown in Figure 1, curve (a), where we have normalised to a density of $4 \times 10^3 cm^{-3}$ at 94 Km. In Figure 1, curve (b), we show the average distribution measured at São José dos Campos

($23^{\circ}$S, $46^{\circ}$W). In view of the lack of agreement it is clear that one or more of our assumptions are wrong. In order to make the equilibrium distribution resemble the measured layer, the ratio $k_1/k_2$ would have to be increased by a factor of $10^4$.

In recent years a number of workers have tried to explain the shape of the layer on the basis of a source layer near to the peak, with a generally unspecified sink at lower heights.

Donahue (1966) has suggested that the sodium evaporates from a mesospheric aerosol layer, and Fiocco and Visconti (1974) have calculated the evaporation rate from such a layer. The latter workers have also shown that the concentration gradient required for the upward diffusion of an adequate number of particles from the lower atmosphere would lead to an unacceptably large particle concentration at lower altitudes. They also considered the possibility of a vertical wind, but encountered the serious problem that if the layer is produced by such a wind its height would vary considerably with time, and, of course, an upward wind could not exist at all latitudes and seasons. According to Fiocco and Visconti a height variation of a few kilometers would result in a factor of ten variation in the sodium density, so it seems that the vertical wind hypothesis is untenable.

Even if we accept that a vertical wind might occasionally lead to layer formation, it is difficult to see how a very thin layer could be produced. Fiocco and Visconti (1974) obtain a layer 6 Km wide for reasonable atmospheric conditions and a monodisperse aerosol. Clearly a

realistic particle size distribution would result in a wider layer. The
purpose of this paper is to report the observation of an extremely narrow
layer, involving scale heights of less than 1 Km, which persisted for
several hours. We believe that such a layer could not result from
terrestrial sources of sodium, and its observation therefore supports
the hypothesis that, at least on some occasions, an influx of extraterrestrial
particles contributes to the sodium layer.

## 2. Observations and Discussion

The sodium distribution shown in Figure 1, curve (b), is
the average of a large number of observations made over a period of five
years. Individual profiles frequently show a much more complicated
structure, generally found to propagate downwards with time. It has been
suggested that this structure is caused by gravity waves (Blamont et al,
1972) and/or tides (Kirchhoff and Clemesha, 1973). In Figure 2 we show
an example of such a propagating peak observed on July 11, 1977. The
structure descends through the layer at a rate of 2 Km $hr^{-1}$, passing
through the peak of the layer at about 2300 LST, at which time the peak
sodium density reaches a value of $1.4 \times 10^{10} m^{-3}$, and the abundance is
$8.5 \times 10^{13} m^{-2}$. We wish to contrast the behaviour of the sodium layer on
July 11, 1977 with that observed on April 19, 1976, shown in Figure 3.
On this occasion, observations were made from shortly after sunset until
0030 LST, when cloud cover intervened. During the greater part of this
time most of the sodium was contained in an extremely narrow layer centered
on 92 Km. Our measurements are usually made with a height resolution of
2 Km, but on this occasion three profiles were taken with 1/2 Km range

bins, at 2013, 2058 and 2132 LST. The average of these three profiles
is shown in curve (a) Figure 4. This profile, an average corresponding
to a period of about 90 minutes, shows a full width of 2.5 Km between 1/e
points, and scale heights of 700 m on the bottomside and 900 m on the
topside. For the sake of comparison we also show in Figure 4, curve (b),
the half hour average profile centred on 2300 LST, July 11, 1977, when
the descending structure is passing through the height of peak sodium
density, and in curve (c) we have repeated the average from Figure 1,
curve (b). We have not included typical error bars for curves (b) and
(c) since they are much smaller than for curve (a). For curve (b) the
width of the layer is 6 Km, the bottomside scale height is 1.8 Km and the
topside scale height is 2.9 Km. It should be emphasized that this is an
extreme example of a descending peak; we do not normally observe such large
peak densities, nor such steep gradients. The width of the average layer
shown in curve (c) is 14 Km.

The narrow peak observed on April 19, 1976, differs from
the descending structure which we normally observe in that it remains at
a constant height for at least five hours, and involves much steeper
gradients of sodium density. There appears to be no way in which this
layer could have been produced by photochemical processes; even if we were
to accept that the rate coefficients are in gross error, the ozone and
atomic oxygen profiles needed would be entirely unrealistic. Two possible
explanations suggest themselves: either the layer was generated by
windshear layering of $Na^+$ ions, which subsequently recombined to produce
neutral sodium, or it was generated by a thin layer meteoric source.

The possibility of windshear concentration of sodium ions,

and their subsequent recombination to produce a layered structure in the
neutral sodium layer, has been suggested by Blamont et al (1972). These
workers suggested that the downward propagating structure observed in
the sodium layer could be produced by this mechanism. Under suitable
circumstances this might lead to the build-up of an ion layer at a constant
height by the dumping mechanism of Chimonas and Axford (1968). On the
other hand, rocket borne mass spectrometer measurements of $Na^+$ generally
indicate rather small concentrations, and it appears that the $Na/Na^+$
ratio is typically of the order of 50 (Donahue, 1969). Megie (1976)
has made a theoretical investigation of the possibility of windshear
concentration of $Na^+$ and finds that the mechanism should have negligible
effect on the neutral sodium distribution.

Strong evidence that the descending structure is not
related to wind shear concentration of ions can be found in simultaneous
observations of the sodium distribution and nightglow. Clemesha et al
(1978) have shown that the sodium density in the region of 88 Km is
highly correlated with the sodium nightglow and that the correlation
results from perturbations of the sodium layer propagating downwards
through the emission region. We have also made simultaneous observations
of the OH(8,3) band intensity and the sodium density and find a similar
correlation, but with the density at 84 Km, the expected OH emission
height. Clearly this correlation with OH, the excitation of which does
not involve ionized species, could not be related to wind shear layering
and must result from perturbations in the neutral density. It appears,
then, that the descending structure is not produced by wind shear.
Having shown that wind shear layering of $Na^+$ ions is not involved in the

normally observed descending structure in the sodium layer, it is clear
that the narrow layer observed on April 19, 1976, involving much steeper
gradients, is most unlikely to have been caused by this mechanism.

On the basis of the above discussion we conclude that the
observed sodium distribution could only have resulted from a thin layer
source  and that such a source could not be terrestrial in origin.  The
source involved could either be a thin layer of particles of extraterrestrial
origin  or could be due to the direct ablation of meteoric particles.
In either case the thinness of the layer requires that the particles
should have a very narrow size distribution and should all enter the
atmosphere with the same vector velocity.  This suggests cometary
particles small enough to be dispersed by radiation pressure and not
necessarily associated with a visible meteor shower.  It is tempting to
connect the appearance of a thin sodium layer on April 19 with the Lyrid
meteor shower which is normally seen between April 20 and April 22.  At
our latitude and longitude, however, the shower radiant would be above
the horizon only between about 2300 LST and 0900 LST.  If the layer was
formed during meteor deposition this would require it to have persisted
for at least 12 hours, in which time it would have been destroyed by diffusion.
It is always possible, of course, that the layer resulted from the day-
time evaporation of sodium from a thin aerosol layer related to the
Lyrid meteor shower.  A second objection, which also applies to the
aerosol mechanism, is that the influx would have to have occurred during
the early morning of April 19, which is outside the period during which
the Lyrids are normally seen.  It should also be noted that measurements
made on the following day, April 20, showed a normal sodium distribution.

If, as we suggest, the layer resulted from an influx of particles caused by the passage of the earth through the orbital plane of a comet, then we might expect to see similar effects on the same date in other years. Observations made on April 18 qnd 22, 1974, and April 18, 19 and 22, 1975, showed no unusual effects, but a sequence of 8 nights from April 14 to April 21, 1978, showed a large increase in sodium abundance between the 18th and 19th. Observations were made for a period of approximately 2 hours on each night, shortly after sunset, and the average profiles obtained are shown in Figure 5. From the 15th till the 18th the abundance steadily decreased, reaching the unusually low average value of $1.29 \times 10^{13} m^{-2}$ on the 18th. On the next day, April 19, the abundance had increased, by a factor of 4.4, to $5.7 \times 10^{13} m^{-2}$. An increase by so large a factor from one day to the next is uncommon, but has been observed on other occasions, and it should also be noted that the abundance was unusually low on April 18 rather than unusually high on the 19th.

Although the total abundance measured on April 19, 1978, is normal for the time of the year, the vertical distribution is unusual. As may be seen from Figure 5, the distribution shows a narrow peak centred on 95 Km. This peak is by no means so pronounced as that observed in 1976, and similar structures have been observed, although infrequently, on other occasions. We have, then, two unusual phenomena occuring simultaneously on April 19, 1978. Neither of these phenomena, taken by itself, can be considered as conclusive evidence for a sodium influx, but the coincidence of a large increase in abundance with a narrow layer at 95 Km strongly suggests that such an influx did in fact take place.

Returning to the layer observed in 1976, it does not seem to be possible to distinguish between the dust layer and ablation theories. If the layer had been observed to grow during the night, the dust layer hypothesis would be ruled out because the evaporation rate in the absence of sunlight would be too slow; the layer was, however, fully formed when observations were commenced shortly after sunset.

The change in the shape of the layer after 2200 LST suggests the effects of diffusion. A lifetime of 3 hours for a 700 meter scale height indicates an upper limit for the diffusion coefficient of the order of 50 $m^2$ $sec^{-1}$, which although perhaps somewhat lower than is usually accepted for this height, is not unreasonable. The molecular diffusion coefficient at 93 Km is about 20 $m^2$ $sec^{-1}$. The maintenance of the thin layer over a period of 3 hours does not, therefore, necessarily indicate the operation of a source throughout this time period. It is interesting to note nevertheless, that Megie (1976) has observed large nocturnal increases in sodium abundance on days of known meteor shower occurence. Such nocturnal increases point to the evaporation of sodium from ablating meteors, rather than a dust layer. Although we have made a large number of observations of the sodium layer we have not seen any meteor shower correlated increases in the abundance. This could be due to the fact that the hour-to-hour and day-to-day variations which we normally see appear to be somewhat larger than those measured at higher latitudes; on July 11, 1977 for example, the sodium abundance falls by a factor of 4.5 in less than four hours. Although this is an extreme example, changes by a factor of 2 are quite common, and variations of this magnitude would undoubtably tend to mask the effect of meteor showers.

## 3. Conclusions

On April 19, 1976, a sodium layer only 2.5 Km thick was observed at a constant height for over three hours with scale heights of 700 m on the bottomside and 800 m on the topside. This distribution is quite different from the normally observed layer structure, believed to result from neutral density perturbations caused by tides and gravity waves. For the layer to have been produced by photochemical processes, unacceptable distributions of ozone and atomic oxygen would be required, and it is therefore suggested that a thin source layer was involved. There appears to be no way in which so thin a layer could have been produced by the vertical transport of particles from the sea surface, and its existence is, therefore, taken as evidence that the sodium was of extra-terrestrial origin.

## Acknowledgements

## References

Blamont, J.E., M.L. Chanin and G. Megie.   Vertical distribution and
temperature profile of the nighttime atmospheric sodium layer by laser
backscatter,  Ann. Geophys. 28, 833-838, 1972.

Chapman, S.  Notes on atmospheric sodium.  Astrophys. J., 90, 309-316,
1939.

Chimonas, G. and W.I. Axford.  Vertical movement of temperate-zone
sporadic E layers, J. Geophys. Res., 73, 111-118, 1968.

Clemesha, B.R., V.W.J.H. Kirchhoff and D.M. Simonich.  Simultaneous
observations of the Na 5893Å nightglow and the distribution of sodium
atoms in the mesosphere, J.Geophys. Res. In press. 1978.

Donahue, T.M.  On the ionospheric conditions in the D region and lower
E region, J. Geophys. Res, 71, 2237-2242, 1966.

Donahue, T.M.  Positive ion chemistry of the D-region, in "Meteorological
and chemical factors in D-region aeronomy", pp. 286-294, Aeronomy
Report No. 32, Aeronomy Laboratory, Dept. of Electrical Engineering
University of Illinois, 1969.

Fiocco, A. and G. Visconti.  Origin of upper atmospheric Na from
sublimating dust: a model, Ann. Geophys., 30, 517-528, 1974.

Hunten, D.M.  Spectroscopic Studies of the twilight airglow, Space
Sci. Rev., 6, 493-573, 1967.

Junge, C.E., O. Oldenberg and J.T. Wasson.  On the origin of the sodium
present in the upper atmosphere, J. Geophys. Res., 67, 1027-1039,
1962.

Kirchhoff, V.W.J.H. and B.R. Clemesha.  Atmospheric sodium measurements
at $23^{o}$S., J. Atmos.Terr. Phys., 35, 1493-1498, 1973.

Megie, G.  Contribution a l'étude du comportement de l'atmosphere à la
mésospause obtenue par sondage laser du sodium, Ph.D. Thesis,
Université Pierre et Marie Curie, Paris, France, 1976.

Shimazaki T. and A.R. Laird.  Seasonal effects on distributions of
minor neutral constituents in the mesosphere and lower thermosphere,
Radio Sci., 7, 23-43, 1972.
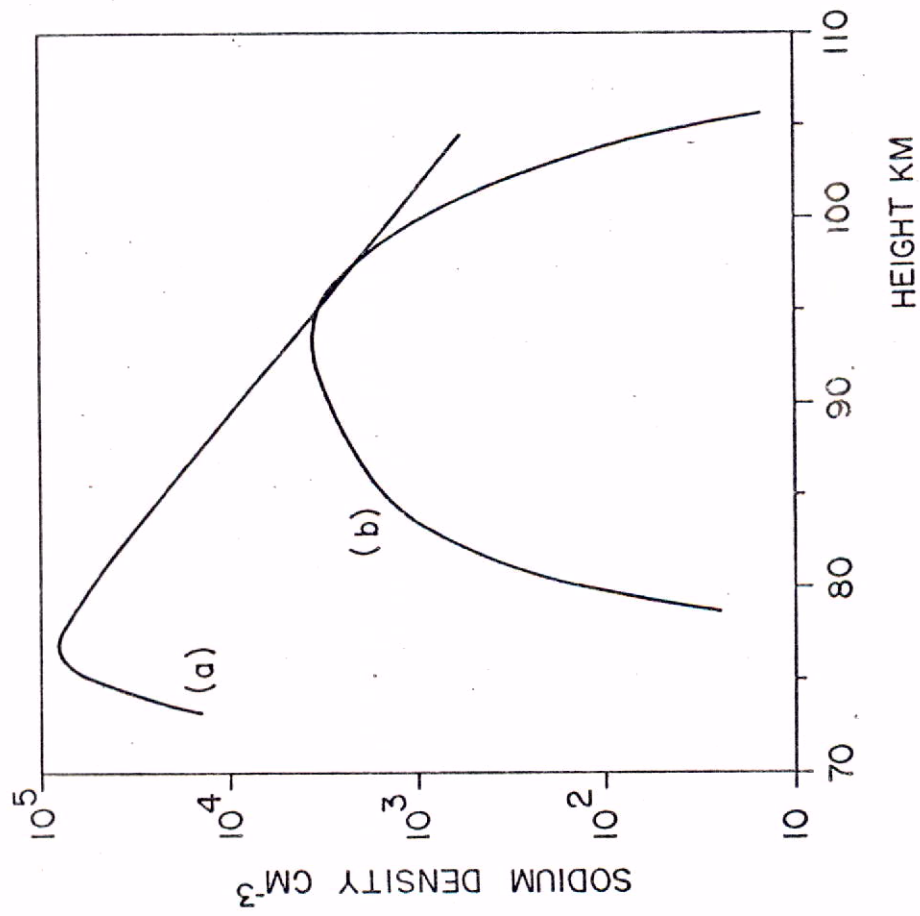
Figure Captions

Fig. 1 (a) Sodium distribution for chemical equilibrium and constant
        mixing ratio of total sodium. (b) Yearly average sodium
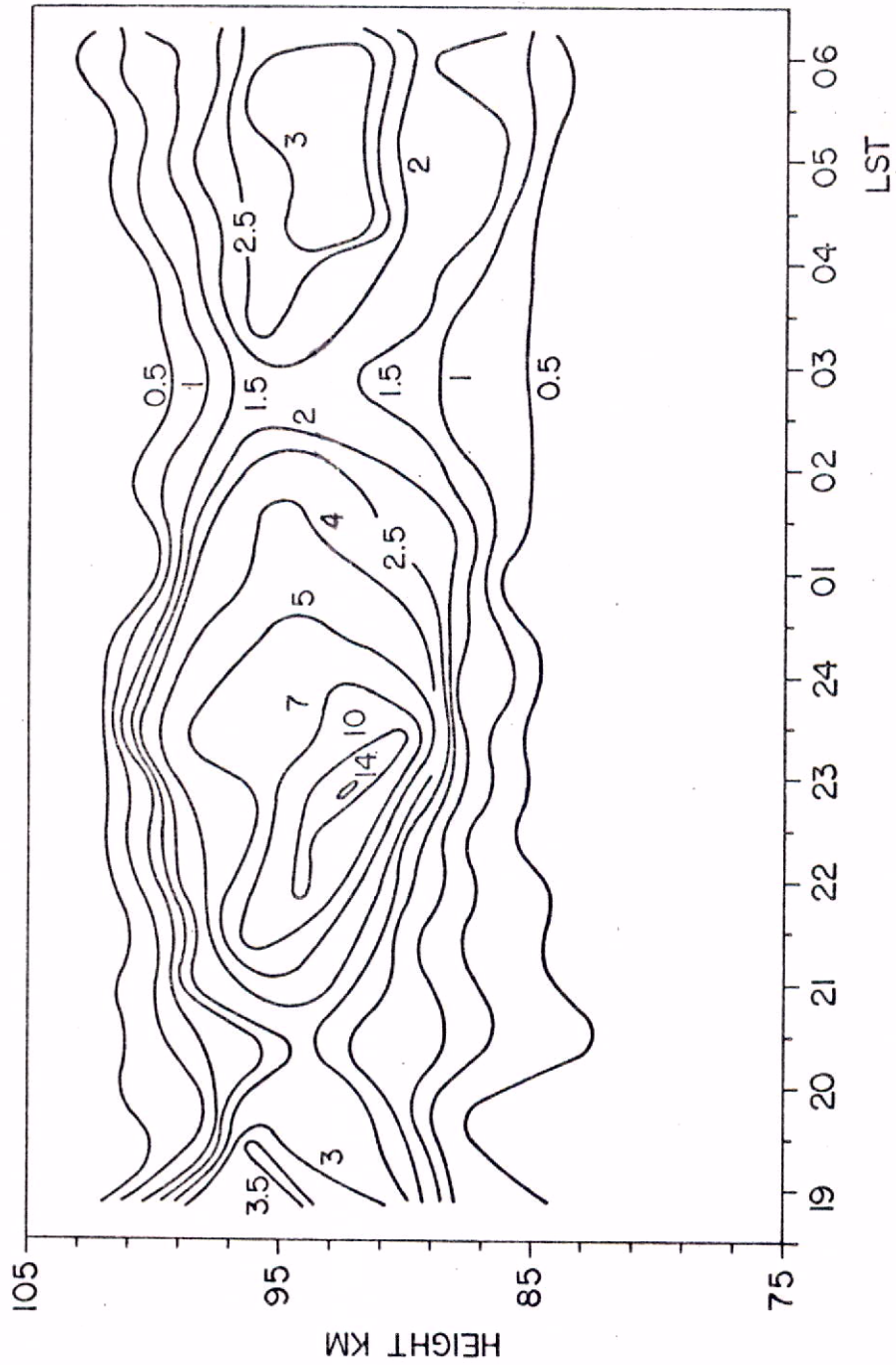        distribution measured at São José dos Campos.

Fig. 2 Nocturnal variation of the vertical distribution of sodium,
        July 11, 1977. The contours are labelled in units of $10^3$ $cm^{-3}$.
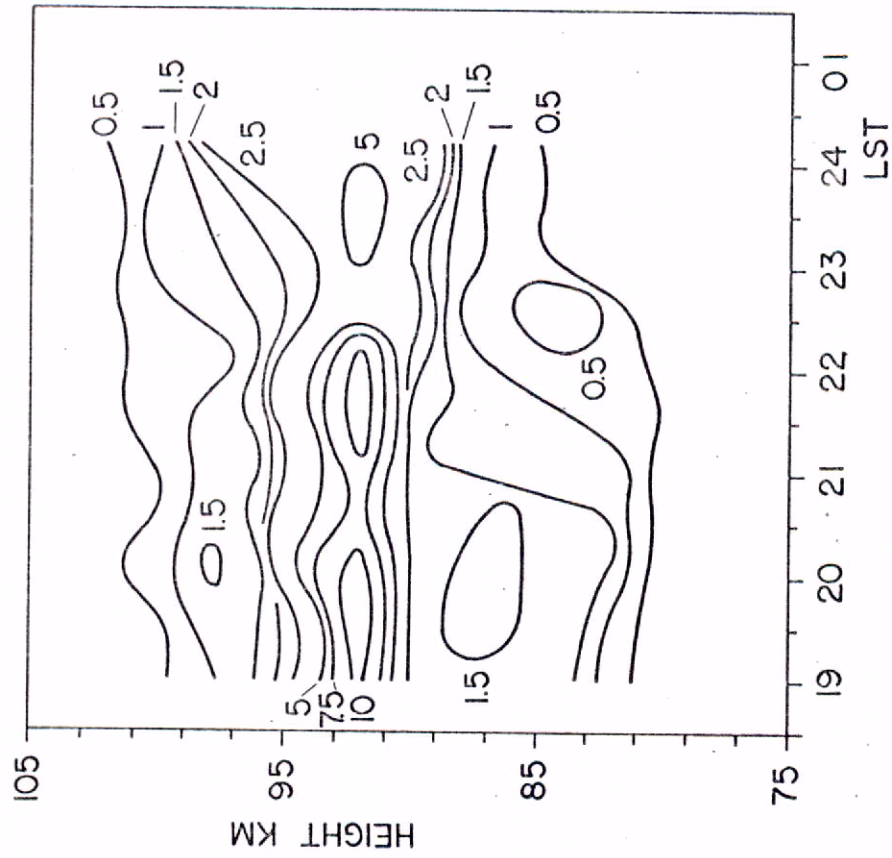
Fig. 3 Nocturnal variation of the vertical distribution of sodium, April
        19, 1976. The contours are labelled in units of $10^3$ $cm^{-3}$.

Fig. 4 (a) Average of 3 high resolution sodium profiles taken at 2013,
        2058 and 2132 LST, April 19, 1976. (b) 30 minute average profile
        for 2300 LST, July 11, 1977. (c) Yearly average profile
        repeated from Figure 1.

Fig. 5 Average sodium profiles for 8 days from April 14 till April 21,
        1978.

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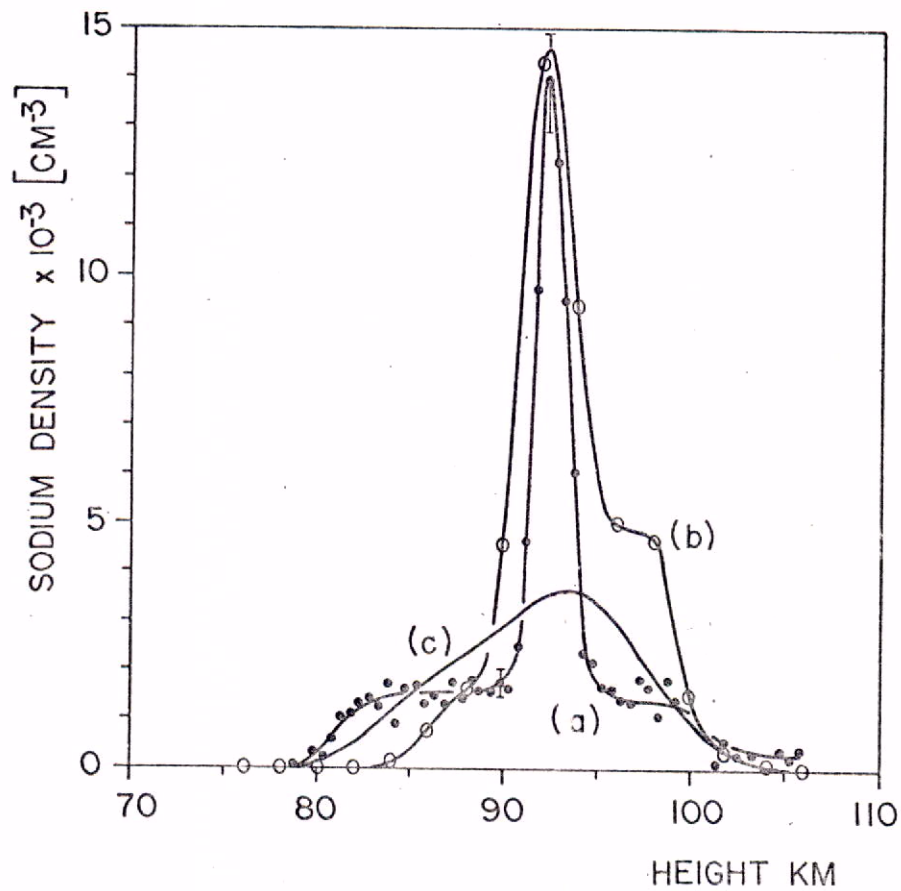
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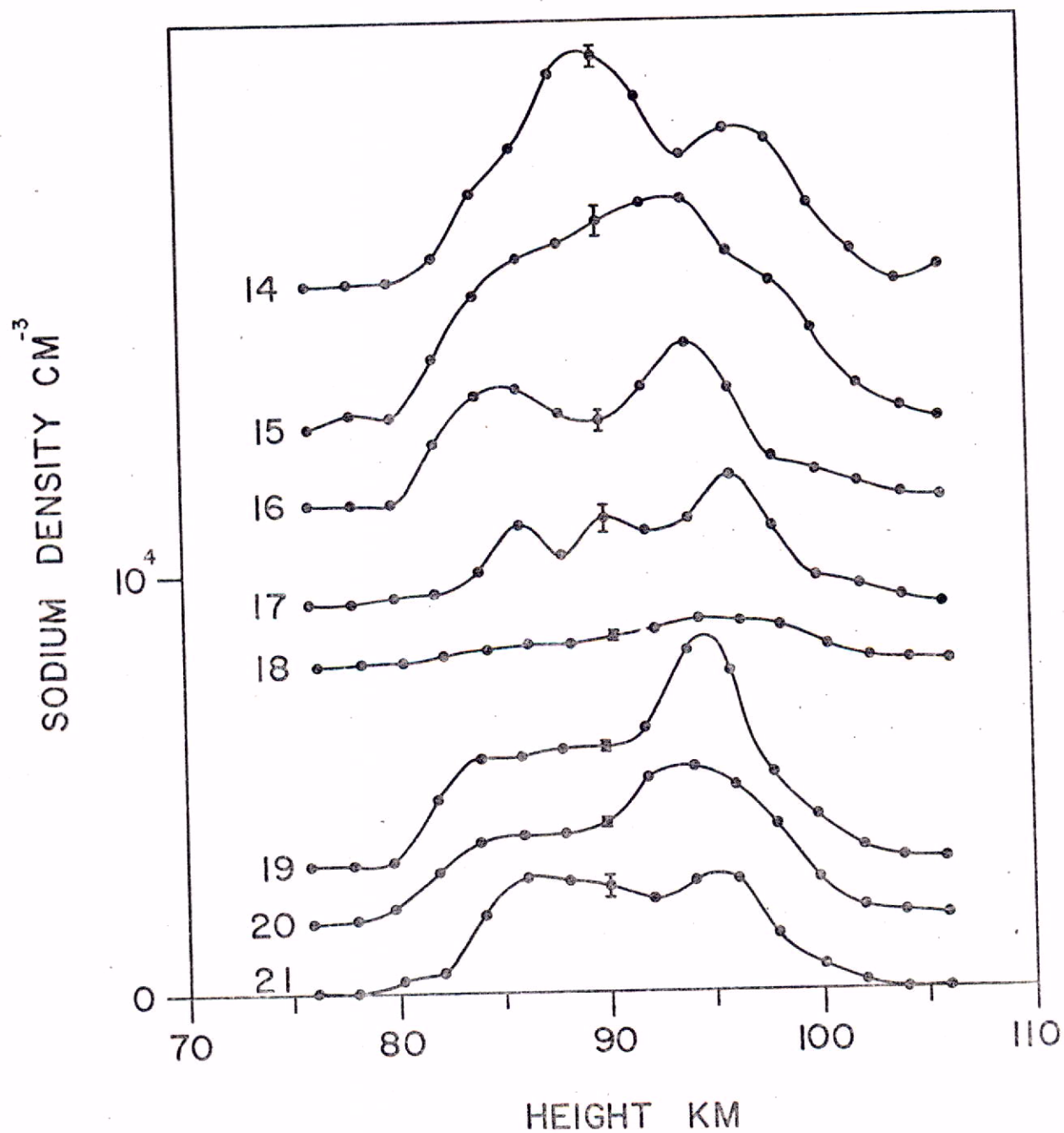average profile repeated from Figure 1.

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