# Utilization of 100 mb Midlatitude Height Fields as an Indicator of Sampling Effects on Total Ozone Variations

A. J. MILLER, R. M. NAGATANI, J. D. LAVER AND B. KORTY

*NOAA, NMC, Upper Air Branch, Washington, DC 20233*

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A major question concerning the observed long-term changes of zonal average total ozone has always been that the spatially limited ground-based ozone sampling sites are susceptible to a sampling problem. That is, the regional (or station) averages are influenced by shifts of the ozone wave patterns with respect to the sites such that a trend may be indicated that is not necessarily indicative of the actual zonal average. In order to help determine whether these sampling errors are short-term random features or have long-term components, we have utilized available synoptic analyses of the 100 mb height patterns (1964–76) and the observation that the 100 mb heights and total $O_3$ patterns in the midlatitudes of the Northern Hemisphere are negatively correlated. Accordingly, the ridge-trough patterns in the 100 mb height field at 50°N from 1964–76 are sampled over the domain of the ground-based $O_3$ observing sites and a zonal average of 100 mb heights calculated using the area-weighting functions of Angell and Korshover. These zonal averages are compared with the actual zonal average computed from all data and the results noted as a function of time. Utilizing linear 100 mb height–total $O_3$ regression relationships, the zonal average total ozone sampling error is on the order of ±2% for midlatitudes of the Northern Hemisphere with a long-term component. With this result, the general shape of the midlatitude $O_3$ trends determined from the ground-based observations appears to be real and not an artifact of the spatially limited ground-based sample. In fact, the increase of ozone from the mid-1960's to early 1970's may be even greater than previously suggested.

## 1. Introduction

It has long been recognized that the atmospheric total ozone is not a static quantity and that significant changes occur in time (e.g., Angell and Korshover, 1978; London and Kelley, 1974; London and Oltmans, 1978). An example of the observed variations, after Angell and Korshover (1978), is shown in Fig. 1 for the north temperate region (27.5–62.5°N), where variations are presented as a percent departure from a long-term average. For the period shown here, we see a general increase in total $O_3$ from the mid-1960's to about 1970 from about −4% to about +5%, a decrease from 1970 to 1972 and a value which has seemed to hold at about plus 1–2% in recent times.

A major question in delineating these variations, however, has always been that the sampling sites are very much biased toward the major continental areas, as depicted in Fig. 2, where the sites are denoted by the triangles (e.g., Moxim and Mahlman, 1978). Clearly, major gaps occur over the Atlantic and Pacific Oceans and any attempt to derive a latitudinal band or hemispherical average must involve interpolation through these areas. The procedures might involve defining a statistical weight to each area (Angell and Korshover, 1978) or it may depend on the construction of synoptic-type analyses (London and Kelley, 1974; London and Oltmans, 1978), but it remains, nonetheless, an interpolation.

The significance of these data gaps is illustrated in Fig. 3 in which we have plotted for three separate years (1965–66, 1967–68, 1969–70) the winter seasonal average (December-January-February) of the 100 mb height as a function of longitude at 50°N, which may be considered as indicative of the lower stratospheric circulation. In addition, at the bottom of the diagram are shown the effective ozone sampling areas for North America (NA), Europe (EU), USSR and Japan (J). For this study, all monthly averaged 100 mb data were obtained from the published series of the Free University of Berlin (1964–76).

We see that for the 100 mb heights, major structural changes do take place from year to year and if we were to sample the heights by the spatially limited $O_3$ sites, we may, in fact, misinterpret the resultant numbers. Over Japan, for example, we see that the measurements are very sensitive to the location of the sharp trough relative to the narrow band of measurement sites. In a somewhat similar vein, over North America and Europe it appears that the relatively high values over the Pacific and Atlantic occasionally extend into the measurement region thereby influencing the values.

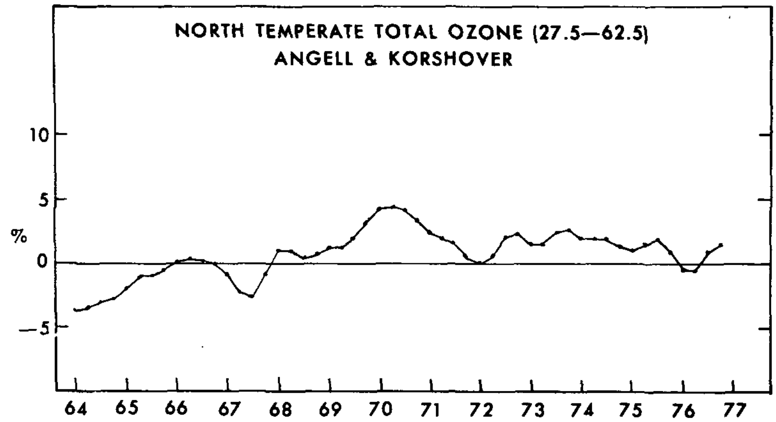


FIG. 1. Variation of north temperate total ozone (27.5–62.5°N) with time (after Angell and Korshover, 1978).

Conceptually, then, we see that the interpolation through the data gap areas without any ancillary information or *a priori* knowledge is risky, at best, and must add a sampling uncertainty to the zonal averages. In terms of establishing long-term trends, however, the question is whether this uncertainty is a short-term random feature or has long-term components that influence the estimates as shown above.

Thus far, of course, we have not stated anything that has not been at least tacitly understood previously. In this paper we have extended the argument by asking whether or not it is possible to utilize information such as the 100 mb height fields that are available from the mid-1960's onward to provide us with sampling precision estimates of the $O_3$ zonal averages in time. Specifically, the question

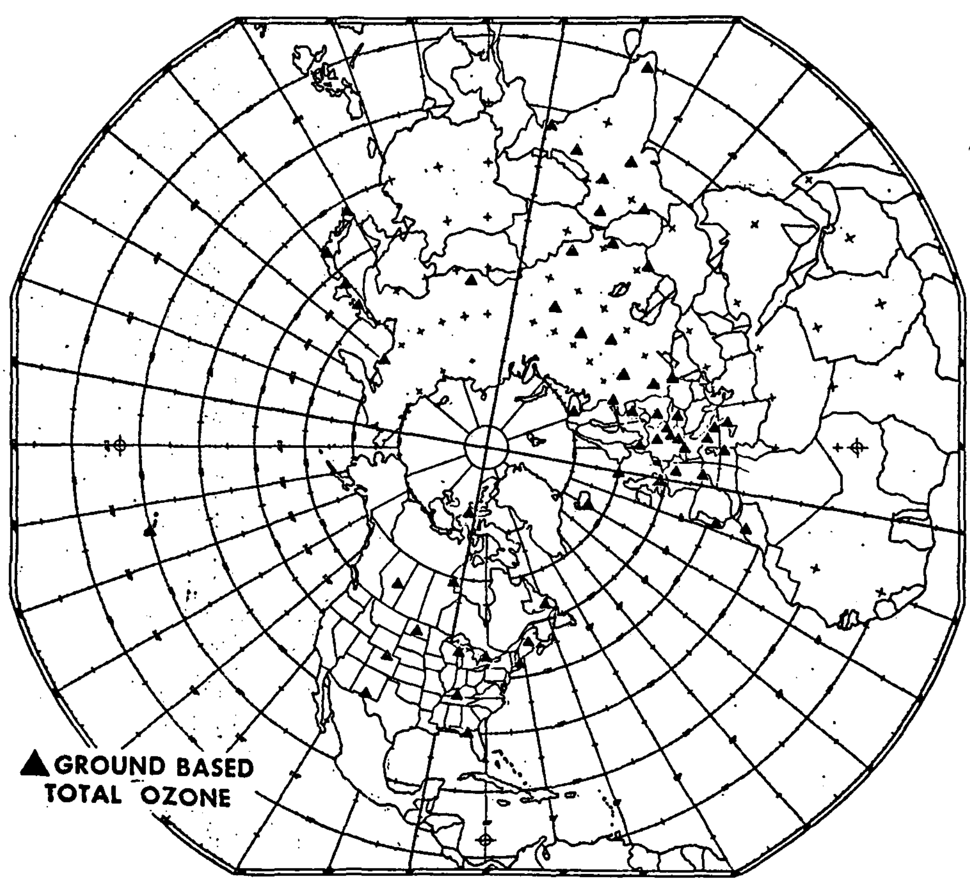


FIG. 2. Location of ground-based total $O_3$ observing sites (triangles).

is how precise is the zonal average height computed using the same technique as Angell and Korshover from data over the $O_3$ sampling areas compared to the zonal average computed from the entire data set. If the stratospheric patterns do, in fact, change in a nonrandom manner in time, the difference between the true and the sampled zonal average may vary in time and this variation would represent the sampling error in the trend. The rationale for limiting this study to a comparison of results from Angell and Korshover is simply that within their technique, precise statistical weights are ascribed to the areas that are amenable to a comparison analysis. For techniques that employ synoptic-type analyses, the data influence functions are not so clearly defined and this will be discussed further below.

## 2. Procedure

As our goal was to estimate the precision of the zonal averages computed by Angell and Korshover, our procedures were made to conform as closely as possible to their technique. Thus, the monthly average 100 mb height fields at 50°N (the rationale for selecting 50°N will be discussed below) were read at 10° longitude intervals, combined into seasonal averages (D-J-F, M-A-M, J-J-A, S-O-N) and average values over the four sampling domains computed. From this point the zonal average was calculated utilizing the weighting of Angell and Korshover with three each for North America and Europe, one for Japan, and two for the USSR. We note that the relatively low weight for the USSR was a subjective decision that included the relative accuracies of the USSR filter instrument versus the Dobson spectrophotometer. This should not be a feature of the height analyses. Our results, then, will be a "true" estimate of the sampling efficiency if the trends of the USSR data are correct. Of course, we could have given the USSR data a greater weight, but this would not be a direct comparison with the results of Angell and Korshover. Following this, the data were treated in the same statistical manner as Angell and Korshover (1978) and the computed zonal averages compared against those calculated from the zonally complete data.

At this point, two major questions arise. The first is how representative the 100 mb height fields are over the extended time period. The answer is presented in Fig. 4 which shows the distribution of observing stations as of 1967 (McInturff and Finger, 1968). As was the case for the ozone stations, we see that substantial gaps exist over the Atlantic and Pacific Oceans, but if we focus on the higher latitudes such as 50°, there appear to be sufficient island and ship stations to provide a meaningful analysis. Following the availability of the satellite temperature retrievals in 1969, several of the stations have been deleted, but the statement above appears to remain in effect. For this study, then, we have focused on 50° which is within the Angell and Korshover north temperate band. We note, however, that for three of the four data areas (North America, Europe, USSR) the average latitude of the ozone data is very close to 50°.

The second question, which is the more difficult of the two, is how to transform the results from the height analysis to ozone units. Our approach is to utilize results on the correlation between 100 mb heights and total ozone that are available from our analysis of the backscatter ultraviolet (BUV) satellite total ozone data (Miller *et al.,* 1978). These are presented in Fig. 5 which depicts the departure from the zonal average as a function of longitude for the two parameters and their correlation for four months during the year, one per season. We see that a significant, negative correlation exists throughout the year. Our approach, then, is simply to utilize these linear regression relationships for each month as representative of that season and by this relationship transform the zonal differences in height to $O_3$. This, of course, assumes that the statistical relationship is accurate and unchanging in time, which may or may not be the case, and these results should then be considered as a first approximation to the true sampling errors in $O_3$.

## 3. Results

Having stated the above caveat, we now turn to the results, presented in Fig. 6. On the top of this figure is shown $\Delta H$ (m), the difference between the sampled and the actual zonal average, and the results regressed to ozone values. For compatibility of this last number to the results of Angell and Korshover we have converted the $O_3$ difference to percent by dividing by the average $O_3$ value of 333 DU obtained from Angell and Korshover. We see that the sampling effect does, in fact, vary with time and that in the mid-1960's the tendency was for Angell and Korshover to overestimate the ozone amount by about 0.5% and to underestimate it in the 1970's by about 1.5% for a net range of about 2%. Within Fig. 6 we see a seasonal variation in the differences with the tendency for maximum differences in winter and spring. This follows from the regression relationships indicated in Fig. 5 with the greatest wave amplitudes in winter and the largest $O_3$ variation to height variation in spring.

On the bottom portion of this figure we have reproduced the Angell and Korshover curve (solid line) from Fig. 1 and added the sampling factor shown on top (dashed line). The net impact is to *increase* the trend from the mid-1960's to 1970 and to maintain the steadiness of the record in the 1970's, but at a higher level.

## 4. Summary

The purpose of this study was to estimate the effect of the spatially limited ozone sampling net-

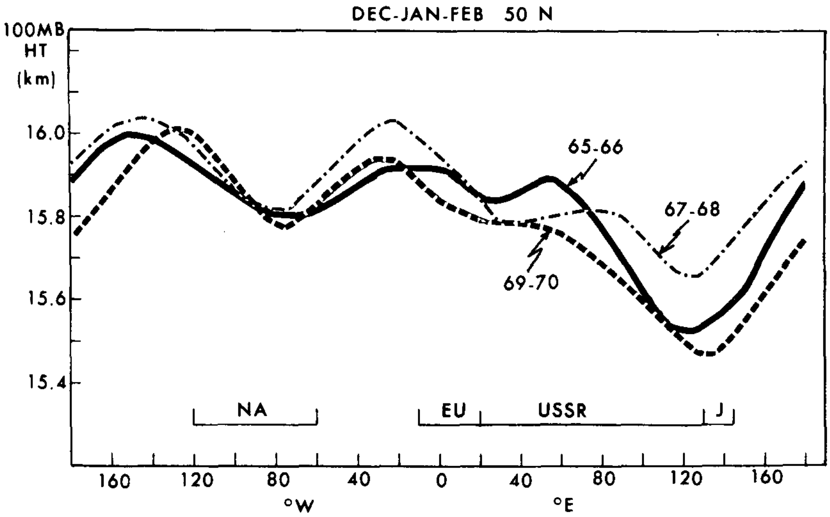


FIG. 3. Winter seasonal average of 100 mb height as a function of longitude at 50°N for the three years 1965–66, 1967–68, and 1969–70. Also noted are the general areas of the ground observing sites for North America (NA), Europe (EU), USSR and Japan (J).

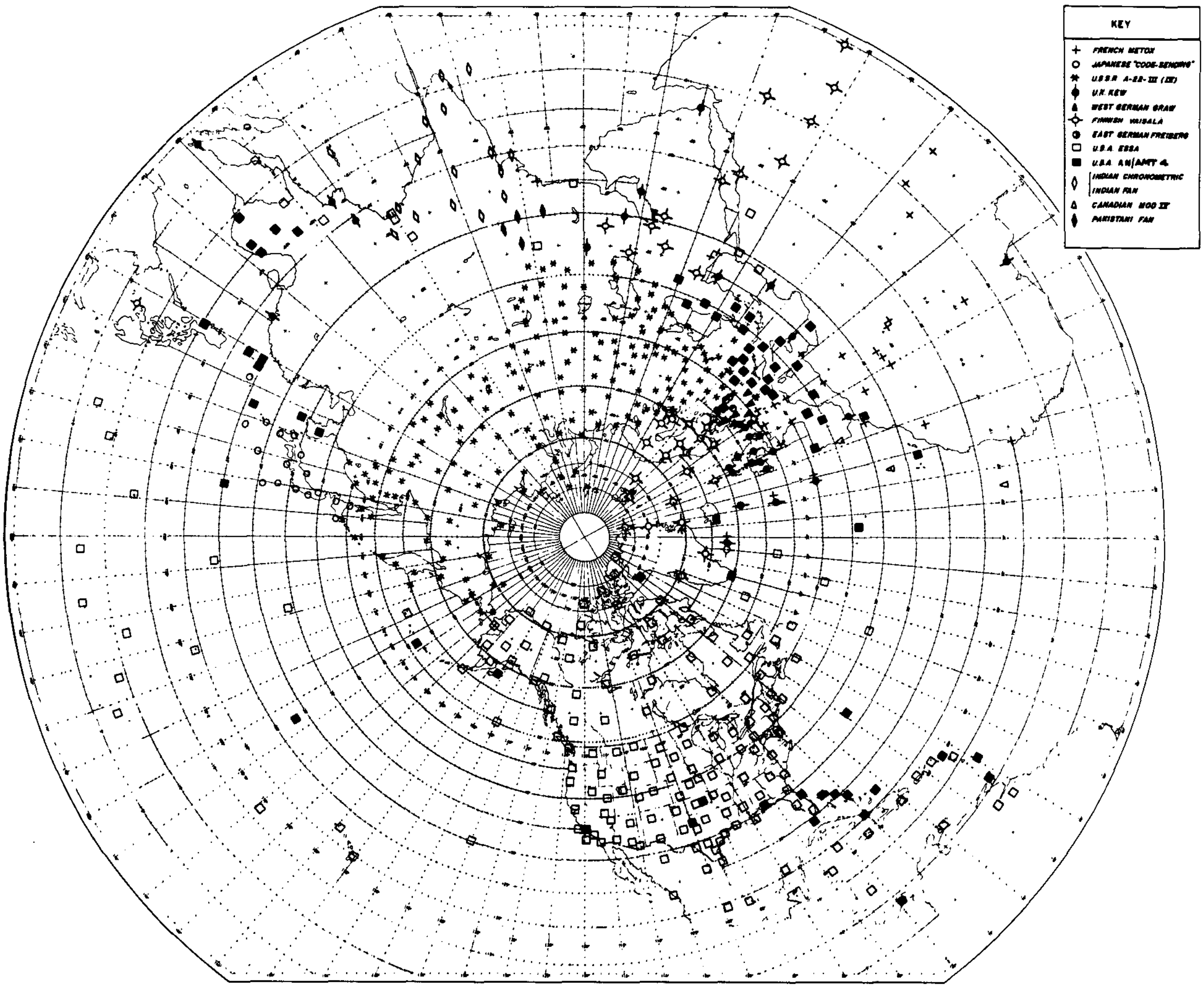


FIG. 4. Location and type of rawinsonde sites as of 1967 (after McInturff and Finger, 1968).

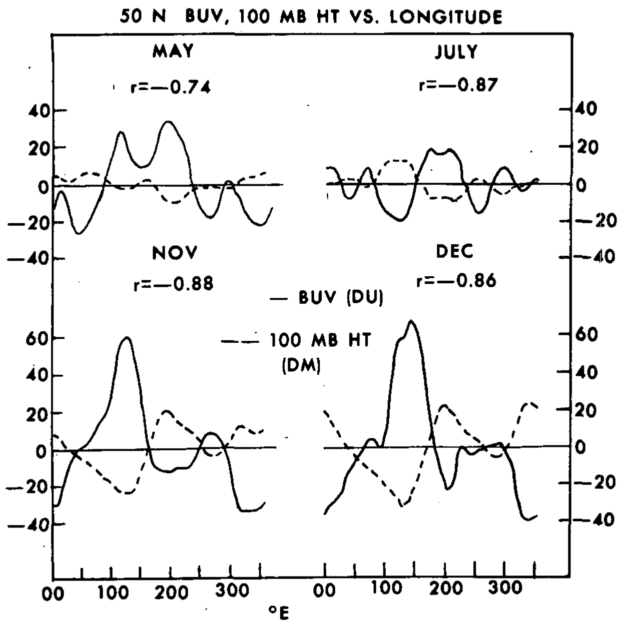


FIG. 5. Monthly average departure from zonal mean at 50° of BUV total ozone (solid line) and 100 mb height (dashed) as a function of longitude. Correlation coefficient ($r$) is shown for each month.

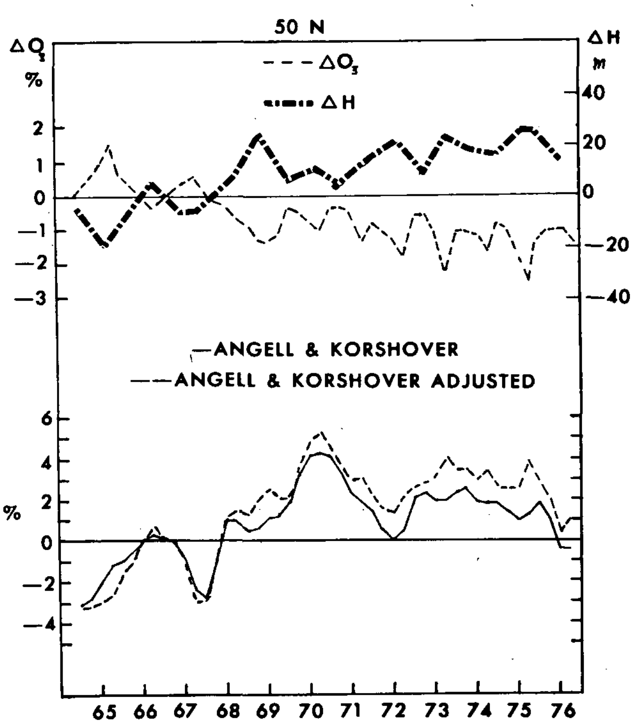


FIG. 6. $\Delta H$ (m) and $\Delta O_3$ (%,ΔDU/333), sampled minus actual zonal average, as a function of time (top). The time variation of the north temperate total ozone from Fig. 1 (solid line) and same curve with sampling factor added (dashed line) are shown below.

work on the determination of long-term trends in midlatitudes of the Northern Hemisphere. Because of severe constraints on the availability of the meteorological information we were restricted to studying the variations at 50°N and, as such, this study can only provide a first guess of the true average midlatitude (27.5–62.5°N) sampling effect. However, as the average latitude of the North American, European and USSR $O_3$ stations is between 45–52°N and as the meteorological wave patterns are generally correlated in latitude over 10–20° latitude bands, it is our feeling that these results are reasonable values.

With this caveat, it appears that the general shape of the midlatitude ozone trends determined by Angell and Korshover from the ground-based observations is real and is not an artifact of the limited sampling of the ground-based observations. In fact, the increase of $O_3$ from the mid-1960's to early 1970's may be even greater than previously suggested.

It should be stressed that the results presented here pertain to the weighting technique utilized by Angell and Korshover (1978) and may differ, in detail, from other techniques utilized such as the synoptic-analysis approach (London and Kelley, 1974; London and Oltmans, 1978). The difficulty in determining the sampling effect of the synoptic analyses is, of course, in delineating the relative influence of the data regions over the non-data areas and, we have not as a result performed this type of analysis. In fact, an infinite number of weighting techniques can be derived that weight the observed areas to varying degrees and it is not our purpose to attempt to seek a "best" method. What does appear clear from Fig. 3, however, is that considerable care must be utilized in interpolating through the no-data regions and that the optimum approach would be to fill in these areas with either ground-based or satellite information.

Finally, with respect to accomplishing an analysis of the sampling effect, similar to that presented here, for the tropics or the Southern Hemisphere, we point out that insufficient data exist for such an attempt. For these regions we must await the satellite information that will provide precise values of the zonal averages that can be compared with those determined from the ground-based observation sites.

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