Reports

Martian Topography: Large-Scale Variations

Abstract. *The variation in carbon dioxide abundances detected in the 1.05-micron band over small, discrete areas on Mars indicates that larger-scale topographical differences are present than had previously been believed. Spectroscopic mapping of the surface also indicates no apparent correlation between albedo and height; the results are in good agreement with topographical data derived from the range-gated radar scan along +21°N. High and low areas are found in both the major equatorial maria and the bright deserts in the northern hemisphere.*

Considerable argument has recently centered on the question: Are the dark areas on Mars higher or lower than the deserts (*1*)? Data from range-gated radar scans (*2*), which directly relate heights on Mars to delay times in the returning echo, have shown that ranges of elevations up to 12 km are situated along 21°N. However, since no comparable data existed along a latitude through the major equatorial maria, no satisfactory conclusion could be drawn regarding the heights of features in the equatorial mare regions with respect to the elevations and depressions recorded along 21°N (*3*).

Since CO_2 appears to be the dominant constituent of the martian atmosphere, the abundance above a point on the surface will be a direct function of the deviation of this point from a geopotential surface. The spectroscopic detection of surface relief therefore relates the relative height between two different areas to the relative abundance of CO_2 present over these same two regions.

If the variations in elevations are on the order of 12 km, as suggested by the range-gated radar data, and the atmospheric scale height is between 9 and 10 km, as indicated by the Mariner 4 measurements, then the CO_2 abundance will vary by about a factor of 4 over this height range. Such a variation can be detected by noting differences in the equivalent widths of pressure-independent CO_2 lines observed in the light reflected from small areas on Mars.

I here report the results of the initial examination of data obtained from Mars with the multislit spectrophotometer designed and built by Belton and Hunten at the Kitt Peak National Observatory. The instrument was used in conjunction with the 13.4-m spectrograph of the McMath solar telescope. A brief description of the instrument has been given by Belton and Hunten (*4*).

I have used the equipment in exactly the same manner as described by the above authors with the exception that only two of the three channels for measuring radiation in the 1.05-μ CO_2 band and continuum were included. The third channel may be added whenever it is desired to look at low- and high-excitation lines separately for the removal of temperature dependence.

Since the R-branch near 1.05 μ is only slightly temperature-dependent, as demonstrated by Belton and Hunten (*4*) and Belton *et al.* (*5*), and since only a topographic map was desired, the separation of high- and low-excitation J-lines was deemed unnecessary. This step also saved considerable time in the initial setting up of equipment and in the alignment procedures.

The image of Mars, electronically stabilized at the entrance aperture of the spectrograph, was 8.4 mm in diameter on the night of closest approach, 7 June, and nearly that for the following week of observing. An image slicer (1 by 1 mm) cut off a portion of the planet with a lateral scale of about 850 km and formed a line 1 by 12 mm which was fed into the spectrograph with the grating operating in the second-order, single-pass mode. Blocking filters in the detector channels removed radiation shorter than about 0.9 μ. The linear dispersion of 0.45 mÅ/μ makes the effective width of the exit slits matched to 16 lines (J0 to J28) in the R-branch of the 1.05 μ band about equal to 0.09 Å. The slit for the branch head is somewhat wider. Each slit therefore admitted radiation from both continuum and line which passed into one detector (International Telephone and Telegraph FW118 S-1 photocathodes) while the continuum between the slits was reflected from the mirror surface of the exit slit reticle into a second S-1 detector.

The same equations used in Belton and Hunten's (*4*) theory are valid here with modification for the use of only two channels. A ratio is defined as

$$R \equiv 1 - \gamma_1(S_1/S_2 = \frac{\Sigma\, b_J(W_J/\delta_J)}{\Sigma\, b_J} \qquad (1)$$

where S_1 and S_2 are the signals from the slits and from the continuum between the slits, respectively; γ_1 is a calibration factor which accounts for the continuum radiation in S_1; b_J are the slit efficiency factors; W_J are the equivalent widths of the lines; and δ_J is the exit slit width of each line.

Belton and Hunten (*4*) and Belton *et al.* (*5*) have shown that

$$R \propto (\eta N)^k \qquad (2)$$

where η is the martian air mass and N is the density of a vertical column of CO_2. The exponential $k \equiv 0.72$ is the slope of the "linear" part of the curve of growth determined by Belton *et al.* (*5*). The departure from linearity is due to the fact that these lines in the martian atmosphere are just beginning to saturate at their centers.

If we follow the assumptions of Belton and Hunten (*4*), the height $\bar{z}$ of the surface above a defined reference level can be expressed as

$$R = \text{const.}\ (\eta)^k \exp\,(-k\bar{z}/H) \qquad (3)$$

where H is the atmospheric scale height, that is, the height through which the density or pressure of the atmosphere decreases by a factor of $1/e$ of the ground level value.

The data presented here are referred to Belton and Hunten's (*4*) zero level defined as $R = 0.12$ for $\eta = 2$. These particular numbers are based on the mean of all of their first observations at the center of the disk.

My observations were performed between 8 and 15 June, during which time the weather held fairly constant with average-to-good seeing conditions. At all times the major dark areas were discernible in the guiding telescope (considerable contrast is lost in the guiding optics).

Figure 1 shows the representation of heights on Mars as contours drawn in 2-km intervals, except where crowding

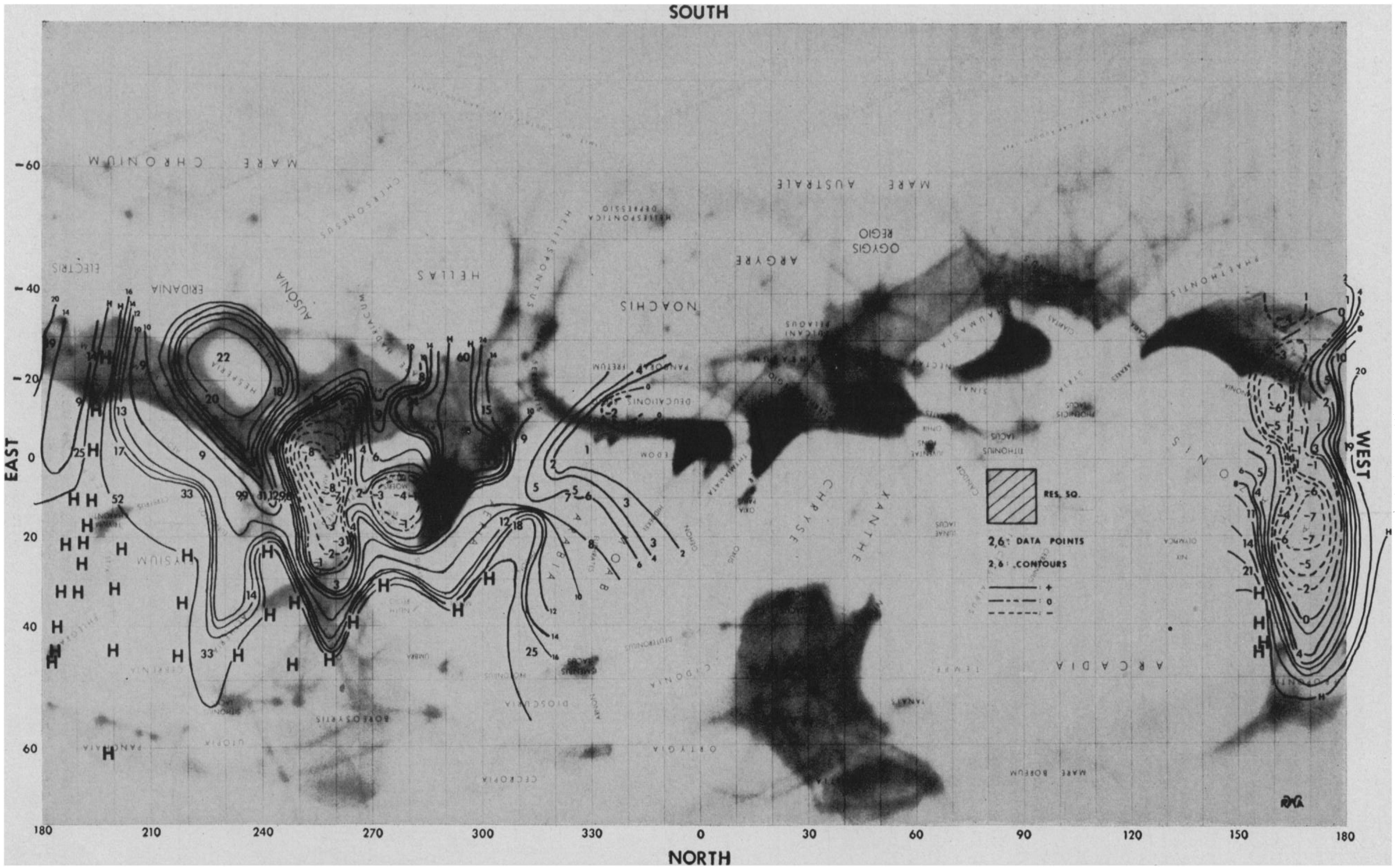

Fig. 1. Martian topographic contours determined from variations in the CO_2 abundances. The heights in kilometers are shown by the dark numbers. The zero level is referred to Belton and Hunten's (*4*) zero. The letter *H* refers to regions so high that no CO_2 was detectable. Contours are drawn in 2-km intervals in the same fashion as in Belton and Hunten's (*4*) contour map with the exception that areas marked *H* are considered to be the highest regions. Dark lines represent positive features; the double-dash broken lines refer to the zero level; and the dashed lines represent negative features. The cross-hatched rectangle on the map represents the resolution element with no consideration of seeing effects. The map is the 1969 chart produced by the U.S. Air Force Aeronautical Chart and Information Center for NASA. The information contained in the contours should be considered with reservation because of the preliminary nature of the analysis and the interpretive manner in which the contour levels are drawn.

of the lines would result. The numbers are obtained from Eq. 3. Areas denoted by H refer to very high areas, that is, regions higher than one scale height where the absorption due to CO_2 becomes negligible. An exact figure for the height of areas denoted by H is difficult to define beyond "greater than 10 km." Also in Fig. 1 several high number values appear (20 to 60 km). These should be similarly interpreted to mean regions higher than one scale height. The values are retained wherever possible for the purposes of ordering the contour levels.

The information exhibited by the contours should be considered with due reservation in this preliminary analysis, but several points are of interest. The data reported by Belton and Hunten (*4*) are included, but contours they reported have been altered because of the additional data obtained in the areas near Syrtis Major. Their main features are still present: a high Syrtis Major, a depressed basin near Isidis Regio, a ridge near Thoth-Nepenthes, and the beginnings of a depression in Aethiopis. The additional data described here have made possible the completion of the contours of this latter basin and indicate that the structure of Syrtis is not a ridge but rather a broader high area. The contours around the tip of Syrtis have necessitated an alteration of Belton and Hunten's (*4*) interpretation of the contouring over Sabaeus Sinus and the deserts to the north. The contours now accentuate the ridge feature near Phison.

To the left of the diagram (south is at the top) is a high area which tapers into a long ridge centered over the Dis, Styx-Trivium, Charontis-Laestrygon complex. The ridge appears to pass through Mare Cimmerium, and there is an indication that it could continue along Scamander which separates Eridania from Electris.

The remaining contours indicate that high and low areas occur in both the deserts and dark areas, particularly Mare Sirenum near the track of Mariner 4. The high structure in the Northern Hemisphere marked by H roughly coincides with all the fainter dark areas ranging from Panchaia to about Dioscuria, though some of these contours overlap into the deserts around Elysium.

A comparison of these data with the range-gated radar measurements of Counselman *et al.* and Pettengill *et al.* (*2*) is of interest. A cross section of the contour data (not the actual individual observational numbers) along 21°N was plotted on a transparent overlay which was subsequently shifted along the vertical axis of the plot of radar data until a match was obtained. This procedure accounts for the difference in zero levels by effectively normalizing the spectroscopic data to the radar information. The match (Fig. 2) is excellent. The departures near longitudes 240° and

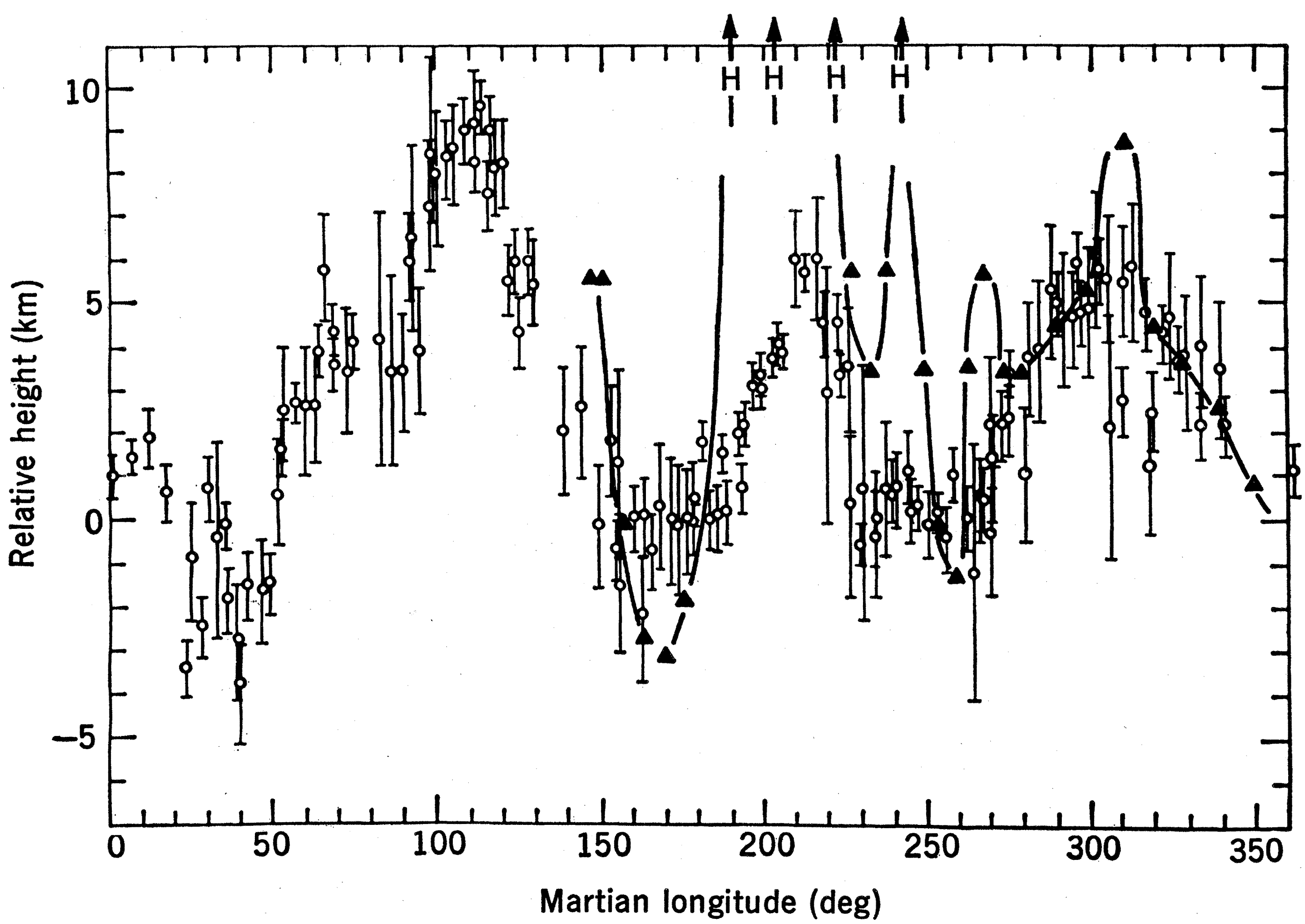

Fig. 2. A comparison of the data contained in Fig. 1 along 21°N and radar data (*2*) located at the same latitude. The circles with error bars are the original radar measurements; the symbol ▲ represents the spectroscopic data; H stands for areas higher than one scale height. The spectroscopic data are normalized to the zero level of the radar data. The close agreement adds considerable support to the manner by which the contours of Fig. 1 were drawn.

265°, moreover, reflect the relative trends of the radar data.

The following tentative conclusions are submitted subject to later revisions:

1) The match between the data that I obtained and those of Belton and Hunten (*4*), working as independent teams, demonstrates a consistency in the measurements and in the successful performance of their instrument.

2) Syrtis Major is a rather broad high area which slopes off fairly steeply on both sides—in one case into a relatively high bright desert, Aeria, and in the other into a basin near Isidis Regio.

3) A larger depressed basin is located partly in Aethiopis and Syrtis Minor (the smaller gulf near longitude 260°)–Mare Tyrrhenum.

4) The Mare Cimmerium–Hesperia region appears to be a very broad high area.

5) Two other depressed basins are located in Amazonis near 170° longitude and in Memnonia–Mare Sirenum.

6) The spectroscopic data are in good agreement with the previous range-gated radar data along +21°N.

7) Both the desert regions and dark maria appear to be situated at high, medium, and low levels, though basin-type features tend to show a proclivity for the deserts.

8) The fact that there is no apparent correlation between albedo and height and that the topography on a macroscopic scale appears to be rougher than previously supposed could indicate that the darkness of the features of the maria is due to differences in chemical composition between the dark areas and the brighter deserts rather than to physical differences. Such an interpretation neglects, of course, the added effect of microstructure, which can be considerable.

9) Finally, for scale comparisons, the basin in Isidis is about twice the size of the Aral sea; the Aethiopis basin is about 1.5 times larger than the Gulf of Mexico; the Amazonis basin is about the size of the Mediterranean Sea; and the Memnonia-Sirenum basin is about the size of the Caribbean Sea. The high broad areas in Cimmerium and Syrtis Major are almost the size of Australia. When the sizes of these areas are compared to the size of the earth and Mars, respectively, the similarity in the presence of continental and ocean basin features on Mars is striking indeed!

On the basis of presently available information, it appears that the equatorial structure of Mars is comprised of protocontinental blocks whereas the high and low areas of the northern deserts resemble ocean basins. A high structural feature is also indicated for the stretch of dusky areas in the northern hemisphere: Panchaia-Cebrenia-Utopia-Boreosyrtis-Cecropia-Dioscuria.

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References and Notes

1. R. A. Wells, *Nature* **207**, 735 (1965); B. T. O'Leary and D. G. Rea, *Science* **155**, 317 (1967); C. Sagan, J. B. Pollack, R. M. Goldstein, *Astron. J.* **72**, 20 (1967); C. W. Tombough, *Nature* **209**, 1338 (1966); R. A. Wells, *ibid.*, p. 1338.
2. C. C. Counselman, G. H. Pettengill, I. I. Shapiro, *Trans. Amer. Geophys. Union* **49**, 217 (1968); G. H. Pettengill, C. C. Counselman, L. P. Rainville, I. I. Shapiro, *Astron. J.* **74**, 461 (1969).
3. R. A. Wells, *Geophys. J. Roy. Astron. Soc.* **17**, 209 (1969); *ibid.* **18**, 109 (1969).
4. M. J. S. Belton and D. M. Hunten, *Science* **166**, 225 (1969).
5. M. J. S. Belton, A. L. Broadfoot, D. M. Hunten, *J. Geophys. Res.* **73**, 4795 (1968).
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Terrestrial Microclimate: Amelioration at High Latitudes

Abstract. *At latitudes north of the Arctic Circle the diel range of sun altitude declines progressively, reducing the frequency of temperature inversions over level, unshaded ground in summer and extending the frost-free season. North of about 70° north, the potential number of inversion-free days increases rapidly with latitude; this ameliorates the microclimate close to the ground—the zone to which terrestrial organisms are increasingly restricted in higher latitudes. The relation between screen and ground-surface temperatures differs north and south of about 70° north; north of that latitude there are progressively more frost-free days than would be inferred from screen temperatures, were no allowance made for this latitude-dependent change.*

Terrestrial climates are generally assumed to become less suitable for the survival and growth of organisms as latitude increases because the July mean of screen temperature declines steadily toward higher latitudes (*1*). Observations of the climate and of the fauna and flora have shown that relatively benign conditions exist in certain high-arctic localities, for example, Peary Land in northeast Greenland (*2*) and Lake Hazen in northeast Ellesmere Island (*3*, *4*). The rich biota of these sites is seen as a consequence of their relatively warm summer, since it is believed that terrestrial organisms, once safely frozen, are little affected by the extreme cold of winter (*5*). The warm summer (as judged by screen temperature) has in turn been attributed to the fact that these places are inland and therefore free from the moderating influence of the Arctic Ocean and that they are located favorably with regard to such features as aspect, inclination of slope, and proximity of katabatic winds (*3*) which, reflecting local topography, are likely to ameliorate summer climate at any latitude, temperate or arctic.

A fact not generally recognized is that there is an improvement in the "plant climate" (*6*)—air within 10 cm of the ground—toward the highest latitudes which is not evident from measurements of "human climate" obtained at the height of the meteorological screen (1.5 to 2.0 m). The improvement results from the progressive, latitude-dependent reduction of the diel (24-hourly) fluctuation of sun altitude. Thus, the period centered on the summer solstice each year during which the sun remains continuously above the horizon increases from about 48 hours at the Arctic Circle to about 6 months at the North Pole; correspondingly, the diel difference between the sun altitude at solar noon and at "midnight" declines from 45 degrees (altitude) to virtually 0 degrees (*7*).

Sørensen (*8*) remarked that, because the diel range of air temperature in east Greenland was less at 74° 10′N than at 72° 50′N, conditions for plant development (on level ground) were more favorable at the former latitude because temperatures there stayed closer to the daily mean, and therefore above the growth threshold, for longer