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The atomic hydrogen content of the earth's thermosphere has been investigated by a number of experimental techniques with only moderate success. Direct mass spectrometer measurements have proved difficult to interpret [Reber et al., 1970; Harpold and Horowitz, 1971]. All airglow techniques suffer to various degrees from the fact that they measure integral effects; interpretation of the observations in terms of hydrogen densities requires prior knowledge of the hydrogen global distribution. In particular, Lyman-α is not a sensitive indicator of thermospheric hydrogen concentration because of the optical thickness of the exosphere and the consequent importance of high-altitude scattering [Meier, 1970]. Ground-based observations of Balmer-α emission provide a better measurement of thermospheric hydrogen variations [Tinsley, 1970], but determination of absolute hydrogen concentration is difficult due to uncertainties in the intensity of the solar Lyman-β line and in the integrated hydrogen content along the line of observation.

This paper presents early results of a correlative study of Explorer 32 data obtained in the period June 1966 - January 1967, which has provided the first in situ determination of the temporal variations of thermospheric hydrogen. The measurements were made in the altitude range 280-450 km, within a limited range of latitude (23° to 47°) and longitude (-65° to -124°). The hydrogen concentration has been derived from the chemical equilibrium relationship

$$n(H) = \frac{8}{9} \frac{n(H^+)}{n(O^+)} \quad n(O) \qquad (1)$$

[Hanson and Ortenburger, 1961], using $n(H^+)$ measurements by the Explorer 32 Bennett RF ion mass spectrometer (described in Brinton et al., 1969). Simultaneous measurements of n_e by two cylindrical Langmuir probes on the same satellite (L. H. Brace, experimenter) provided $n(O^+)$ values (in the altitude range of interest $n_e = n(O^+)$ to a close approximation). The values of n(O) were obtained from the model atmosphere of Jacchia [1964], computed for the solar and geophysical conditions existing at the time of each $n(H^+)$ and n_e measurement. The validity of the model for this time period, altitude range, and geographic location has been affirmed by Explorer 32 density gage measurements, as reported by Newton [1970]. (A more recent model [Jacchia, 1970] includes n(O) values which are at most 10% higher than those of the 1964 model.)

The upper panel of Figure 1 shows the n(H) values derived from data obtained under quiet magnetic conditions ($a_p \leqslant 10$, six hours prior to the measurement). To simplify subsequent analysis the hydrogen concentrations have been normalized to an altitude of 350 km, assuming a scale height of 600 km which corresponds to a temperature of 900°, the average of the day and night values for this period. (The exospheric temperature at the time of each measurement has been calculated using the model equations of Jacchia [1964].) During the eight-month period of measurement the satellite orbit phased through two diurnal cycles while maintaining almost constant altitude at a given geographic location, a characteristic of the Explorer 32 orbit which makes it ideal for study of the diurnal variation in n(H). The progression of local time is indicated by the scale at the top of Figure 1; note that local time decreases from left to right.

The daily and 54-day mean values of the 10.7 cm solar flux for the period of the n(H) observations are shown in the lower panel of Figure 1. The overall decrease in n(H) during the period of observation correlates with the steady increase in solar activity; superimposed on this long-term behavior is a less pronounced periodic variation of n(H) arising from the 27-day solar activity variation associated with solar rotation.

A curve fitting technique has been used to resolve the complex variation of n(H) shown in Figure 1 into a number of density components, each of which is associated with a primary component of the exospheric temperature. The expressions for the temperature components are those of Jacchia [1964], and include contributions associated with 11-year solar cycle, 27-day solar rotation, diurnal variation, geomagnetic activity, and semi-annual variation.

The results of this analysis for the n(H) components associated with solar activity are shown in the left-hand panel of Figure 2. The light solid line represents the n(H) component due to 11-year solar cycle; its behavior indicates that during the eight months of measurement the hydrogen content of the thermosphere decreased by a factor of approximately 2.5 due to the long-term increase in thermospheric temperature associated with increasing solar activity. Superimposed on the solar cycle component is the n(H) contribution associated with the 27-day variation of solar activity due to solar rotation. This periodic component accounts for n(H) variations of as much as a factor of 1.3, with hydrogen density again varying inversely with the associated temperature component.

The diurnal component of the n(H) variation is shown, superimposed on the solar cycle contribution, in the right-hand panel of Figure 2. The diurnal effect is observed as approximately a factor of two increase in n(H) between day and night. Further, the error in our curve-fit analysis is minimized when a phase lag of approximately three hours between the diurnal variation of model exospheric temperature and hydrogen density is introduced. There also are indications that the magnitude of the phase lag is different at night than during day, as has been suggested by Patterson [1966]; this question is currently under investigation.

Table 1 compares the n(H) diurnal variation determined from Explorer 32 with several models currently in use and with recently reported airglow results. (The models chosen are for $F_{10.7} \approx 100$.) The quantities compared are the night-to-day thermospheric hydrogen density ratio and the diurnal density-temperature phase shift. The Explorer 32 in situ observations are in considerable disagreement with the COSPAR International Reference Atmosphere 1965 (CIRA, 1965) and the Jacchia [1964] model. However, our results are within the limit of four on the diurnal density ratio deduced from Lyman-α measurements by Meier and Mange [1970] and are in excellent agreement with the Balmer-α observations of Tinsley [1970] and with the theoretical predictions of Patterson [1966] and McAfee [1967] whose models include the effect of lateral hydrogen flow.

Our thermospheric hydrogen densities are approximately a factor of three higher than those given by the Kockarts and Nicolet [1962, 1963] theoretical model. Prior [1971] has derived two high altitude n(H) values from satellite drag data obtained in the period March-May 1967; his densities, derived for altitudes above 2300 km and for local times near 0600 hours, also exceed the Kockarts and Nicolet values by about a factor of three.

ACCURACY OF RESULTS

Determination of the <u>relative</u> variation of n(H) by the method employed in this study is extremely accurate, since systematic errors associated with instrument calibration and performance affect only the derivation of absolute hydrogen density. The primary sources of inaccuracy in the relative variations of n(H) are random factors such as data reading error. The amplitude of this "noise" on the n(H) variation, based on estimated uncertainties in n(H^+) and n(O^+) and substantiated by the curve-fit analysis, is ±15%. This random error has been filtered out of the n(H) components plotted in Figure 2.

The possible inaccuracy of the <u>absolute</u> hydrogen density is primarily due to an uncertainty of ±25% in the experimental verification of the model n(O) values [Newton, personal communication]. Inflight calibration of the ion spectrometer for H^+ using n_e data from the companion cylindrical Langmuir probe [Brinton et al., 1969] eliminates possible errors due to mass discrimination in the spectrometer and to aerodynamic effects in the satellite sheath. Further, any systematic error in the probe measurement of n_e is canceled out, since it is the ratio $n(H^+)/n(O^+)$ which enters in the derivation of n(H). A small systematic error, of magnitude 0 to +10%, arises from the use of equation 1 when $T_i \neq T_g$ [Banks, 1967]. In summary, the absolute uncertainty of our n(H) values is (+35/-25)%.

SUMMARY

The concentration of atomic hydrogen at 350 km altitude has been derived from in situ measurements of ion composition and model n(O) values; the selected measurements were made within a limited geographic region between June 1966 and January 1967. The variation of n(H) between approximately 4×10^5 and 8×10^4 cm^{-3} during this period has been resolved into density contributions associated with the primary exospheric temperature components. The results for the three most significant components are summarized below:

(1) Solar Cycle: The increase in average solar activity ($F_{10.7}$) from 100 to 140 and resultant atmospheric temperature increase caused a factor of 2.5 decrease in n(H).

(2) Solar Rotation: The 27-day variation in solar activity and the corresponding temperature component were correlated with an inverse n(H) variation of as much as a factor of 1.3.

(3) Diurnal: The concentration of hydrogen increased by approximately a factor of two between day and night, with a phase delay of about three hours between model exospheric temperature and n(H).

Variations in n(H) associated with magnetic storms and the atmospheric semi-annual variation are currently under investigation.

ACKNOWLEDGMENTS

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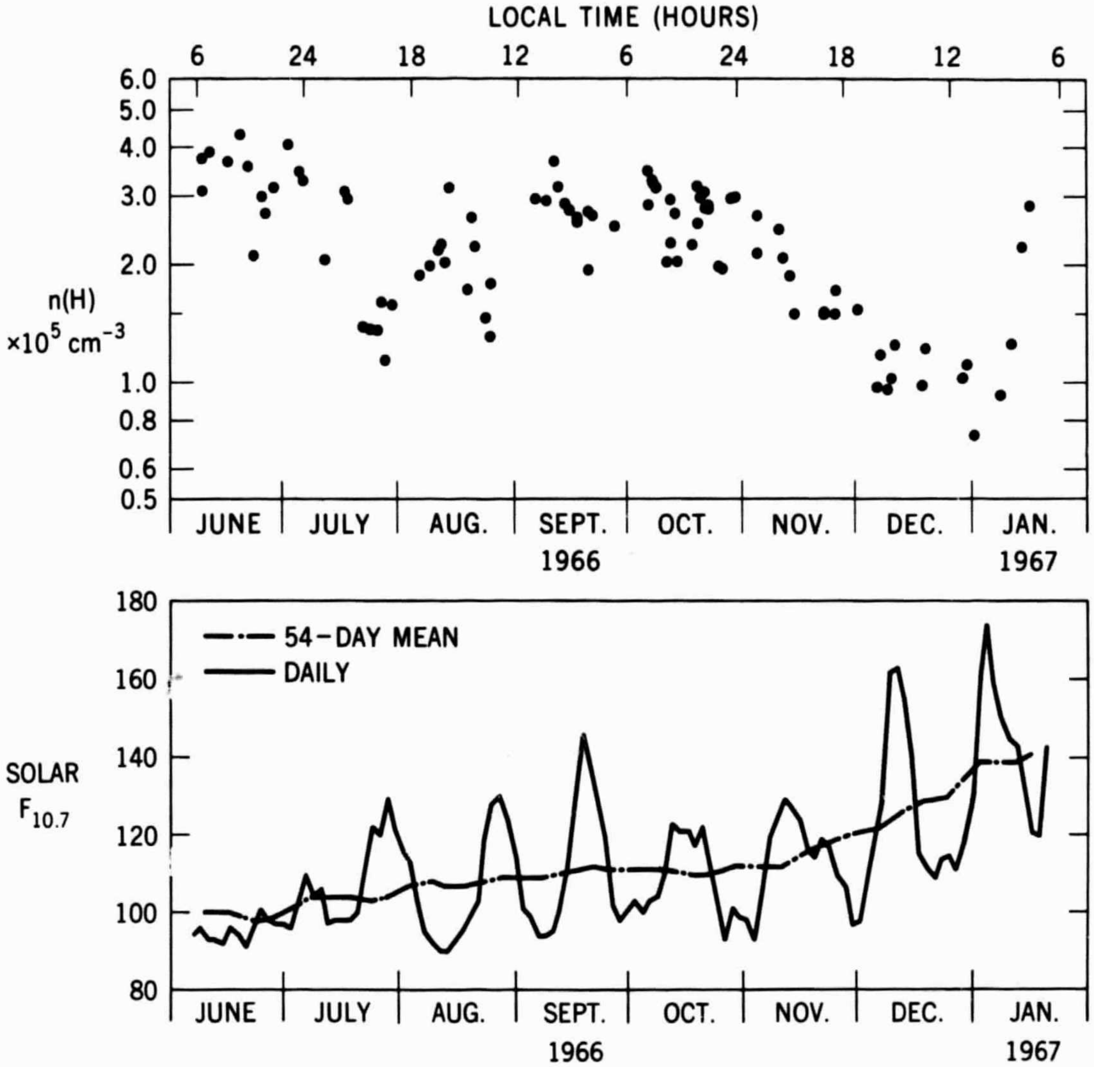

Figure 1. Concentration of atomic hydrogen at 350 km altitude, derived from in situ measurements of ion composition and model n(O) values, for period June 1966-January 1967. Variations of daily and 54-day mean values of $F_{10.7}$ solar flux during measurement period are also shown.

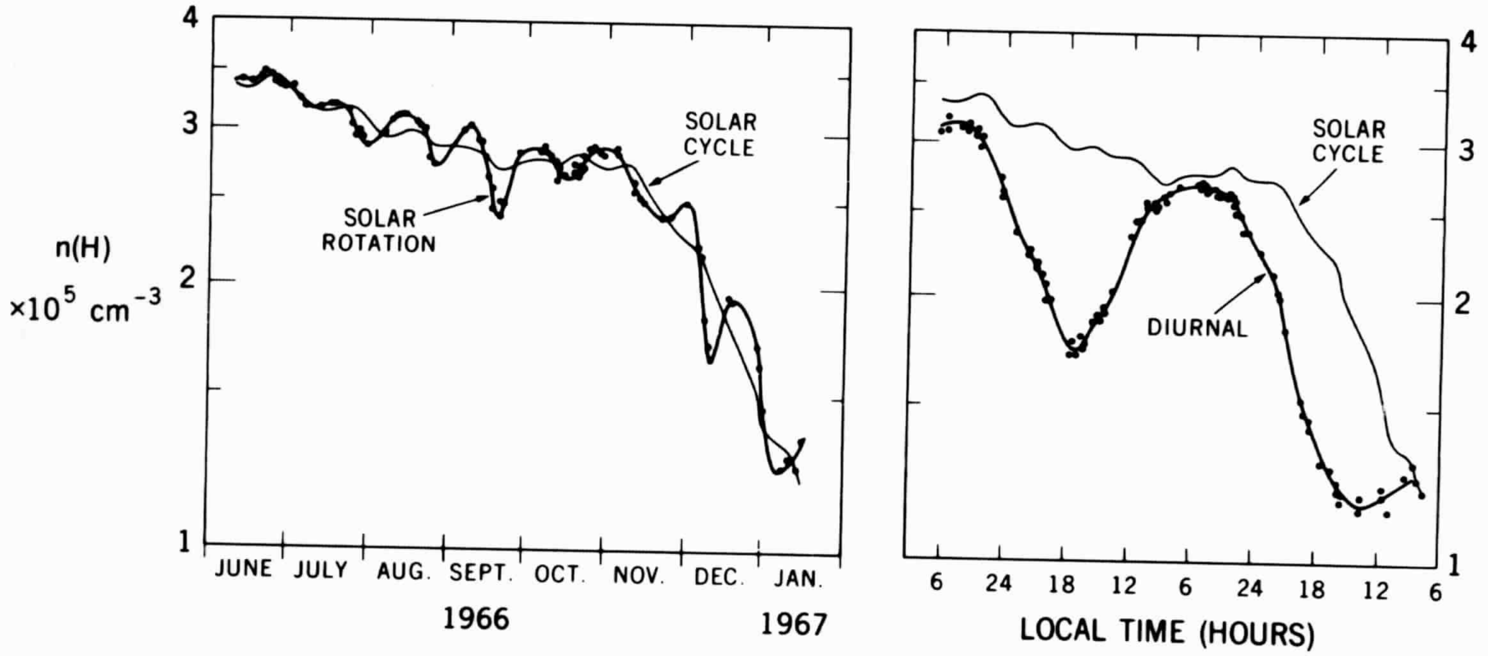

Figure 2. Contributions to n(H) associated with exospheric temperature components related to 11-year solar cycle, 27-day solar rotation, and the diurnal variation. Note, in right-hand panel, that local time progresses toward earlier values.

TABLE 1. Diurnal Variation of Thermospheric Hydrogen Concentration

	$\frac{n(H)_{Night}}{n(H)_{Day}}$	n(H)-Temperature Phase Shift (Hours)
CIRA 1965 Model	$\sim$ 1.1	0
Jacchia 1964 Model (based on Kockarts and Nicolet, 1962, 1963)	$\sim$ 4	0
McAfee Model (1967)	$\sim$ 2	
Patterson Model (1966)	$\sim$ 2	$\sim$ 2
OGO-4 Lyman-α (Meier and Mange, 1970)	1-4	
Ground-based Balmer-α (Tinsley, 1970)	$\sim$ 2	$\sim$ 2
Explorer 32 (present study)	$\sim$ 2	$\sim$ 3