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THE GLOBAL HYDROGEN BUDGET

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Atomic hydrogen is one of the most important, and at the same time least understood, constituents of the Earth's atmosphere. Because of difficulties associated with the measurement of hydrogen, neither its absolute density nor its complex temporal variations are known with certainty. Today I would like to report on a study, based on Explorer 32 data, that has produced unique experimental results bearing on the atomic hydrogen question.

Figure 1 depicts the major processes governing the distribution of hydrogen. It is produced by photodissociation of water vapor in the mesosphere, and diffuses upward into the thermosphere. Because of its low mass, hydrogen is subject to thermal planetary escape, and its concentration and global distribution are therefore largely governed by the atmospheric temperature T_g.

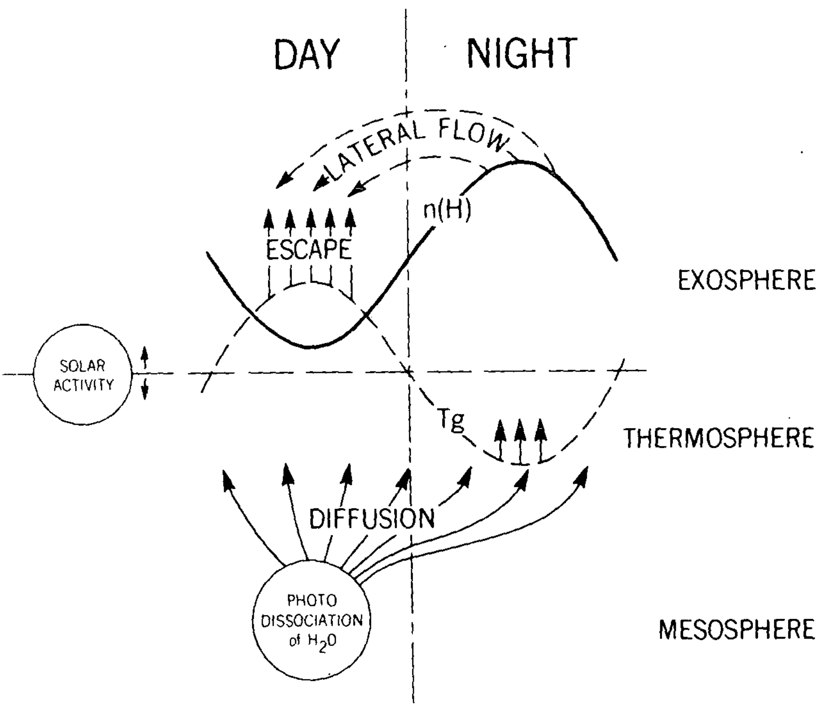

Figure 1–The major processes governing the distribution of hydrogen.

Since T_g is higher on the dayside of the Earth than on the nightside, the escape rate is higher during the day and the dayside hydrogen density $n(H)$ is consequently lower.

The process referred to as lateral flow, in which hydrogen is transported around the Earth from the region of high concentration to the region of lower concentration, reduces the magnitude of the diurnal variation which would result from escape alone.

Adding to the complexity of the daily variation is the fact that the range of T_g rides up and down with long-term variations of solar activity.

The upper graph of Figure 2 shows the observed variation of hydrogen concentration at 350-km altitude above the continental United States during the period June 1966 to January 1967. The hydrogen densities were derived from the chemical equilibrium relationship shown at the left of the graph, which holds at thermospheric heights. The H^+ to O^+ ratio was obtained directly from Explorer 32 measurements; the $n(O)$ values by which the ratio is multiplied to obtain the hydrogen densities were obtained from an atmospheric model, the accuracy of which was verified by Explorer 32 pressure gage results.

During the period of measurement, the satellite orbit phased through two diurnal cycles; the local time scale is shown at the top of the graph. Note that periods of higher concentration correspond to nighttime hours and periods of lower concentration correspond to daytime hours. This behavior is evidence of the diurnal variation that I described earlier. The general decrease in hydrogen concentration during the measurement period resulted from an increase in solar activity, and hence atmospheric temperature and thermal escape, during the 8-month interval.

Analysis has resolved the observed hydrogen temporal variation into a number of density components, each associated with a primary factor affecting the atmospheric temperature. The solid line in the lower graph represents the diurnal density component, and indicates that the thermospheric hydrogen concentration increases by about a factor of 2 between day and night. This diurnal component is shown superimposed on the observed hydrogen densities in the top graph. The scatter of points about the diurnal curve is caused by the presence of other components in the hydrogen temporal variation, one of the most important being the solar activity component, shown by the dashed line in the bottom graph. Note the long-term density decrease due to rising solar activity and the 27-day variation in this component associated with solar rotation.

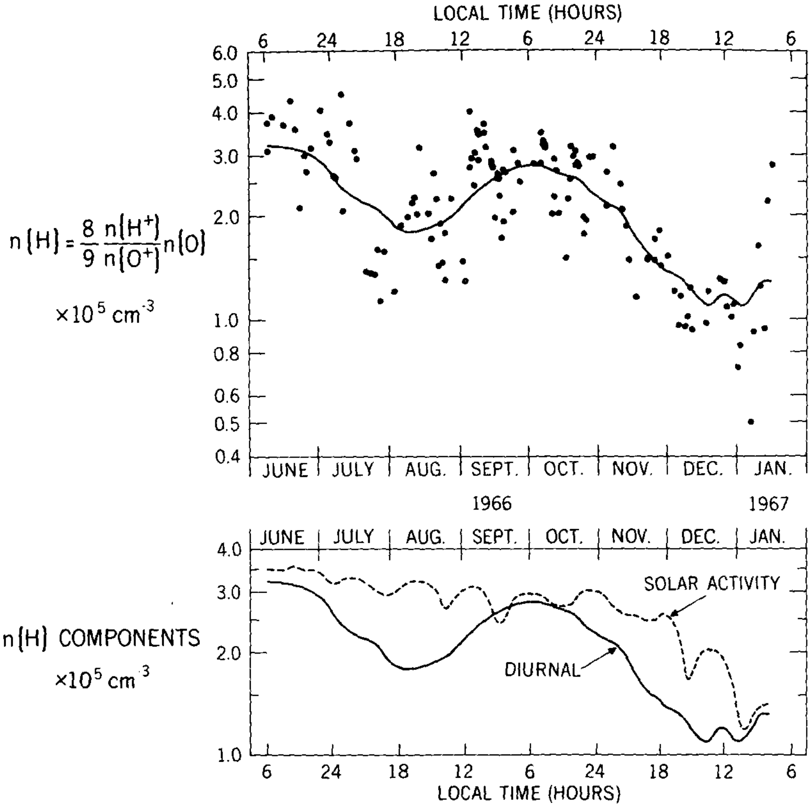

Figure 2–The observed hydrogen temporal variation and two of its components.

In conclusion, I would like to speak about the significance of these results. As shown in Table I, our observations differ markedly from the hydrogen behavior given by several model atmospheres currently in use, both in the amplitude of the diurnal variation and in absolute hydrogen density. Our factor of 2 for the night-to-day density ratio clearly disagrees with both the CIRA (Ref. 1) and Jacchia (Ref. 2) empirical models. It tends to confirm, instead, the theoretical hydrogen models of McAfee (Ref. 3) and Patterson (Ref. 4), both of which include the effects of lateral flow.

The last column in this table shows that our observed hydrogen density at 350-km altitude exceeds previous estimates by a factor of 3 to 10. This new information on the thermospheric hydrogen content could have important implications, and I will mention two.

TABLE I. Atomic Hydrogen in the Thermosphere

		$\frac{n(H)_{NIGHT}}{n(H)_{DAY}}$	$\overline{n(H)}$ at 350 km
MODEL ATMOSPHERES	CIRA	~1.1	4×10^4
	JACCHIA	~4	1×10^5
THEORETICAL HYDROGEN MODELS (INCLUDING LATERAL FLOW)	McAFEE	~2	
	PATTERSON	~2	
EXPLORER 32 IN SITU OBSERVATIONS		~2	3×10^5

First, the interpretation of airglow observations of the hydrogen geocorona is dependent on an assumed global hydrogen distribution at thermospheric heights; a spherically symmetric distribution (that is, one with no day-to-night difference), which is frequently assumed, is not correct according to our results.

Second, a revised hydrogen distribution could have important implications for our understanding of the ionosphere because the protonosphere is populated during the day by hydrogen ions created at lower altitudes by charge transfer between atomic hydrogen and O^+. At night this process reverses, and the protonosphere contributes to the maintenance of the nighttime *F* region. A full evaluation of these processes is clearly dependent upon knowledge of the atmospheric hydrogen density and its variation with time.

CHAIRMAN:

Questions?

MEMBER OF THE AUDIENCE:

You have shown that some of your measurements deviate somewhat from the standard models, but they do not reflect the knowledge of the atomic oxygen concentrations based on the same models. What reason do you have to believe that oxygen does not vary just as much as your deduced hydrogen content?

MR. BRINTON:

As I mentioned, we verified the model which we use for oxygen by means of pressure gage results from the same satellite, Explorer 32. Now, in the altitude range of these observations, the composition of the atmosphere is almost pure oxygen; and in the very limited range of latitude and longitude covered by these observations, George Newton's pressure gage results (Ref. 5) are in essentially perfect agreement with the model that we use.

I think that it is the latitude limit on the observations that makes the model good; that is, we confine ourselves to midlatitudes above the continental United States.

CHAIRMAN:

Are there other questions?

MEMBER OF THE AUDIENCE:

There is another comment to that. The reason why I think the model is incorrect as far as hydrogen is concerned is that it assumes diffusive control. You have to include thermal escape; this has not been taken care of in the hydrogen models.

MEMBER OF THE AUDIENCE:

Would your higher hydrogen densities say something about the rate of escape of water from the atmosphere?

MR. BRINTON:

They may. Since hydrogen is formed by dissociation of water vapor, and the hydrogen escape rate is proportional to its density, and since we are obtaining densities a factor of 3 to 10 times higher than previous estimates, it would be implied that the loss of water vapor from the Earth's lower atmosphere is proceeding at a greater rate than heretofore thought. Most of the water vapor, of course, does not reach high enough altitudes because of the cold-trap effect.

MEMBER OF THE AUDIENCE:

I was wondering if you had compared your new results with the results that Keating and some of his associates had come up with.

MR. BRINTON:

Yes, we have. I think you are speaking of his drag results at very high altitude, 2000 km or so (Ref. 6). His results also indicate higher hydrogen densities by about a factor of 3 than predicted by the models.

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