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VELOCITY VARIATIONS OF AN EQUATORIAL PLUME THROUGHOUT A JOVIAN YEAR

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ABSTRACT

Analysis of features in the Equatorial Zone of Jupiter has shown that the equatorial plume reported by Pioneer 10 has existed for an 11-year interval. During this interval the plume has shown an acceleration which can be interpreted as a constant component of 3×10^{-8} m/sec^2 and a sinusoidal component which anticorrelates with the planetocentric declination of the sun, D_s, and has an amplitude of -0.96 meters per second per degree change of D_s. The sinusoidal component has been interpreted in terms of solar heating.

Throughout this interval of time the Equatorial Zone has appeared abnormally dark and has contained many dark projections along the northern edge. When the plume approaches to within 25 to 30° of these features they are deflected in the direction of motion of the plume and then dissipate or become obscured as the plume passes. After passage of the plume normal features are again observed.

INTRODUCTION

Based on data presented by Peek [1958], the Equatorial Zone has been abnormally dark and orange since 1961 with a short-term brightening occurring during the 1965-66 apparition. During this time interval most of the well-defined features observed on ground-based photographs have originated along the northern boundary of the zone. In general the most distinct features are dark projections extending southward toward the equator and are separated from each other by roughly 36° in longitude. In the intervening regions more nebulous white patches and ovals are observed. The dark features have drifted with an average longitudinal velocity of approximately 1.0 m/sec relative to System I over the 12-year interval. Interspersed among these normal features are slow-moving bright features measured by Reese (unpublished) and the equatorial plumes observed by the photopolarimeter team on Pioneer 10 and 11 as reported by Fountain et al. [1974] and further interpreted by Gehrels [1974].

The earlier slow-moving features and the equatorial plumes share several characteristics: they are frequently bright in blue light unlike other bright features in the Equatorial Zone, both types of features characteristically occur in pairs separated by roughly 180° longitude, and both types of features appear as a small bright nucleus preceded in the direction of motion by a well-developed dark region extending 5 to 6° ahead of the nucleus and followed by a bright elongated plume-like structure. In light of the fact that these two types of features display such similar characteristics while possessing maximum and minimum observed velocities relative to System I, a detailed analysis has been carried out in an attempt to ascertain the relationship of these features.

DATA REDUCTION

The data were reduced by a combination of detailed measurements and eye estimates of longitudinal position relative to a System I coordinate system. Since the magnitude of the data reduction would have been monumental had all photographs been measured in detail, a compromise technique was adopted. Photographs for a given apparition were subjected to the method of estimating the longitudinal positions and plotting directly onto a time versus longitude (Sys. I) coordinate system. These measurements consist of 20-50 individual observations of approximately 20 features each apparition. These data were then used to select specific photographs of highest quality which were subjected to the measuring technique described below. These accurate positional measurements indicate that the longitudinal drifts indicated by the eye estimate method are accurate to within ±2° longitude. Although this accuracy is not adequate to determine short-term oscillatory periods it is certainly accurate for the long-term drifts that are discussed in this analysis.

In an effort to determine the interaction of the equatorial plumes with other features in the Equatorial Zone, detailed measurements of the 1974-75 apparition have been made. Each discrete atmospheric feature to be measured is located with respect to the apparent center of the image which is defined by the equatorial and polar limbs of the planet. Due to geometric and photometric phase effects, the apparent center of the disk always appears displaced toward the bright limb with respect to the true center. Corrections for this exaggeration are included in the reduction in the manner described by Reese and Smith [1968]. The corrected positions and times of observation are converted to planetographic latitude and longitude. Since each plate contains 25 to 60 images obtained at recorded times over a short time span, coordinates of a feature can be derived based on an average of computed positions obtained for each of the better images on a photographic plate. The standard deviation for the feature can be computed and a typical value is less than 0°2.

DIRECT OBSERVATIONAL RESULTS

The plume-like features have been traced throughout the time interval from 1963 to the present. Figure 1 illustrates the general drift of these features relative to System I. It should be noted that the slow-moving features measured by Reese and the equatorial plumes reported by the photopolarimeter team of Pioneer 10 and 11 appear to be the same features which have existed for the greater part of a Jovian year. The plume observed by Pioneer 10 is labeled *a* while a less enduring companion is labeled *b* or *b'*. The thin solid lines represent dark projections into the Equatorial Zone from the northern edge of the equatorial jet. A comparison of features preceding 1963 with those following indicates that the dark projections are considerably disturbed by the passage of the plumes. It should be noted that this interval of time does not represent the average condition of the Equatorial Zone throughout photographic history. A similar darkening of the Equatorial Zone was generally reported from 1869 to 1888 with a brief brightening in 1877. Although this behavior coincides closely with the current condition, extensive darkening has not been reported during the intervening period.

Longitudinal measurements ranging in time from 9 March 1974 to 12 February 1975 yielded an average drift velocity relative to System I of 5.4 m/sec for the nucleus of plume *a* and 7.23 m/sec for plume *b*. During the apparition plume *b* showed an acceleration beginning on 31 July 1974 such that the average velocity over the period from 31 July 1974 to 11 December 1974 was 10.3 m/sec. Any correlation between a shift in latitude and the observed velocity of a plume occurs in a sense contrary to the conservation of angular momentum of the feature and must be interpreted as evidence of interaction of the feature with its surroundings. On 1 October 1974 the nucleus of plume *a* appeared to dissolve and another took its place following by approximately 15° longitude and traveling with the same velocity as the original nucleus.

The nuclei of the features *a* and *b* are observed to vary in size in a manner such that the nucleus of *a* varied from 4°.0 to 7°.0 in width and from 4°.0 to 8°.5 in length, while the nucleus of *b* varied from 4°.5 to 6°.0 in width and 4°.6 to 8°.0 in length. In both cases variations in length and width were strongly correlated in the sense of a general increase or decrease in the observed area of the nucleus. This variation in area was further correlated to a measured shift in latitude of the center of the feature indicating that as the feature increased in size it expanded southward as though it were constrained on the northward edge. The average latitude was 6°.7 ± 0°.1 for the nucleus of *a* and 7°.1 ± 0°.1 for the nucleus of *b*.

At any given time during the apparition approximately 10 dark projections are observed along the northern edge of the zone. When one of the plumes approaches to within 25 to 30° of a dark projection the velocity of the projection increases and the feature moves toward the nearest leading projection. The accelerated feature either dissolves or coalesces with the leading feature. After a plume has passed, dark projections again appear rotating at a rate less than or about equal to System I.

ANALYSIS OF THE DATA

From measurements of plume α, longitudinal positions listed in Table I have been derived for times near the beginning and end of each apparition.

TABLE I

System I Longitudes of Plume A

Date	Longitude
63/05/30	182°
64/03/27	310
64/06/15	355
64/11/07	59
65/04/15	90
65/07/11	108
65/12/12	176
66/05/08	212
66/08/26	249
67/05/20	223
67/10/15	196
68/07/10	180
68/10/25	179
69/07/03	151
69/12/07	130
70/03/18	109
70/04/28	87
70/08/28	6
71/01/02	299
71/06/25	181
71/09/14	157
72/02/20	95
72/11/20	22
73/03/29	326
74/04/29	148
75/02/17	37

Velocities have been computed as simple differences of this table ($\Delta L/\Delta t$) and assigned to times corresponding to the midpoint of each time interval. The resulting velocities as a function of time are plotted in Fig. 2. Inspection of this plot suggests the observed variation is the result of a constant acceleration term and an oscillatory component. When maximum and minimum velocities are compared with the variation of the planetocentric declination of the sun, D_s, it is observed that the minimum velocity occurs when D_s is a maximum and the maximum velocity at minimum D_s. In light of of this fact, a least squares solution of the form

$$V(T) = A_0 + A_1(T - T_0) + A_2 D_s(T) \qquad (1)$$

with T_0 equal to 30 May 1963 has been obtained yielding values A_1 corresponding to a constant acceleration of 2.9 x 10^{-8} m/sec^2 and for A_2 of -0.96 meters per second per degree change of D_s. This result is plotted in Fig. 2.

A separate analysis of the longitudinal data requires a constant acceleration of 3.04 x 10^{-8} m/sec^2 and a sinusoidal component having a period of 4,333 days, equal to Jupiter's period of revolution, and an amplitude of 126° with a zero phase on 25 September 1964 to produce minimal residuals. When these two components are removed a secondary oscillation having a period of 1,196 days is suggested. This also agrees with the variation of D_s, since D_s was at a maximum on 25 September 1964.

INTERPRETATION OF THE SINUSOIDAL DRIFT OF PLUME A

The velocity of thermal winds predicted by Stone [1967] is directly related to the distance from the solar equator; therefore, since the nucleus of the plume remains relatively fixed at 7° latitude and the planetocentric declination of the sun varies from -3°.07 to +3°.07, the observed velocity may reflect a variation in the zonal wind due to solar heating. Using Stone's equation (17) and modifying it to include the drift of the solar equator, we get

$$\left[\frac{T(0°) - T(10°)}{10°} - \frac{T(0°) - T(4°)}{4°}\right]\frac{\Delta Z\ g}{fT\Delta y} = \Delta u \qquad (2)$$

where Δu is the observed change in velocity at 7° latitude, f is the Coriolis parameter $2\Omega \sin \phi$ and equal to 4.29×10^{-5} sec^{-1} at $\phi = 7°$, T is the temperature and is assumed to be 160°K, the local gravitational acceleration g is 2.6×10^{3} cm/sec^{2}. A conversion factor Δy equal to 10^{8} cm/degree of latitude is required to express the results in terms of latitudinal variation. $T(\phi)$ can be evaluated if simple radiative equilibrium is assumed by applying the expression given by Stone [1972], where for the case of an isotropic internal heat source

$$T(\Delta\phi, Z) = T(Z)\left[\frac{(4/\pi)\cos\Delta\phi + q}{1 + q}\right]^{1/4} . \qquad (3)$$

Here $\Delta\phi$ is the distance from the solar equator, q is the ratio of heat flux received from the interior to the solar flux and is taken equal to 1.0 based on values reported by Chase et al (1974). When T(Z) is equal to 160°K, T(10°) = 164°.85, T(4°) = 165°.15 and T(0°) = 165°.20K. If these values are substituted into equation (2) a value of the depth to which the horizontal temperature gradient extends, ΔZ, equal to 70 km is required to predict a 6 m/sec change in the velocity at +7° latitude. This value is within the currently accepted range; therefore, solar heating may be the source of the sinusoidal component of the velocity.

CONCLUSION

The equatorial plumes appear to be long-lived and drifting at a rate which is independent of dark projections at the same latitude. Their long-term motion can be interpreted as a two-component velocity. A linear term yielding an acceleration of 3×10^{-8} m/sec^2, which may be associated with the zonal darkening, is modulated by a sinusoidal component that can be interpreted as variation in solar heating due to the shift of the sun's declination.

As the plumes catch up and overtake dark projections along the northern edge of the Equatorial Zone they appear to generate a disturbance which propogates 25 to 30° ahead of the nucleus and modifies the motion of the projections. There is evidence that some of the dark projections have lifetimes greater than one year.

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REFERENCES

Chase, S. C., Ruiz, R. D., Münch, G., Neugebauer, G., and Schroeder, M. 1974. Pioneer 10 Infrared Radiometer Experiment: Preliminary Results. *Science* 183: 315-317.

Fountain, J. W., Coffeen, D. L., Doose, L. R., Gehrels, T., Swindell, W., and Tomasco, M. G. 1974. Jupiter's Clouds: Equatorial Plumes and other Cloud Forms in the Pioneer 10 Images. *Science* 184:1279-1281.

Gehrels, T. 1974. The Convectively Unstable Atmosphere of Jupiter. *J. Geophys. Res.* 79: 4305-4307.

Peek, B. M. 1958. *The Planet Jupiter*. London: Faber and Faber.

Reese, E. J. and Smith, B. A. 1968. Observations of Io at Inferior Geocentric Conjunction. *Contributions of the Observatory, New Mexico State University* 1: 66-69.

Stone, P. H. 1967. An Application of Baroclinic Stability Theory to the Dynamics of the Jovian Atmosphere. *J. Atmos. Sci.* 24: 642-652.

Stone, P. H. 1972. Simplified Radiative-Dynamical Model for the Static Stability of Rotating Atmospheres. *J. Atmos. Sci.* 29: 405-418.

FIGURE CAPTIONS

Fig. 1. Longitudinal drift of plume-like features in the Equatorial Zone. The feature designated a is the plume which was reported by the photopolarimeter team of Pioneer 10 while the features labeled b and b' are less enduring but similar features. The longitudinal scale has been expended beyond 0-360° to illustrate the total drift of the features in System I with respect to dark projections (thin dark lines) along the north edge of the zone.

Fig. 2. The relation of the velocity of plume a to the planetocentric declination of the sun. The velocities as a function of time are compared with a least squares solution of the data, where $A_0 = -3.98$, A_1 corresponds to 3×10^{-8} m/sec^2 and $A_2 = -0.96$ m/sec per degree shift of D_s. A residual is observed which suggests a secondary oscillation with a period of 1,196 days.

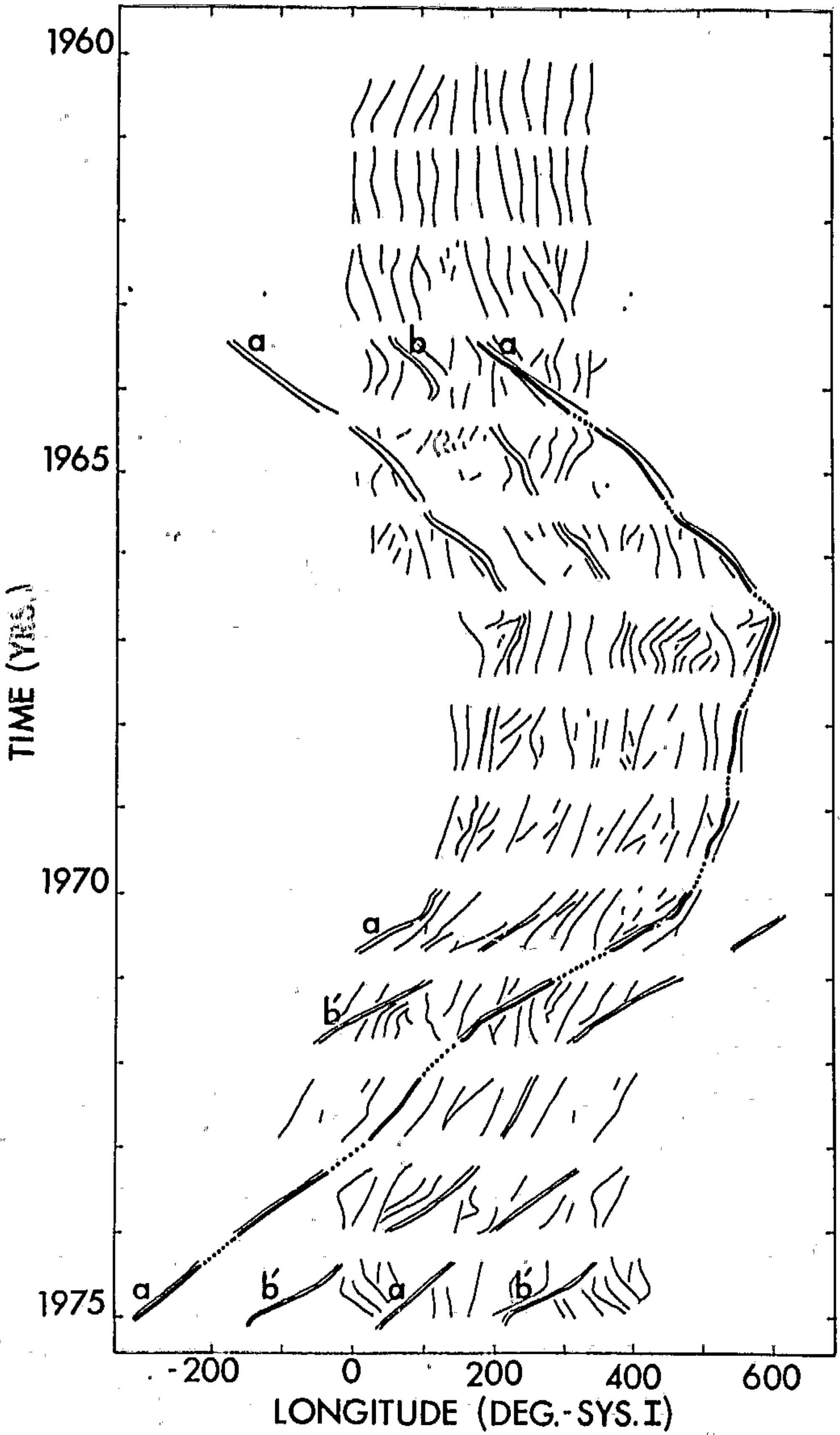
1960
1965
1970
1975
TIME (YRS.)
-200
0
200
400
600
LONGITUDE (DEG.-SYS.I)
a
b
a
a
b
a
b
a
b

FIG 1

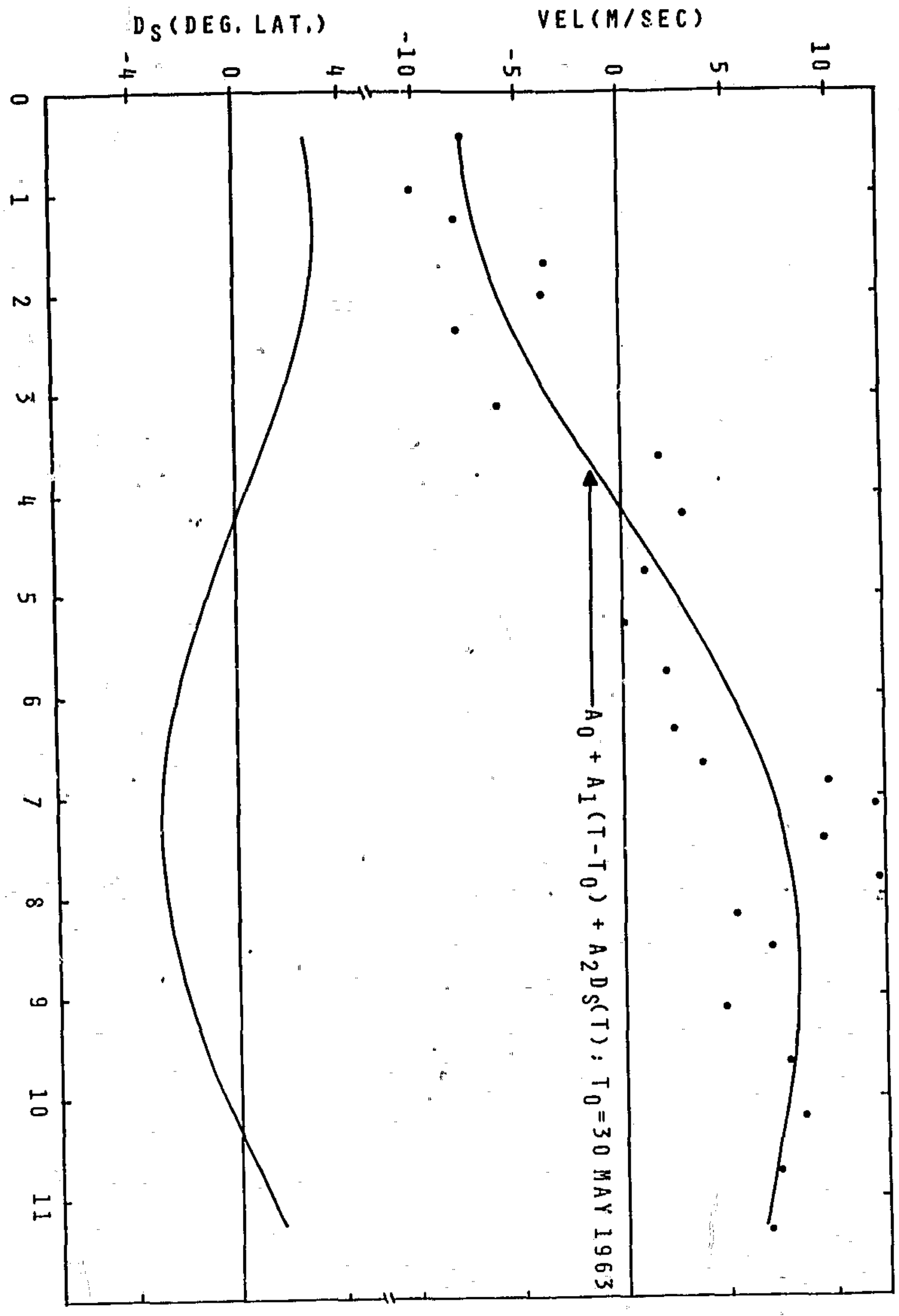

FIG. 2.