ing drift rate prevents the establishment of a base line for the removal of frequency bias, which has so far made the further analysis of the exit data impossible.

It has been mentioned previously that the temperature profiles derived from radio occultation and those derived from Earth-based and spacecraft spectroscopic observations can only be reconciled under one of two conditions. The first is the presence of obscuring layers high in the atmosphere of Jupiter, which in effect may cause the infrared observations to be taken at pressures of about 1 to 10 mbar. This explanation, however, is difficult to reconcile with the determinations of the abundance of H_2, CH_4, and NH_3 above the visible clouds on Jupiter, as well as the observations at microwave wavelengths, which also indicate a temperature of 130 K at a pressure of 0.5 atm (*6*).

The other explanation involved the presence of propagation effects other than pure refraction in the layers of Jupiter atmosphere probed by radio occultation. It must be pointed out that the process of radio occultation data inversion is strictly valid only under the assumption that all the phase change is being introduced by refraction in a homogeneous, spherically symmetrical atmosphere. Deviations from these assumptions will introduce errors in the results. Several such mechanisms have been suggested including turbulent scattering, ducting, and diffraction.

In order to help visualize the nature of the disagreement, the expected residual phase change as a function of time for an atmosphere corresponding to the IR model was computed and is shown in comparison with the observed Pioneer 11 entry data in Fig. 5. It is clear that in the actual data the phase always changes at a slower rate than that required by the IR model. Thus, any explanation of the IR–radio occultation disagreement must show a rate of phase change as a function of time lower than that expected under the conditions of atmospheric refraction only. It is apparent that explanations such as turbulent scattering would necessarily require that the total phase path be lengthened; hence, they are difficult to reconcile with the observation. The possibility of extraneous phase changes being introduced by diffraction around an NH_3 vapor absorption layer having a small scale height has recently been suggested (*7*) and is currently under investigation. It remains for the results

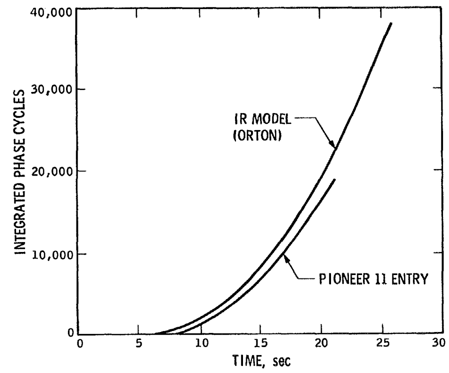

Fig. 5. Comparison of the residual phase expected from the Pioneer 11 trajectory with the IR model atmosphere and observed data.

of this investigation to determine whether or not this could be a possible explanation for the disagreement.

The Pioneer 11 profile of pressure versus radial distance from the center of Jupiter was combined with similar measurements from Pioneer 10 to determine the oblateness of the planet. Ellipses were fitted to the radii of equal pressure in a least-squares sense down to 1000 mbar. At the 1-mbar level the oblateness calculated was 0.06496 ± 0.0001, the equatorial radius was 71,610 ± 6 km, and the polar radius was 66,958 ± 4 km. At the 160-mbar level the calculated oblateness was 0.06547 ± 0.0001, the equatorial radius was 71,494 ± 6 km, and the polar radius was 66,812 ± 4 km. Using the results of the Pioneer 10 celestial mechanics experiment on the gravity harmonics J_2 and J_4, the mass of Jupiter (*8*), and the above values of the oblateness, we calculated the rotation period at the 1-mbar level to be 9 hours, 55 minutes, 46 seconds ± 1 minute, 6 seconds, which is in excellent agreement with the system II rotation of Jupiter. The rotation period at the 160-mbar level was calculated to be 9 hours, 50 minutes, 30.4 seconds ± 1 minute, 5 seconds, in good agreement with the ground-based observations of the system I rotation of Jupiter.

Ionospheric data were also obtained from both the entry and exit measurements. The new measurements confirmed earlier results obtained for Pioneer 10 (*2*) and show that Jupiter's ionosphere consists of a number of layers distributed over an altitude range of about 3000 km. A preliminary analysis indicates a topside plasma temperature of about 750 K on the assumption that H^+ is the principal ion.

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References and Notes

1. A. Kliore, D. L. Cain, G. Fjeldbo, B. L. Seidel, S. I. Rasool, *Science* **183**, 323 (1974).
2. ———, paper II-VII.1.4 presented at the 17th Committee on Space Research (COSPAR) meeting (São Paulo, Brazil), 24 June to 1 July 1974.
3. G. Münch, G. Neugebauer, A. Ingersoll, paper II-VII.1.5 presented at the 17th Committee on Space Research (COSPAR) meeting (São Paulo, Brazil, 24 June to 1 July 1974.
4. G. Fjeldbo and V. R. Eshleman, *Planet. Space Sci.* **16**, 1035 (1968); A. Kliore, in *Mathematics of Profile Inversion*, L. Colin, Ed. (National Aeronautics and Space Administration Publication TM X-63, 150, Washington, D.C., 1972), p. 3-1.
5. G. Orton, personal communication.
6. S. Gulkis, M. J. Klein, R. L. Poynter, in *Exploration of the Planetary System*, Woszczyk and Iwaniszewska, Eds. (Reidel, Dordrecht, Netherlands, 1974), p. 367.
7. S. Gulkis, personal communication.
8. J. D. Anderson, G. W. Null, S. K. Wong, *J. Geophys. Res.* **79**, 3661 (1974).
9. We thank C. F. Hall of the Pioneer Project Staff at NASA Ames Research Center and the Deep Space Network personnel and the Pioneer Navigation Team at the Jet Propulsion Laboratory (JPL) for the acquisition of our data. Special thanks is due to the Occultation Planning Group at JPL and NASA Ames Research Center. This work represents one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under NASA contract NAS 7-100.

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Gravity Field of Jupiter from Pioneer 11 Tracking Data

Abstract. *Significantly improved values of the zonal gravity harmonic coefficients* J_3, J_4, *and* J_6 *of Jupiter have been obtained from a preliminary analysis of Pioneer 11 spacecraft Doppler data taken while the spacecraft was near Jupiter. The new results, which will have an important application as boundary conditions for theoretical models of Jupiter's interior, are consistent with a planet in hydrostatic equilibrium.*

Two-way S-band Doppler data were obtained from Pioneer 11 during its Jupiter encounter by stations of the National Aeronautics and Space Administration–Jet Propulsion Laboratory Deep Space Network. Three 64-m antennas (at Goldstone, California; Canberra, Australia; and Madrid, Spain) provided data with a typical root-mean-square noise of 0.005 hertz for a 60-

second counting interval or, equivalently, a one-way range rate error of 0.3 mm/sec over the same interval.

The distance of closest approach of Pioneer 11 to the center of Jupiter was about 1.62 Jupiter radii (R_J). Two-way Doppler data were taken up to 1.75 R_J on the incoming trajectory to Jupiter, and again starting at 2.0 R_J on the outgoing trajectory. The remaining 1 hour of data down to 1.62 R_J was lost because of occultation by the planet. Because Pioneer 11 was inside the closest approach distance of Pioneer 10 (2.8 R_J) for 2.7 hours, it has been possible to obtain unprecedented detail in the Jupiter gravity field from the Pioneer 11 data.

The zonal harmonic coefficients J_2, J_3, J_4, and J_6 in Jupiter's gravity field are given in Table 1 for Pioneer 10 and Pioneer 11 for an assumed equatorial radius of 71,398 km. Because our analysis of spacecraft gas leaks and other systematic errors is incomplete, we have assigned conservative standard errors to our Pioneer 11 results. These results are in excellent consistency with those from Pioneer 10. The solution for parameters depending on higher inverse powers of distance in the potential function (J_3, J_4, and J_6) was much improved by the close Pioneer 11 flyby. On the other hand, the more distant Pioneer 10 trajectory had yielded only a loose bound on J_3 and no significant solution for J_6. The small values obtained for J_3 and J_6 from Pioneer 11 support the assumption that Jupiter is in hydrostatic equilibrium.

The zonal coefficients J_2, J_4, and J_6 are used as boundary conditions for interior modeling of Jupiter. In particular, the higher coefficients J_4 and J_6 determine the pressure-density profile in the outer envelope, which is currently limited in accuracy by the error in J_4 (*1*). The profile from Pioneer 10 has been used along with other modeling assumptions to derive a temperature of 250° ± 40°K at a pressure of 1 bar (*1*).

Table 1. Jupiter gravity harmonics from an analysis of Doppler data from Pioneer 10 (*2*) and Pioneer 11. Values are based on an assumed equatorial radius of 71,398 km.

Coefficient (× 10^6)	Pioneer 10	Pioneer 11
J_2	14,720 ± 40	14,750 ± 50
J_3	< 150	10 ± 40
J_4	− 650 ± 150	− 580 ± 40
J_6	Assumed zero	50 ± 60

Values for the masses of Jupiter and its four Galilean satellites were obtained simultaneously with solutions for the harmonic coefficients. These values were consistent with those from Pioneer 10 (*2*) but less accurate by a factor of 3 because of our incomplete analysis of unpredictable nongravitational accelerations. Satellite and planet masses will be presented elsewhere (*3*).

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References and Notes

1. J. D. Anderson, W. B. Hubbard, W. L. Slattery, *Astrophys. J.* **193**, L149 (1974).
2. J. D. Anderson, G. W. Null, S. K. Wong, *J. Geophys. Res.* **79**, 3661 (1974).
3. G. W. Null, J. D. Anderson, S. K. Wong, in preparation.
4. This report presents the results of one phase of research carried out at the Jet Propulsion Laboratory, California Institute of Technology, under NASA contract No. NAS 7-100.

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Stratospheric Dust-Aerosol Event of November 1974

Abstract. *A strong incursion of dust and aerosol at an altitude of 20 kilometers was noted over Baja California and southern Arizona in mid-November 1974, as indicated by bluish-ashen daylight skies and colorful twilight glows of the type usually associated with volcanic eruptions. Infrared satellite observations and reports from other sources eliminated a possible oceanic origin in the eastern Pacific. The stratum is probably from the extensive eruption of Volcan de Fuego in Gautemala in October 1974.*

Major volcanic eruptions inject sufficient gas and ash into the high atmosphere to produce worldwide effects. The last volcano to cause such effects was Agung on Bali in 1963, but this event was undoubtedly augmented by the subsequent eruptions the same year of Irazu in Costa Rica and Surtsey in Iceland. The effect on the 20-km aerosol layer of the SO_2 and other material emitted in that eruption lasted 4 years, long after the initial ash particles would have precipitated out of the atmosphere. There have been minor enhancements of the aerosol layer from lesser eruptions since then.

The high ash clouds and aerosol layer associated with volcanic eruptions cause the appearance of highly colored twilight glows, first described in scientific detail after the eruption of Krakatoa in 1883 (*1*). This glow stratum is illuminated by sunlight after lower clouds are in the earth's shadow. When skies are free from clouds 200 to 500 km westward of the observer at sunset (or eastward at sunrise) the sunlight passing through a long atmospheric path is reddened, so that the aerosol stratum is deeply colored. The maximum display occurs about 35 to 40 minutes after sunset (or before sunrise), when the upper edge of the glow shows the curved limb of the earth projected on the stratum with the deepest red coloration at the upper edge of the glow. The altitude of the stratum can readily be deduced from the time the upper edge sets on the horizon. At Tucson (32°N) this glow-set time averages 45 to 47 minutes after apparent sunset, which yields altitudes in the range of 20 km. When distant clouds are present the time is shortened in proportion to the height of the screening cloud deck. The intense orange and red colors are also absent on these occasions. When only scattered clouds are present over the horizon these clouds often cast spectacular shadows on the glowing stratum.

Continued surveillance of the twilight sky from Tucson, which we began shortly after the appearance of twilight glows from the 1963 eruption of Agung (*2*), showed that the aerosol layer had remained at its normal level since 1970; an exception to this was a brief stratospheric cloud in 1971 reported by Volz (*3*), which he traced to an unreported eruption in the Aleutian chain. It should be noted that even during quiescent years the 20-km aerosol layer shows a fall enhancement beginning in late September or early October, apparently when the ozone concentration rises in the lower ozonosphere. On the night of 9 November 1974, however, we saw a brilliant twilight glow while we were flying southeast out of Mazatlan, Mexico. Timing of the glow set was complicated since our aircraft was flying toward Guadalajara, but after estimating our velocity and altitude and the time of disappearance of the glow, we became suspicious that the glow was due to an unusual enhancement of the 20-km aerosol layer. All the usual color and intensity