N86-11139

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A Modeling Analysis Program for the
JPL Table Mountain Io Sodium Cloud Data

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October 1985

Interim Report for Period
June 1, 1985 to August 31, 1985

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle A Modeling Analysis Program for the JPL Table Mountain Io Sodium Cloud		5. Report Date October 1985
		6. Performing Organization Code
7. Author(s) William H. Smyth		8. Performing Organization Report No.
9. Performing Organization Name and Address Atmospheric and Environmental Research, Inc. 840 Memorial Drive Cambridge, MA 02139		10. Work Unit No.
		11. Contract or Grant No. NASW-3949
		13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address NASA Headquarters Contracts and Grants Division Washington, DC 20546		Interim Report 6/1/85 – 8/31/85
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract

    A data quality review for the entire set of the 1981 Region B/C images has been completed and is presented. The review indicates that almost all images are of sufficent quality to be valuable in our analysis of this data set. Five data-correlation studies for the same data set have also been completed and are useful in classifying and studying the sodium cloud morphology and its interactions with solar radiation pressure and the plasma torus. Additional progress in developing new image processing techniques and in improving the Io sodium cloud model is also discussed.

17. Key Words (Selected by Author(s)) satellite atmospheres planetary magnetospheres	18. Distribution Statement		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 21	22. Price*

*For sale by the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151.

I. Summary of Research Performed in the First Quarter

Research activities in the first quarter have successfully included
(1) completion of a data quality review for the entire set of the 1981 Region
B/C images, (2) completion of five data-correlation studies for the entire set
of 1981 Region B/C images useful in studying the sodium cloud morphology and
its interactions with solar radiation pressure and the plasma torus, and
(3) continuation of data processing and model preparation to support image
analysis to be undertaken in the second quarter.

1. Data Quality Review of the 1981 Region B/C Images

Observational parameters for the 263 Region B/C images of the 1981 JPL
data acquired over 14 nights are summarized in numerical form in Table 1 and
in graphical form in Figure 1. Most of these images have been processed only
preliminarily to remove background signals. Images on May 4, 5, 12, 13 and
June 4 had undergone further processing to remove the instrumental response
function and to normalize the image intensity. Because of this, the 110
images (42% of the data set) acquired on May 4, 5, 12 and 13 were chosen and
thoroughly reviewed during the first project year. As a result of this
review, further refinements in the image processing of these data frames were
identified and the development of an improved image processing procedure is
now nearing completion. The quality of the remaining 153 images is reviewed
here as a prerequisite for selection of images in our model-data studies.

The results of this data quality review are summarized in Table 2 and
were compiled by manual inspection of photographical products for each image
produced prior to this project by the Image Processing Laboratory of JPL.
Most images are composed by adding three data frames, where each data frame
generally represents an exposure time of approximately ten minutes. Some
images are, however, composed of only one or two data frames. The quality of
the images is rated in the right hand column of Table 2 and qualifying
comments are also indicated. As can be seen, almost all of the images are of
sufficient quality to be valuable in our analysis of this data set. Those
images selected for more detailed studies will, as noted earlier, undergo
further image processing.

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2. Data Correlation Studies

Five data correlation studies are defined in Table 3 for the set of 1981 Region B/C images. Each study provides a different classification for these images based upon their Io geocentric phase angle, ϕ, and their Io System III magnetic longitude angle, ψ. The five classifications are useful in identifying and then studying the effects of radiation pressure, the atom source characteristics, and the plasma torus sink characteristics on the morphology of the sodium cloud. Each correlation study lists those images that are appropriate for the defined classification, regardless of the image data-quality summarized in Table 2. Incorporating the results of Table 2 will then aid in selection and prioritization of images to undergo further image processing and then model-data analysis.

The results of the five data correlation studies of Table 3 are summarized in Tables 4-8, respectively. From Table 4, consecutive image studies are possible on all 14 nights, but short exposure times on March 25 and questionable data quality on June 4 might eliminate these two evenings (see Table 2). From Table 5, cloud stability studies are available for three image sequence pairs (also see Figure 1) which all have good to excellent data quality. If comparisons of these image sequence pairs indicate that the sodium cloud and its interaction with the plasma torus are stable over a few month time interval, then the procedure of comparing images of different dates in the correlation studies III, IV and V will represent a valid multi-faceted look at a common (although periodically time dependent) cloud-torus state. From Table 6, east-west image studies of the cloud morphology may be undertaken and used to explore the nature of east-west difference in the plasma torus also identified by optical torus emissions (Morgan and Fertel, 1984; Morgan, 1985) and by UV emission from the Io plasma torus (Sandel and Broadfoot, 1982; Shemansky and Sandel, 1982). From Table 7, System III variations in the electron properties of the plasma torus may be investigated by comparison and analysis of images. From Table 8, the effects of viewing angle on the cloud morphology may be investigated. The effects of system III variation can also be investigated by comparing images for somewhat similar phase angles, and excellent cases exist for ψ in the range from about 160° to 310° (see Table 8 and Figure 1).

3. Data Processing and Model Preparation

Development of image processing techniques to refine the 1981 Region B/C images has proceeded slower than expected at MIPL (Multimission Image Processing Laboratory of JPL) during the first quarter. Completion and verification of these techniques (Task 1b of Table 9) are now expected in the second quarter. Selected images will then be processed (Task 3a of Table 9) and data-model comparisons will then focus on some of the image studies discussed in the previous section. The new lifetime for sodium atoms in the Io plasma torus further improved in the third quarter of the first project year has been fully integrated in the cloud model this quarter in anticipation of these modeling studies in the second quarter.

II. Program for the Second Quarter

Data processing priority 1.b of Table 9 will be completed and selected images will be processed using this new technique (initiating Task 3.a of Table 9). Modeling analysis of these newly processed images will then begin and specific studies outlined in Table 3 will be pursued.

References

Morgan, J.S. (1985) Models of the Io Torus. Icarus, 63, 243.

Morgan, J.S., and Fertel, J.H. (1984) An Imaging Search for Optical East-West Asymmetries in the Io Torus, BAAS, 16, 662.

Sandel, B.R. and Broadfoot, A.L. (1982) Io's Hot Plasma Torus - A Synoptic View from Voyager. J.G.R., 87, 212.

Shemansky, D.E., and Sandel, B.R. (1982) The Injection of Energy into the Io Plasma Torus. J.G.R., 87, 219.

1981 IO SODIUM CLOUD DATA
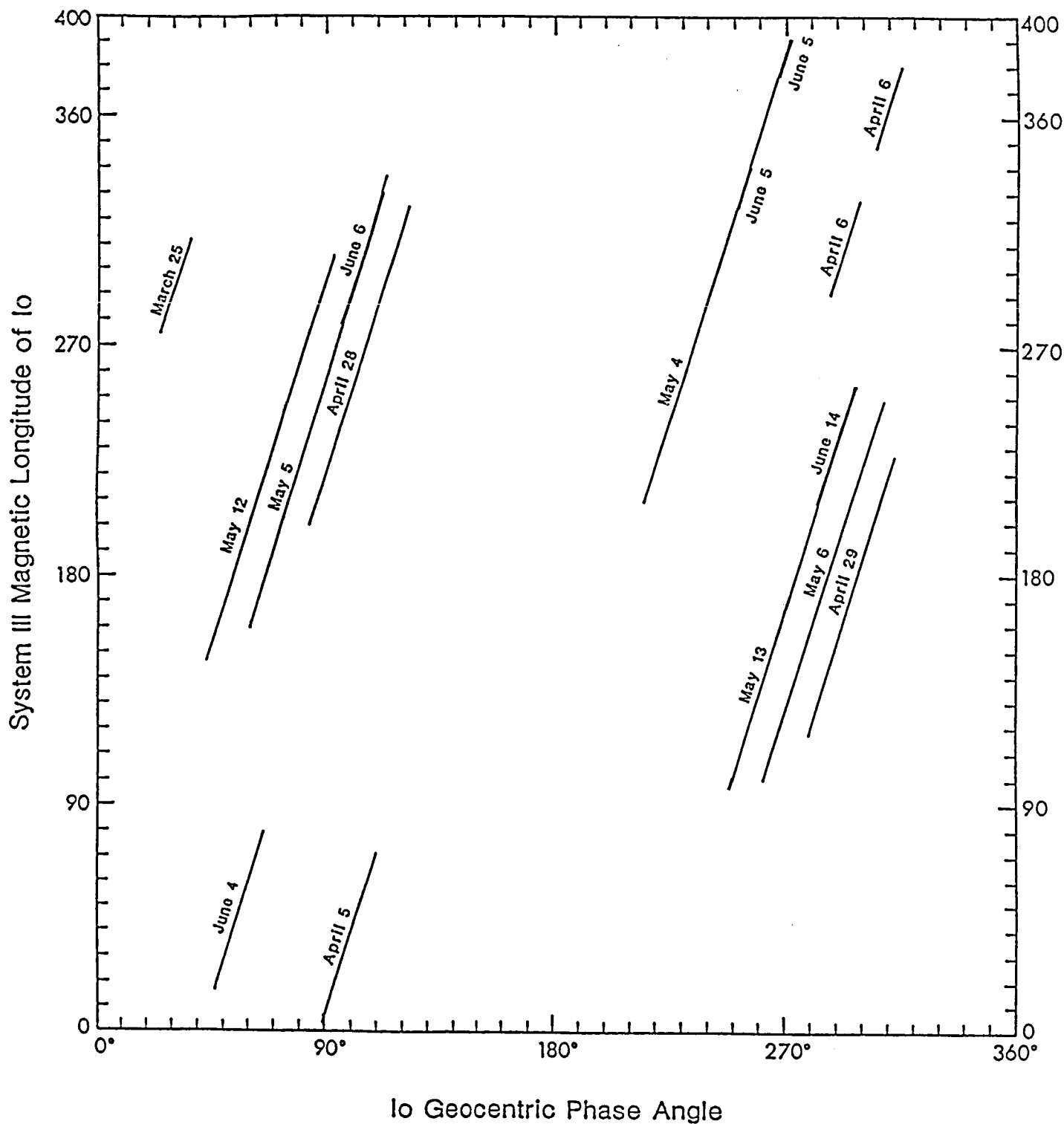## FROM TABLE MOUNTAIN OBSERVATORY

Figure 1. Observing Parameters for 1981 Io Sodium Cloud Images.

The angular coverage for the Io geocentric phase angle and the System III magnetic longitude of Io over which Region B/C images were recorded in the JPL Table Mountain Data Set is indicated for all 14 nights of observations.

Table 1

1981 Region B/C Images: Observing Chronology

Date of Observations	Start Conditions			End Conditions		
	Time (UT)	Io Phase Angle (deg)	Magnetic Longitude of Io[†] (deg)	Time (UT)	Io Phase Angle (deg)	Magnetic Longitude of Io[†] (deg)
25 March	7:03	25.2	275.3	8:23	36.5	312.7
5 April	5:18	89.6	365.0	7:40	109.5	70.9
6 April	4:33	287.3	290.7	5:52	298.5	327.3
6 April	6:38	305.1	348.5	7:44	314.4	19.1
28 April	4:21	84.0	200.2	8:50	121.9	324.9
29 April	3:18	279.2	117.5	7:15	312.9	227.1
4 May	3:10	215.4	209.2	9:43	271.4	30.8
5 May	3:17	60.0	159.4	9:25	111.7	330.2
6 May	3:07	262.5	101.4	8:27	307.9	249.5
12 May	3:15	44.5	147.5	8:56	92.4	305.7
13 May	3:20	248.9	96.6	8:51	296.0	249.6
4 June	3:34	47.2	377.3	5:48	66.0	79.5
5 June	3:38	251.7	325.6	4:07	255.8	339.1
5 June	5:27	267.2	16.0	5:55	271.1	29.0
6 June	3:48	95.8	278.0	5:56	113.9	337.3
14 June	3:38	282.7	208.4	5:20	297.1	255.7

[†]System III (1965)

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Table 2
1981 Region B/C Images: Data Quality Review

Date (UT)	UT Start	UT End	Frames	Quality
March 25	–	–	–	– [1]
	5:11	8:15	29	usable[1]
	–	–	–	– [1]

[1]only raw data available; 16 images with most exposures 1 1/2 minutes, since images were so close to Jupiter; must add images for useful results; images were heavily masked in both east and west directions.

Date (UT)	UT Start	UT End	Frames	Quality
April 5	5:18	5:22	18	marginal[2]
	5:25	5:32	19	good[2]
	5:36	5:46	20	good[2]
	5:48	6:03	21	good[2]
	6:05	6:20	22	good (some saturation)[2]
	6:24	6:44	23	good (some saturation)[2]
	6:47	7:02	24	good[2]
	7:04	7:14	25	very good[2]
	7:17	7:24	26	very good[2]
	7:26	7:36	27	very good[2]
	7:40	7:50	28	very good[2]

[2]Part of forward cloud truncated by mask.

Date (UT)	UT Start	UT End	Frames	Quality
April 6 (one)	4:33	4:40	11	good[3]
	4:42	4:52	12	good[3]
	4:54	5:09	13	good[3]
	5:11	5:28	14	good[3]
	5:30	5:50	15	good[3]
	5:52	6:09	16	good[3]
(two)	6:38	6:55	22	good[3,4]
	6:59	7:09	23	good[3,4]
	7:11	7:23	24	good[3,4]
	7:25	7:42	25	good[3,4]
	7:44	8:01	26	good[3,4]

[3]only raw data available.
[4]probably part of forward cloud truncated.

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Table 2

(continued)

Date (UT)	UT Start	UT End	Frames	Quality
April 28	4:21	5:01	25-27	good
	4:37	5:13	26-28	very good
	4:49	5:24	27-29	very good
	5:03	5:34	28-30	very good
	5:15	5:45	29-31	very good
	5:25	5:56	30-32	very good
	5:36	6:07	31-33	very good
	5:47	6:18	32-34	very good
	5:58	6:30	33-35	very good
	6:09	6:40	34-36	excellent
	6:31	6:52	36,38[5]	very good
	6:43	7:03	38,39[6]	very good
	6:54	7:16	39,41[7]	very good
	7:07	7:27	41,42[6]	excellent
	7:07	7:37	41-43	excellent
	7:18	7:46.5	42-44	very good
	7:28	7:57.5	43-45	very good
	7:39	8:07	44-46	very good
	7:49	8:18	45-47	very good
	7:59	8:28	46-48	good
	8:10	8:38	47-49	good
	8:20	8:48	48-50	good
	8:30	8:58	49-51	good

[5]two frames only with 9 minute gap in the middle.
[6]two frames only.
[7]two frames with 1 minute gap in center.

Date (UT)	UT Start	UT End	Frames	Quality
April 29	3:18	3:43	1-3	usable
	3:26	3:57	2-4	good
	3:35	4:07	3-5	good
	3:48	4:19	4-6	good
	3:58	4:32	5-7	very good
	4:10	4:42	6-8	very good
	4:22	4:53	7-9	very good
	4:32	5:05	8-10	very good
	4:44	5:16	9-11	very good[8]
	4:55	5:32	10-12	very good
	5:06	5:43	11-13	very good
	5:21	5:55	12-14	very good[9]
	5:33	6:08	13-15	very good

Table 2

(continued)

Date (UT)	UT Start	UT End	Frames	Quality
April 29 (cont.)	5:45	6:21	14-16	good
	5:57	6:32	15-17	good
	6:10	6:42	16-18	good
	6:23	6:52	17-19	good
	6:33	7:02	18-20	good
	6:43	7:14	19-21	good
	6:53	7:25	20-22	good

[8] background level increasing.

[9] little portion of forward cloud truncated by mask.

May 6	3:07	3:25	5-7	usable (twilight)
	3:12	3:36	6-8	good
	3:18	3:46	7-9	good
	3:27	3:57	8-10	very good
	3:37	4:08	9-11	excellent
	3:47	4:20	10-12	excellent
	3:58	4:32(?)	11-13	excellent
	4:09	4:44	12,13[10]	good
	4:22	5:01	13,15[10]	good
	4:50	5:12	15,16[10]	good
	4:50	5:24	15-17	excellent
	5:03	5:35	16-18	excellent
	5:14	5:47	17-19	excellent
	5:25	5:59	18-20	excellent
	5:36	6:10	19-21	excellent
	5:48	6:20	20-22	excellent
	6:00	6:31	21-23	excellent
	6:11	6:43	22-24	excellent
	6:22	6:54	23-25	excellent
	6:33	7:04	24-26	excellent
	6:44	7:14	25-27	very good
	6:55	7:28	26-28	very good
	7:05	7:40	27-29	very good
	7:18	7:52	28-30	very good
	7:30	8:05	29-31	good
	7:41	8:16	30-32	good
	7:54	8:26	31-33	usable[11]
	—	—	32-34	no good

[10] no signal in frame 14.

[11] Jupiter close to horizon.

Table 2

(continued)

Date (UT)	UT Start	UT End	Frames	Quality
June 4	–	–	–	– [12]
	4:57	5:35	12-14	usable[13]
	5:09	5:47	13-15	usable[13]
	5:24	6:00	14-16	usable[13]

[12]perhaps more images, but must examine date on tapes.
[13]forward cloud may be partially truncated.

June 5 (one)	3:38	4:05	5-7	marginal[14]
	3:47	4:18	6-8	good[15]
(two)	5:27	6:09	11-13	good[15]
	5:40	6:25	12-14	good
	5:56	6:39	13-15	good
	6:12	6:54	14-16	good
	6:26	7:07	15-17	good

[14]lots of background noise.
[15]some background noise.

June 6	–	–	–	– [16]
	4:08	4:41	9-11	very good
	4:19	4:53	10-12	very good
	4:30	5:05	11-13	very good
	4:42	5:23	12-14	very good
	4:54	5:42	13-15	very good
	5:08	5:55	14-16	very good
	5:24	6:07	15-17	very good

[16]possibly more images.

June 14	3:38	4:04	5-7	usable[17,18]
	3:47	4:15	6-8	good[18]
	3:56	4:28	7-9	good
	4:05	4:40	8-10	good
	4:17	4:52	9-11	good
	4:29	5:05	10-12	good
	4:41	5:19	11-13	good
	4:53	5:32	12-14	good

[17]signal to noise not very good
[18]portion of forward cloud truncated by mask

Table 3

1981 Region B/C Images: Five Correlation Studies†

I. Consecutive Image Study: $\phi(t)$, $\Psi(t)$

II. Cloud Stability Study: $(\phi_1, \Psi_1) \approx (\phi_2, \Psi_2)$
    image sequences separated by 32 days

III. East/West Image Study: $\phi_W = \phi_E + 180°$

    $\Psi_E \approx \Psi_W$ only one image-sequence pair

    $\Psi_W \approx \Psi_E + 180°$ no image pairs

    $\Psi_E \neq \Psi_W$ many comparison images

IV. System III Variability Study: $\phi_1 = \phi_2$, $\Psi_1 \neq \Psi_2$

V. Io Phase Angle Variability Study: $\phi_1 \neq \phi_2$, $\Psi_1 = \Psi_2$

†ϕ = Io Geocentric Phase Angle

Ψ = Io System III Magnetic Longitude Angle

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Table 4

1981 Region B/C Images: Correlation Study I

<u>Consecutive Image Study</u>: $\phi(t)$, $\psi(t)$

Image data suitable on all 14 nights

1.	March 25	
2.	April 5	
3.	April 6	
4.	April 28	
5.	April 29	
6.	May 4	(June 5)
7.	May 5	(June 6)
8.	May 6	
9.	May 12	
10.	May 13	(June 14)
11.	June 4	

Table 5

1981 Region B/C Images: Correlation Study II

<u>Cloud Stability Study</u>: $(\phi_1, \psi_1) \approx (\phi_2, \psi_2)$

Three Image Sequence Pairs Suitable

(May 5, June 6)   Io east of Jupiter

(May 4, June 5)   Io west of Jupiter

(May 13, June 14)   Io west of Jupiter

Table 6

1981 Region B/C Images: Correlation Study III

East/West Image Study: $\phi_W = \phi_E + 180°$

1. East Images

ϕ_E	ϕ_W
March 25	May 4
May 12	May 4, May 6, May 13, June 5 (one, two)
June 4	May 4
May 5	April 29, May 4, May 6, May 13, June 5 (one, two)
June 6	April 6 (one), April 29, May 4, May 13, June 14
April 28	April 6 (one)*, April 29, May 4, May 6, May 13, June 5 (two), June 14

2. West Images

ϕ_E	ϕ_W
May 4	March 25, April 5, April 28, May 5, May 12, June 4
June 5 (one)	May 5, May 12
June 5 (two)	April 5, April 28, May 5, May 12
May 13	April 5, April 28, May 5, May 12, June 6
May 6	April 5, April 28, May 5, May 12, June 6
April 6 (one)	April 5, April 28*, May 5, June 6
April 6 (two)	no candidates
June 14	April 5, April 28, May 5, June 6
April 29	April 5, April 28, May 5, June 6

$*\psi_E \approx \psi_W$ in addition

Table 7

1981 Region B/C Images: Correlation Study IV

<u>System III Variability Study</u>[†]: $\phi_1 = \phi_2$, $\Psi_1 \neq \Psi_2$

Io East of Jupiter				Io West of Jupiter		
ϕ	Date	Ψ		ϕ	Date	Ψ
50	June 4	26		250	May 13	102
	May 12	167			May 4	323
60	June 4	58		255	May 13	118
	May 12	198			May 4	338
					June 5	338
65	June 4	72				
	May 5	172		260	May 13	133
	May 12	212			May 4	353
70	May 5	190		270	June 5	25
	May 12	231			May 4	25
					May 6	128
80	May 5	222			May 13	167
	May 12	263				
				280	May 6	157
90	April 5	5			May 13	197
	April 28	219				
	May 5	256		290	April 29	153
	May 12	294			May 6	190
					May 13	232
100	April 5	37			June 14	232
	April 28	251			April 6(one)	299
	May 5	288				
	June 6	288		300	April 29	185
					May 6	223
110	April 5	70				
	April 28	283		305	April 29	202
	May 5	322			May 6	238
	June 6	322			April 6(two)	350
				310	April 6	4
					April 29	219

[†]angles ϕ and ψ given in degrees

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Table 8
1981 Region B/C Images: Correlation Study V

Io Phase Angle Variability Study†: $\phi_1 \neq \phi_2$, $\psi_1 = \psi_2$

Ψ	Date	ϕ		Ψ	Date	ϕ
0	May 4	262		140	May 13	262
	April 16(two)	309			May 6	274
10	May 4	265			April 29	286
	April 6(two)	312		150	May 12	45
20	June 4	48			May 13	265
	April 5	94‡			May 6	277
	May 4	268‡			April 29	289
	June 5(two)	268‡		160	May 12	48
30	June 4	51			May 5	60
	April 5	97‡			May 13	268
	May 4	271‡			May 6	280
40	June 4	54			April 29	292
	April 5	100		170	May 12	51
50	June 4	57			May 5	63
	April 5	103			May 13	271
60	June 4	60			May 6	283
	April 5	106			April 29	295
70	June 4	63		180	May 12	54
	April 5	109			May 5	66
110	May 13	253			May 13	274
	May 6	266			May 6	286
120	May 13	256			April 29	298
	May 6	268		190	May 12	57
	April 29	280			May 5	69
130	May 13	259			May 13	277
	May 6	271			May 6	289
	April 29	283			April 29	301

Table 8
(continued)

Ψ	Date	φ		Ψ	Date	φ
200	May 12	60		250	May 12	75
	May 5	72			May 5	87
	May 13	280			April 28	99
	May 6	293			May 4	228
	April 29	304			June 14	295
210	May 12	63		260	May 12	78
	May 5	75			May 5	90
	April 28	87			April 28	102
	May 4	216			May 4	231
	May 13	283		270	May 12	81
	June 14	283			May 5	94
	May 6	296			April 28	105
	April 29	307			May 4	234
220	May 12	66		280	March 25	26
	May 5	78			May 12	84
	April 28	90			June 6	96
	May 4	219			May 5	97
	May 13	286			April 28	108
	June 14	286			May 4	237
	May 6	299		290	March 25	29
	April 29	310			May 12	87
230	May 12	69			June 6	99
	May 5	81			May 5	100
	April 28	93			April 28	111
	May 4	222			May 4	240
	May 13	289		300	March 25	32
	June 14	289			May 12	90
	May 6	302			June 6	102
240	May 12	72			May 5	103
	May 5	84			April 28	114†
	April 28	96			May 4	243
	May 4	225			April 6(one)	290†
	May 13	292				
	June 14	292				
	May 6	305				

Table 8

(continued)

Ψ	Date	φ		Ψ	Date	φ
310	March 25	36		330	June 6	111
	June 6	105			May 4	252
	May 5	106			June 5(one)	252
	April 28	117†		350	May 4	258
	May 4	246			April 6(two)	306
	April 6(one)	294‡				
320	June 6	108				
	May 5	109				
	April 28	120†				
	May 4	249				
	April 6(one)	297‡				

†Angles φ and ψ given in degrees

‡Io phase angles differ by approximately 180°

Table 9

Data Processing Priorities

1. Improve Techniques to Remove Distortion in the Brightness Distribution of Images

    a. Implement improved background subtraction techniques for images.

    b. Improve techniques for removal of image distortion near Io produced by continuum light scattered by Io.

2. Determine the Absolute Brightness Calibration for the Images

    a. Analyze 1981 1-D slit data on Io's disk and Region A image data to establish an absolute brightness calibration for the 1981 data.

    b. Analyze 1976-79 1-D slit data on Io's disk to establish a brightness calibration for the 1976-79 data.

3. Prepare Images for Modeling Analysis

    a. Using improved techniques in 1 above, remove brightness morphology distortions in a selected subset of images.

    b. Using the information in 2 above, absolutely calibrate this selected subset of images.