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Part III.

SOLUTION TO THE SMS DIGITAL DATA REGISTRATION PROBLEM.

PART III

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The method of treatment as well as the method of solution of the registration of SMS digital data are delineated herein. This portion of the final report concerns task 3.2.7.

Foreward

This is Part III of the final report under Contract DAEA18-76-C-0019 entitled Atmospheric Transmittance Study with the Meteorological Satellite Technical Area ~~of the Atmospheric Sciences Laboratory~~ at White Sands *see pt 1* Missile Range. Part I contains a study and development of band models for use in connection with techniques for the calculation of atmospheric transmittance along slant-paths. Part II contains the report on the studies related to the inversion of the radiative transfer equation for temperature, composition and possible cloud correction techniques in the 15μ CO_2 band region. Also included there is a discussion of the method used in this study for the calculation of atmospheric transmittances using line spectral parameters. Part III deals with the study of SMS digital data and their use in severe storm and cloud studies.

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1. Discussion of Effort

At the onset of the contract, discussion of the objectives brought to light the necessity of an accurate SMS digital data registration scheme to complete task 3.27, an examination of the relation of severity of storm to cloud development. Since an interest in that area was expressed by the contractor and it had been stated in the contract that the problem of registration would be looked into, it was decided to tackle the problem. Many other organizations have already and are dealing with the problem. It would ultimately be our task to assimilate the knowledge and expertise of those individuals in the field of registration to arrive at an accurate scheme adapted to the needs of the contractor.

A straightforward geometrical approach to the problem was proposed by the contractor. While work began on the dynamical aspects of geometrical transforms and Euler angles, a survey of the field was conducted. It was discovered that, among others, E. Smith, now of Colorado State University (C.S.U.) and formerly of Wisconsin, and C.E. Velez, of NASA Goddard Space Flight Center (NASA GSFC)[1] are experts in the field of registration and that their schemes, the former of a short-term attitude predictive nature and the latter of a long-term orbit and attitude predictive nature, are representative of the current two approaches to the problem. Contact with the two was initiated. A trip to CSU to talk to E. Smith was arranged. A demonstration of CSU's registration capabilities and a copy of a write-up on the system E. Smith and D. Phillips had developed at Wisconsin[2] was provided along with an offer of a copy of the software. Further study of the write-up indicated that the software would indeed be helpful so the request was made. A copy of the software was received in early December.

Dr. Velez was also contacted and offered to send us a copy of a report on the system his group at NASA along with a group from NOAA National Environmental Satellite Service (NOAA NESS) had developed.[3] We requested a copy of the software but this was not seen to be feasible because their package was actually part of two huge multipurpose software packages that require a lot of storage and that are virtually undocumented. Dr. Velez suggested a trip to NASA GSFC sometime after the first of the year to determine if their system would be suited to the needs of the contractor. Also, his group was in the process of rewriting and consolidating their software into one package for their new PDP 1170, which is compatible with Met. Sat.'s PDP 1145, and he anticipated the completion of the program by January. A trip to Washington, D. C. to include visits to both NASA GSFC and NOAA NESS was arranged.

The trip to Washington, D. C. on January 5-6, 1976 provided invaluable insights into the registration problem [see trip report in Appendix A]. Based on the facts that 1) the adaptation of Velez's scheme to the PDP 1170 was not completed, nor 2) was it accurate enough for our purposes (30-40 pictel elements vs. the needed 1-2 pictel elements), plus the fact that, 3) our attempt at a straightforward geometrical scheme proved to be futile [See Summary of SMS Data Processing System in Appendix B], it was decided all around that the best route would be to adapt a version of Wisconsin's, or the D. Phillips-E. Smith routine, a copy of which E. Smith had already sent us and the accuracy of which was professed to be 1-2 pictel elements. It was also decided that it would help if a copy of the mini-computer adapted Wisconsin version in use and offered by J. Billingsley's group at NASA GSFC was obtained.[4] A letter was sent requesting the software and documentation of the navigation segment of their METPAK. Meanwhile, an attempt was made to decipher NOAA NESS's version of their registration program, a copy of which was received during the trip to Washington. Because the large program is almost totally undocumented, it was decided that the great amount of effort that would be required to comprehend the program would not be justified by the result. Therefore, we proceeded with an in-depth analysis of the theory behind the D. Phillips-E. Smith routine which necessitated periodical communications with E. Smith. A mathematical overview of that analysis, based on the write-up of the scheme by D. Phillips and E. Smith, follows in Appendix C. The requested NASA GSFC software, which is a version of Wisconsin's McIDAS and which had already been adapted to a PDP 1145 system, was received mid-April. Based on the fact that it had already been adapted to a PDP 1145 and that its documentation was a great improvement over that in E. Smith's program, we decided to use the NASA GSFC version, developed by C. T. Mottershead of the Computer Sciences Corporation (CSC), as a basis for the prototype to be developed for the needs of the contractor.

Because the theory behind the Mottershead version is basically that of the D. Phillips-E. Smith scheme, the analysis in Appendix C also applies to Mottershead's. A thorough flowchart and investigation of parameters used was undertaken in the process of which correspondence with Mottershead was and is still being maintained. Basic IO handling routines, which are machine-dependent, are the major obstacle to the utilization of Mottershead's scheme as is. Approval for the use of Met Sat's PDP 1145, in conjunction with one of their personnel, on which to adapt the navigation program was given in June by the contractor. However, the PDP was not ready for routine use (thorough hardware and software system check-out was necessary) until recently. In the interim, sample calculations of various segments of Mottershead's navigation program (based on the test landmark data furnished within the program) were performed by hand to determine expected values of parameters. Time-consuming iteration calculations necessitated computer assistance. Therefore, the process of revising Mottershead's program to fit UTEP's IBM capabilities was undertaken, i.e. editing capabilities (mid-stream, interactive) were removed and PDP system-based software (data-manipulative) was either removed or revised. The error-checking process is still on-going; however, an undocumented listing of the program in its present, unusable state is included for reference [see Appendix D]. Mottershead is in the process of revising and consolidating NASA GSFC's navigation program for use on their new PDP 1170. When it is operational, he will send us a card deck of the final program to be implemented on Met Sat's PDP 1145.

Further consultation with Mottershead will be necessary in order for us to adapt the editing capabilities of his program to the peripherals of Met Sat's PDP 1145. Also, it will be necessary for us to work with the engineers of the Met Satellite Technical Area to develop the needed data IO package.

The organizations with which we had been in contact all routinely use video refresh capability (CRT screen with cursor) to locate the landmarks needed to determine satellite attitude and reference satellite position in each photograph [see Appendix A]. Since the contractor does not have the necessary video refresh hardware, some other method of locating landmarks needed to be developed. A group at NOAA NESS is experimenting with a cross-correlation scheme [see Appendix A] and provided us with a partial copy of their unfinished software, totally undocumented. Their scheme works best with visible data and requires at least a year of testing with sample data because it is based on having predetermined blocks of expected data in storage. It is our impression that a more generalized scanning method applicable to both IR and visible data would best suit the needs of the contractor.

In order to get a better idea of the scanning method needed, we decided to take a look at a few examples of dumps of digital SMS data. We looked first at IR data because of the lesser quantity of data necessary to view a relatively large area and because of our ultimate aim of relating IR-derived temperatures to cloud height for both the severe storm case study and incorporation into VTPR retreivals. By looking at the corresponding IR laser image, we were able to define approximate count boundaries between land and ocean or cloud. We then correlated these approximate count ranges for land, oceans and clouds with the temperatures represented using the chart shown in Figure 1 and making sure that the temperatures "made sense" with what we expected climatologically.

Only 64 gray shades are available for our use in the IR because the least significant bit is dropped from the data so that it will fit on a 7 track tape to make it compatible with the UNIVAC computer. (This makes it necessary to multiply all count values by 4 to compare with the chart value in Figure 1.). When the PDP system is complete, it will be equipped with a 9-track tape drive along with the capability of providing all 256 gray shades in the IR.

We are very much aware of the fact that the amount of land-ocean contrast and the actual boundary counts found are functions of the landmark location, the time of day and the time of year. For this reason we proposed a yearly study of land-ocean contrasts to determine which landmarks are best for different times of the day and year. The maximum contrast would seem to occur during late summers and late winter and during mid-afternoon and early morning since at these times are maximum land temperature extremes and also ocean surface temperatures change relatively little diurnally or seasonally.5 Because at certain times of the day and of the year, there is only one count difference between land and ocean it is sometimes very difficult to determine where the water actually stops and the land starts. (Itis possible that when all 256 gray shades are made available to us a larger relative temperature difference between land and water might become evident.), Also, because the resolution of the IR is 4 km X 8 km, each data point is an average of the temperatures in that block. The coastline could actually be anywhere within that block of data so the uncertainty in determining a coastal landmark point is at least one data block, not withstanding any calculatory manipulations of data. For these reasons, it has become our idea that the best way to approach the automatic landmark retrieval problem is with a scheme that first scans in the IR to locate a landmark point $\pm$ one pictel element and then to call up the corresponding visible lines and elements that correspond to the IR line and element plus uncertainty (visible data resolution is 1 km X 1 km so each IR pictel element is equivalent to 32 visible pictel elements) and scan for the landmark in the corresponding visible block of data. It is sometimes difficult in visible digital data dumps to distinguish between the brightness values associated with low clouds and those associated with highly reflective land or ocean surfaces. By scanning in the IR first where, except in high latitudes in the winter, the cloud counts will most certainly be higher (representing colder temperatures) than land or water counts, we have the capability of automatically ruling out cloud-covered landmarks.

During the year a "Landmark Scanning Program" was written and is in the course of testing. The program is designed to demonstrate the feasibility of identifying specific coastal landmarks using computer techniques. It determines the coastal outline by identifying high contrast regions with a first order difference technique. A cloud identification is incorporated into the program.

The program, included in Appendix E, has not been optimized and should not be considered as a finished product. Several cleanup problems, all of a relatively minor nature, must be completed. An example of these problems is the fact that the coastline is generally displaced eastward and southward; this is purely the result of the differencing technique being used.

In its present form, the program demonstrates that coastal features, including islands, can be efficiently obtained from the IR data. Although we have not, as yet, obtained the desired accuracy of $\pm$ 1 pictel element, we can see no reason why this will not be accomplished when the program cleanup is completed.

The present technique requires the computer to identify the coastline and then to obtain its most westward point. It is clear that another coastal landmark identification will require a different search criteria. Landmark identification schemes of this type will require that particular search algorithms must be associated with each different landmark. This problem may be overcome by obtaining a more generalized pattern recognition scheme or by developing a more general search routine. With respect to the former we have initiated efforts to use both fourier and mellin transforms in the recognition scheme. These efforts are in the first stages of programming. The later approach will not be pursued until we have developed successful search routines for several different types of coastal landmarks.

2. Task 3.2.7

The contract stated in task 3.2.7 that a study would be performed in which we would "examine conventional synoptic data and satellite images of severe storm systems and determine the correlation that exists between cloud type and development and time of greatest severity." We were unable to perform this study because of unforeseen problems.

In the first place, in a severe storm study, the nature of the image-making process necessitates using the digital data from which the images are made to get necessary detail.[6] Conclusions about the relative brightness levels of clouds in the visible data or about the cloud top temperatures in the IR cannot be made from satellite images. Two factors are the basic reason for this: 1) the film density is not constant within one image, let alone from one image to the next,[7] and 2) often the same exposure setting from one image to the next cannot be utilized because of such factors as the sun angle over the area of interest.

Secondly, in order to use the digital SMS data, it must be registered accurately; and, as has been shown above, this is no easy task. Often landmarks from which to register the data cannot be found near the severe storm cell in question, especially if the cell is enmeshed in the cloud mass of a much larger system. Because 1) the SMS satellites spin as they record the data, each pictel element having been taken at a different time, and 2) the satellites are not perfectly geostationary and their positions must be mathematically derived, a simple interpolation between the pictel elements of known landmarks to locate severe storm cells becomes impossible.

The registration must be accurate. Overshooting tops, a sign of particularly active and well-developed cumulonimbus or severe storm cells, have been seen on SMS images to cover only a fraction of the area of the underlying cirrus shield, which is typically on the order of 30-35 km. in the E-W direction by 20-25 km. in the N-S direction. In the IR digital data, from which the temperature and hence approximate cloud top heights can be derived, one pictel element is 4 km. in the E-W direction by 8 km. in the N-S direction at the sub-satellite point. Since the overshooting tops might be detectable in only one to three IR pictel elements, an error of ± one pictel element in registering the data becomes crucial.

Because of the previously mentioned, unforeseen software and hardware problems, we were unable to complete the necessary registration scheme. It is for this reason that we were unable to perform the severe storm study. However, we do intend to perform the study when the registration scheme is operable during the next contract year.

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* These references were used in our studies but not referenced in the report.

FIGURES

FIGURE 1: Furnished by Bruce T. Miers, Atmospheric Sciences Laboratory, White Sands Missile Range, NM, from a Memorandum by James H. Lienesch, NOAA NESS, Washington, D.C., January 15, 1975.

GOES CODED COUNT-TEMP

CT	TA	TC	TF	CT	TA	TC	TF	CT	TA	TC	TF	CT	TA	TC	TF	CT	TA	TC	TF
0	330.0	56.8	134.3	51	304.5	31.3	88.4	102	279.0	5.8	42.5	153	253.5	-19.7	-3.4	204	214.0	-59.2	-74.5
1	329.5	56.3	133.4	52	304.0	30.8	87.5	103	278.5	5.3	41.6	154	253.0	-20.2	-4.3	205	213.0	-60.2	-76.3
2	329.0	55.8	132.5	53	303.5	30.3	86.6	104	278.0	4.8	40.7	155	252.5	-20.7	-5.2	206	212.0	-61.2	-78.1
3	328.5	55.3	131.6	54	303.0	29.8	85.7	105	277.5	4.3	39.8	156	252.0	-21.2	-6.1	207	211.0	-62.2	-79.9
4	328.0	54.8	130.7	55	302.5	29.3	84.8	106	277.0	3.8	38.9	157	251.5	-21.7	-7.0	208	210.0	-63.2	-81.7
5	327.5	54.3	129.8	56	302.0	28.8	83.9	107	276.5	3.3	38.0	158	251.0	-22.2	-7.9	209	209.0	-64.2	-83.5
6	327.0	53.8	128.9	57	301.5	28.3	83.0	108	276.0	2.8	37.1	159	250.5	-22.7	-8.8	210	208.0	-65.2	-85.3
7	326.5	53.3	128.0	58	301.0	27.8	82.1	109	275.5	2.3	36.2	160	250.0	-23.2	-9.7	211	207.0	-66.2	-87.1
8	326.0	52.8	127.1	59	300.5	27.3	81.2	110	275.0	1.8	35.3	161	249.5	-23.7	-10.6	212	206.0	-67.2	-88.9
9	325.5	52.3	126.2	60	300.0	26.8	80.3	111	274.5	1.3	34.4	162	249.0	-24.2	-11.5	213	205.0	-68.2	-90.7
10	325.0	51.8	125.3	61	299.5	26.3	79.4	112	274.0	.8	33.5	163	248.5	-24.7	-12.4	214	204.0	-69.2	-92.5
11	324.5	51.3	124.4	62	299.0	25.8	78.5	113	273.5	.3	32.6	164	248.0	-25.2	-13.3	215	203.0	-70.2	-94.3
12	324.0	50.8	123.5	63	298.5	25.3	77.6	114	273.0	-.2	31.7	165	247.5	-25.7	-14.2	216	202.0	-71.2	-96.1
13	323.5	50.3	122.6	64	298.0	24.8	76.7	115	272.5	-.7	30.8	166	247.0	-26.2	-15.1	217	201.0	-72.2	-97.9
14	323.0	49.8	121.7	65	297.5	24.3	75.8	116	272.0	-1.2	29.9	167	246.5	-26.7	-16.0	218	200.0	-73.2	-99.7
15	322.5	49.3	120.8	66	297.0	23.8	74.9	117	271.5	-1.7	29.0	168	246.0	-27.2	-16.9	219	199.0	-74.2	-101.5
16	322.0	48.8	119.9	67	296.5	23.3	74.0	118	271.0	-2.2	28.1	169	245.5	-27.7	-17.8	220	198.0	-75.2	-103.3
17	321.5	48.3	119.0	68	296.0	22.8	73.1	119	270.5	-2.7	27.2	170	245.0	-28.2	-18.7	221	197.0	-76.2	-105.1
18	321.0	47.8	118.1	69	295.5	22.3	72.2	120	270.0	-3.2	26.3	171	244.5	-28.7	-19.6	222	196.0	-77.2	-106.9
19	320.5	47.3	117.2	70	295.0	21.8	71.3	121	269.5	-3.7	25.4	172	244.0	-29.2	-20.5	223	195.0	-78.2	-108.7
20	320.0	46.8	116.3	71	294.5	21.3	70.4	122	269.0	-4.2	24.5	173	243.5	-29.7	-21.4	224	194.0	-79.2	-110.5
21	319.5	46.3	115.4	72	294.0	20.8	69.5	123	268.5	-4.7	23.6	174	243.0	-30.2	-22.3	225	193.0	-80.2	-112.3
22	319.0	45.8	114.5	73	293.5	20.3	68.6	124	268.0	-5.2	22.7	175	242.5	-30.7	-23.2	226	192.0	-81.2	-114.1
23	318.5	45.3	113.6	74	293.0	19.8	67.7	125	267.5	-5.7	21.8	176	242.0	-31.2	-24.1	227	191.0	-82.2	-115.9
24	318.0	44.8	112.7	75	292.5	19.3	66.8	126	267.0	-6.2	20.9	177	241.0	-32.2	-25.9	228	190.0	-83.2	-117.7
25	317.5	44.3	111.8	76	292.0	18.8	65.9	127	266.5	-6.7	20.0	178	240.0	-33.2	-27.7	229	189.0	-84.2	-119.5
26	317.0	43.8	110.9	77	291.5	18.3	65.0	128	266.0	-7.2	19.1	179	239.0	-34.2	-29.5	230	188.0	-85.2	-121.3
27	316.5	43.3	110.0	78	291.0	17.8	64.1	129	265.5	-7.7	18.2	180	238.0	-35.2	-31.3	231	187.0	-86.2	-123.1
28	316.0	42.8	109.1	79	290.5	17.3	63.2	130	265.0	-8.2	17.3	181	237.0	-36.2	-33.1	232	186.0	-87.2	-124.9
29	315.5	42.3	108.2	80	290.0	16.8	62.3	131	264.5	-8.7	16.4	182	236.0	-37.2	-34.9	233	185.0	-88.2	-126.7
30	315.0	41.8	107.3	81	289.5	16.3	61.4	132	264.0	-9.2	15.5	183	235.0	-38.2	-36.7	234	184.0	-89.2	-128.5
31	314.5	41.3	106.4	82	289.0	15.8	60.5	133	263.5	-9.7	14.6	184	234.0	-39.2	-38.5	235	183.0	-90.2	-130.3
32	314.0	40.8	105.5	83	288.5	15.3	59.6	134	263.0	-10.2	13.7	185	233.0	-40.2	-40.3	236	182.0	-91.2	-132.1
33	313.5	40.3	104.6	84	288.0	14.8	58.7	135	262.5	-10.7	12.8	186	232.0	-41.2	-42.1	237	181.0	-92.2	-133.9
34	313.0	39.8	103.7	85	287.5	14.3	57.8	136	262.0	-11.2	11.9	187	231.0	-42.2	-43.9	238	180.0	-93.2	-135.7
35	312.5	39.3	102.8	86	287.0	13.8	56.9	137	261.5	-11.7	11.0	188	230.0	-43.2	-45.7	239	179.0	-94.2	-137.5
36	312.0	38.8	101.9	87	286.5	13.3	56.0	138	261.0	-12.2	10.1	189	229.0	-44.2	-47.5	240	178.0	-95.2	-139.3
37	311.5	38.3	101.0	88	286.0	12.8	55.1	139	260.5	-12.7	9.2	190	228.0	-45.2	-49.3	241	177.0	-96.2	-141.1
38	311.0	37.8	100.1	89	285.5	12.3	54.2	140	260.0	-13.2	8.3	191	227.0	-46.2	-51.1	242	176.0	-97.2	-142.9
39	310.5	37.3	99.2	90	285.0	11.8	53.3	141	259.5	-13.7	7.4	192	226.0	-47.2	-52.9	243	175.0	-98.2	-144.7
40	310.0	36.8	98.3	91	284.5	11.3	52.4	142	259.0	-14.2	6.5	193	225.0	-48.2	-54.7	244	174.0	-99.2	-146.5
41	309.5	36.3	97.4	92	284.0	10.8	51.5	143	258.5	-14.7	5.6	194	224.0	-49.2	-56.5	245	173.0	-100.2	-148.3
42	309.0	35.8	96.5	93	283.5	10.3	50.6	144	258.0	-15.2	4.7	195	223.0	-50.2	-58.3	246	172.0	-101.2	-150.1
43	308.5	35.3	95.6	94	283.0	9.8	49.7	145	257.5	-15.7	3.8	196	222.0	-51.2	-60.1	247	171.0	-102.2	-151.9
44	308.0	34.8	94.7	95	282.5	9.3	48.8	146	257.0	-16.2	2.9	197	221.0	-52.2	-61.9	248	170.0	-103.2	-153.7
45	307.5	34.3	93.8	96	282.0	8.8	47.9	147	256.5	-16.7	2.0	198	220.0	-53.2	-63.7	249	169.0	-104.2	-155.5
46	307.0	33.8	92.9	97	281.5	8.3	47.0	148	256.0	-17.2	1.1	199	219.0	-54.2	-65.5	250	168.0	-105.2	-157.3
47	306.5	33.3	92.0	98	281.0	7.8	46.1	149	255.5	-17.7	.2	200	218.0	-55.2	-67.3	251	167.0	-106.2	-159.1
48	306.0	32.8	91.1	99	280.5	7.3	45.2	150	255.0	-18.2	-.7	201	217.0	-56.2	-69.1	252	166.0	-107.2	-160.9
49	305.5	32.3	90.2	100	280.0	6.8	44.3	151	254.5	-18.7	-1.6	202	216.0	-57.2	-70.9	253	165.0	[illegible]	-162.7
50	305.0	31.8	89.3	101	279.5	6.3	43.4	152	254.0	-19.2	-2.5	203	215.0	-58.2	-72.7	254	164.0	[illegible]	-164.5

APPENDICES

APPENDIX A

Trip Report

by

Sandra K. Weaver

TRIP REPORT

TO

NOAA AND NESS, WASHINGTON, D.C.

January 1976

by

S. Weaver

University of Texas, El Paso

Contract DAEA 18-76-C-0019

TRIP REPORT

Several different groups at NASA Goddard Space Flight Center and NOAA National Environmental Satellite Service are working on various registration schemes of two main categories: long and short term prediction of satellite position. C.E. Velez and his group at NASA GSFC along with J. Ellickson and his group at NOAA NESS have been working on the long term (2 weeks) predictive route and have met with reasonable success. However, their scheme is one that requires a lot more work initially and does not have nearly as good accuracy as the short term predictive schemes in existence. Dr. Velez suggested that we look into Wisconsin's scheme (which is a version of the Dennis Phillips - Eric Smith routine) and offered to send us a copy of the report on the Velez scheme adopted to a PDP 1170, NAVPAK. Another group at NASA GSFC has already adopted Wisconsin's scheme to their mini-computer system, the Image Data and Manipulation System, in their METPAK, for which write-ups of each were provided. They agreed to send a copy of their navigation software and documentation if requested in writing. Such a request was made upon return from the trip. Another group in NOAA NESS uses a similar scheme, a copy of which was furnished but is undocumented. Also, they are currently working on their own in-house scheme.

One of the main purposes of the trip was to find out what scanning or landmark detection methods others had devised and their present stage of development. It became evident that all groups with working registration schemes in both NASA GSFC and NOAA NESS use video refresh as the most efficient means to at least initially track down the landmarks. At NASA, Dr. Velez demonstrated the LANDTRAK scanning method they used; and R. Adler, STORMSAT researcher, and J. Billengsley, systems developer for IDAMS and their new system, AOIPS (Atmospheric and Oceanographic Information Processing Systems), demonstrated the METPAK navigation technique. NOAA NESS has been working on a cross-correlation method of scanning which works well for visible data but poorly for IR. Many more test cases are needed to determine the minimum number of reference chips necessary to consistently achieve accurate registration. Mike Crowe gave us a copy of the program, which has some documentation. A.L. Booth, also from NOAA, has worked with ITOS data in a cloud pattern recognition scheme that works best with IR data. He furnished a copy of his thesis and suggested we contact Dr. Laveen

Kanal of the University of Maryland, who has worked with SMS data in pattern recognition. We are in the process of searching the literature for possible articles by Dr. Kanal on that subject.

On the severe storms aspect, NASA GSFC has already implemented a scheme in their METPAK for the IDAMS which computes divergence and vorticity using interpolated wind fields from SMS digital data and which R. Adler and J. Billingsley also demonstrated. A vertical velocity scheme is planned. NASA is aiming toward a real-time data system for severe storm research. R. Adler and C. Peslen, also STORMSAT researchers, are interested in maintainig close ties and offered their assistance when needed. R. Adler is also interested in January 10, 1975 data and offered to track down B.T. Miers request if the data had not yet arrived. It had not arrived, so R. Adler was contacted via phone January 13, 1976. He promised to look into the data request and who to contact at NASA about being placed on the orbit parameter mailing list. He was contacted again January 29, 1976 and said that about half of the January 10, 1975 tapes were on their way along with some hard copy of the data he had requested on his own be sent to Met Sat. Also, he suggested we ask Dr. Velez about the orbit parameter mailing list. At NOAA, R. Gurd demonstrated the capabilities of their Man Machine Interactive Processing System, the most impressive features being the VTPR and NMC-based, large scale cloud height determination schemes. M. Young, head of the winds section, offered some advice on cloud height determination for severe storms applications.

Lastly, the quality of SMS data was investigated. J. Lienesch of NOAA discussed the quality of IR data in particular, possible limb effects in the IR, and data quality control done by NOAA. He also discussed his experience in working with IR data as to land-ocean and cloud top contrasts. He suggested H. Jacobowitz , also of NOAA, be contacted about limb effects in the visible data. Dr. Jacobowitz said that such a study was being planned. As to the orbit parameters sent with the housekeeping data, Dr. Velez of NASA said the beta values are relatively accurate and require only minor corrections. J. Ellickson of NOAA said they will be working with NASA on much improved and many more orbital parameters being sent as housekeeping data by the end of '76. He provided copies of two SMSA and B data manipulation reports.

APPENDIX B

Summary of Data Processing System

by

Neil R. Guard

Sandra K. Weaver

Rufus E. Bruce

The University of Texas at El Paso

Department of Physics
El Paso, Texas 79968

March 2, 1976

Commanding Officer
Atmospheric Sciences Laboratory
White Sands Missile Range
White Sands, New Mexico 88002

ATTN: Dr. Richard Gomez

RE: Contract DAEA 18-76-C-0019

Dear Dr. Gomez:

Attached is a short summary of the SMS Data processing system on which Mrs. Weaver, Mr. Guard and I are working.

This report outlines our objectives, approach and to some degree the flexibility that we are intending to put into the system. Before we get too far into developing this concept, I believe that it should be reviewed by you and those personnel at the Atmospheric Sciences Laboratory who are most concerned with the work.

Would you please advise me if our approach is satisfactory for your needs.

Very truly yours,

Rufus E. Bruce

REB/gla

SMS DATA PROCESSING SYSTEM

I. Overall Program Concept

  A. Input Consideration

  B. Projected Output Capabilities

  C. Computational Technique

II. Current Areas of Activity

  A. Pattern Recognition
    1. Initial programing goals
    2. Results of current testing
    3. Further desirable capabilities

  B. The Registration Transformation
    1. Direct geometric approach
      a. initial concept
      b. diagram and equations
      c. result of testing
    2. Eric Smith's registration program

III. Research In the Near Future

  A. Modification & Incorporation of Eric Smith's Work

  B. Final Landmark Acceptance Criteria

  C. Severe Storms Applications

PROGRAM CONCEPT

A system is proposed which processes SMS-GOES visible and Infra-Red data to be used in severe storm case studies and atmospheric radiation transmission research. Our support toward the overall system includes development of software for landmark registration, and subsequent registration and transformation of desired data blocks based on known and calculated parameters. Presently efforts have emphasized techniques for handling I.R. data.

This software is currently being written for and tested on the UNIVAC 1108 computer at WSMR. Consideration is being made during coding and documentation to allow implementation of the final system on a PDP-11 with minimal difficulty.

Landmark registration will be automatic, with manual decision override capabilities during critical stages of processing. Once a suitable number of landmarks has been identified, control will enter a modified version of portions of a program by Dennis Phillips and Eric Smith, where these landmarks and satellite orbit parameter data will be used in calculating satellite attitude parameters necessary for the final transformations. Final program output will include time sequenced transformed data blocks and predicted parameter values. Expansion of output capabilities to rough prediction of future satellite parameters will be considered at a later time.

CURRENT INTERESTS

The automatic landmark recognition program uses a previously sectored version of the original data tape. A user defined area from the tape is stored, and coastal outline, cloud covered areas, and specific landmark locations are calculated using temperature differentials as decision criteria. These criteria are not extremely stable; time of day and seasonal variation, as well as weather conditions greatly affect the reliability of results on any specific trial.

To ensure maximal accuracy, observed prevailing conditions and anticipated approximate coastal outlines of each landmark site are considered in developing specific recognition criteria for each similar group of areas, e.g. different approaches are applied for recognizing an island than for finding a protrusion or indentation in an approximately vertical or horizontal coast. Construction of a large table of potential landmarks is important to guarantee enough usable points for accurate registration. Each site would be identified by approximate location, and by area type (indicating which recognition routine to use). Presently work is being done to analyze various sets of landmark data in both the visible and the IR to eventually develop a set of scan routines suited for most landmarks encountered. A few representative data cases in terms of temperature extremes are being used in this development. However, to effectively reduce the diurnal and seasonal uncertainty, an on-going yearly study of land-ocean contrasts at least twice daily is necessary.

Predicted coastal outlines and landmark locations are visually displayed on a hard-copy printer where manual confirmation of acceptability can be made before further processing. This information can also be used later as a check on the applicability of the recognition routine being used at each site, and updating of the master list can be made where necessary. The capability for users to update the master list during processing will be incorporated into the routine if this is found to be necessary to ensure the acceptance of a large enough usable data set.

Once such a set is identified, the approximate location tags of each site allow the program to choose those landmarks from the identified set that minimize later error in the calculation of transformation parameters. For this decision, landmark separation, to be maximized for points equally distant from the subsatellite point, and distance from the edge of the observed earth disk, to be maximized for sets of points with equal separation, are considered. A final set of landmarks is then output for user acceptance or rejection.

Tests of existing software have shown that islands and previously defined coastal outlines can be recognized for data collected under good conditions: minimal cloud cover, and distinct land/water boundary temperatures. For less-than-perfect conditions, further testing is necessary to emphirically determine optimal coastal recognition criteria adapted to anomalies in regions surrounding prospective landmark sites.

An initial attempt was made to obtain necessary transformation parameters from a purely geometric standpoint. The transformation from earth reference frame to photograph line and element was qualitatively correct, but accuracy was limited. This procedure might be utilized to find initial approximate search areas to be processed by the landmark recognition program described above. The complexity and nature of the inverse transformation made it unstable during computer testing, and the occurance of negative radicals caused program termination in all cases attempted. This transformation was, therefore, insufficient for implementation.

A more sophisticated approach to this problem is a result of work done by Dennis Phillips and Eric Smith. Portions of their routine are used by numerous other research groups in this field with adequate results. A copy of software in NASA's version of this scheme adapted to a minicomputer has been requested. Two main procedures from this program are to be used in our system. The first utilizes various observed orbit parameters and landmark registration results to compute satellite attitude parameters. The other makes use of these values in the block data transformation. Final output includes user requested transformed data and calculated parameters. A long range satellite position predictive technique being worked on by C.E. Velez and his group at NASA Goddard Space Flight Center and associates at NOAA NESS has not had as good success but their progress will be noted.

FUTURE PLANS

Those portions of Phillip's and Smith's program applicable to our proposed system will be modified where necessary and integrated into our program. Studies of the specific computational procedures used by Smith will be used to determine the nature of an optimal decision function for the acceptance of a final landmark set from those points successfully identified. Tests involving these areas will be completed when a sufficient table of identifiable prospective landmarks has been compiled. Also, the possibility of incorporating a cross-correlation method of scanning, the software for which was provided by M. Crowe of NOAA NESS, to reduce scanning error will be investigated. If the registration scheme developed is of reasonable accuracy, it will be feasible to determine cloud top height and monitor storm development in a severe storm case study.

APPENDIX C

Mathematical Overview of D. Phillips-E. Smith Report

by

Toran Hostbjor

Sandra K. Weaver

Rufus E. Bruce

[This mathematical overview is to be used in conjunction with the D. Phillips-E. Smith report "Geosynchronous Satellite Navigation Model" referenced in the Bibliography to help clarify the report. All terms are identified in the Phillips-Smith paper, as are the equations referenced.]

Equation (1) gives the position vector of the satellite in the earth coordinate system.

The initial vector

$$\begin{pmatrix} H(t)\cos(2\pi(t-t_{eqc})/P_s) \\ H(t)\sin(2\pi(t-t_{eqc})/P_s) \\ 0 \end{pmatrix}$$

is a vector of magnitude H(t) (the satellite's altitude) lying in the earth's equatorial plane. This vector is operated on by the matrix

$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(I) & \sin(I) \\ 0 & -\sin(I) & \cos(I) \end{pmatrix}$$

which rotates the vector into the satellite's orbital plane.

The resultant vector is then operated on by the matrix

$$\begin{pmatrix} \cos(2\pi(t-t_{eqc})/P_e) & \sin(2\pi(t-t_{eqc})/P_e) & 0 \\ -\sin(2\pi(t-t_{eqc})/P_e) & \cos(2\pi(t-t_{eqc})/P_e) & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

which rotates the vector about the earth's axis by an angle of $\dfrac{2\pi\Delta t}{P_e}$.

Then the resultant vector is operated on by the matrix

$$\begin{pmatrix} \cos(EQC) & -\sin(EQC) & 0 \\ \sin(EQC) & \cos(EQC) & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

which rotates the vector about the earth's axis through the longitudinal angle.

Equation (3) gives the position vector of a landmark measurement $\vec{K}_i$ in polar spherical coordinates

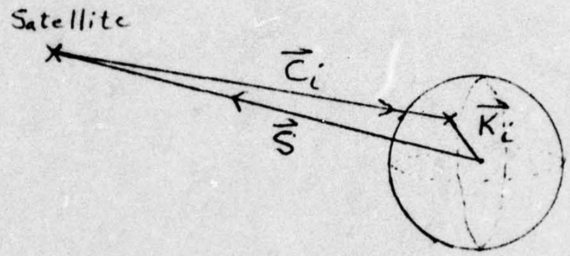
$$\vec{K}_i = \begin{pmatrix} r_i \cos\theta_i \cos\lambda_i \\ r_i \cos\theta_i \sin\lambda_i \\ r_i \sin\theta_i \end{pmatrix}$$

Where

r_i = Radius of earth at landmark i

θ_i = Latitude of landmark i

λ_i = Longitude of landmark i



Since $\vec{S}(t)$ is the position vector of the satellite, the vector $\vec{C}_i$ to the landmark i from the satellite may be written as

$$\vec{C}_i = \vec{K}_i - \vec{S}(t) \; .$$

The unit vector in that direction is

(Equation 6)

$$\frac{\vec{K}_i - \vec{S}(t)}{|\vec{K}_i - \vec{S}(t)|} \; .$$

If the position $\vec{S}(t)$ of the satellite is known for a time to, then the unit vector may be found for a later time t by rotating the unit vector at $t = t_o$,

$$\frac{\vec{K}_i - \vec{S}(t_o)}{|\vec{K}_i - \vec{S}(t_o)|}$$

through the necessary angle.

This is done by operating on the vector with the matrix

$$\begin{pmatrix} \cos((t-t_o)2\pi/P_s) & -\sin(2\pi(t-t_o)/P_s) & 0 \\ \sin(2\pi(t-t_o)/P_s) & \cos(2\pi(t-t_o)/P_s) & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

with equation (6) as the result.

The transformation from satellite imagery coordinates (L, E) to an earth reference frame is achieved by transforming from imagery coordinates to the nominal satellite coordinate system and then transform from the nominal satellite coordinate system to the earth's reference system.

Equation (27) gives the third column of the rotational matrix which performs the transformation from the nominal satellite coordinate system to the earth's reference frame. The resultant vector is the pointing vector of the satellite spin axis in the earth's reference frame. The first column of the rotational matrix is obtained by the Gram-Schmidt Orthogonalization method. We have the vector $\overrightarrow{AROT}_3(t)$ (column 3 of the matrix) and we have the satellite pointing vector S(t). Then using the Gram-Schmidt method we can get the first column of the matrix $\overrightarrow{AROT}_1(t)$ and equation (30) is the result:

$$\overrightarrow{AROT}_1(t) = \frac{\dfrac{\vec{S}(t)}{|\vec{S}(t)|} - \left(\dfrac{\vec{S}(t)}{|\vec{S}(t)|} \cdot \overrightarrow{AROT}_3(t)\right) \overrightarrow{AROT}_3(t)}{\left|\dfrac{\vec{S}(t)}{|\vec{S}(t)|} - \left(\dfrac{\vec{S}(t)}{|\vec{S}(t)|} \cdot \overrightarrow{AROT}_3(t)\right) \overrightarrow{AROT}_3(t)\right|} .$$

This is equation 30. The second column of the matrix is a vector perpendicular to the other two so it may be obtained by taking the cross product of $\overrightarrow{AROT}_3(t)$ and $\overrightarrow{AROT}_1(t)$ resulting in equation (31)

$$\overrightarrow{AROT}_2(t) = \overrightarrow{AROT}_3 \times \overrightarrow{AROT}_1 .$$

The rotational matrix formed by these three vectors is given in equation (32). Equation (33) is a rotational matrix which corrects for the misalignment between the camera axis and the satellite spin axis.

This matrix is used in equation (34) to get the pointing vector in nominal satellite coordinates. This vector is rotated into a pointing vector in earth coordinates using the inverse of the matrix in equation (32). The intersection of this vector with the earth's surface determines an earth coordinate vector. The remainder of the Phillips-Smith report is mathematically straightforward.

APPENDIX D

Registration Program Listing

by

Sandra K. Weaver

Jack Graves

Toran Hostbjor

Rufus E. Bruce

```
C       MAIN PROGRAM
        COMMON/XLAND/NLAND,LDAY,ICODE(32),PTIME(32),XLIN(32),XELE(32),
       1XLAT(32),XLON(32),DLIN(32),DELE(32),TIMEL(32)
        COMMON/SCANR/ISCAN                 ,NUMSEN,NOPCLN,TOTLIN,DEGLIN,RADLIN
       1 ,PICLIN,TOTELE,DEGELE,RADELE,PICELE,EF,PITCH ,YAW,ROLL,SKEW,ROTM11
       2,ROTM13,ROTM21,ROTM23,ROTM31,ROTM33,REACT,PCASIN,SD,CD,PDIR,PRAT
        COMMON/GDATA/PI,RDPDG,RE,A,B,AB,ASQ,BSQ,ATMHGT,GRACON,EMEGA,SOLSID
       1 ,SHA,IYR,IHR
        COMMON/NAVSLN/INAV,NAVN,LANDN,NIT,MIT,NORB,NDAY,EL,EP,ET,SPIN(3)
       1,RASCEN,DECLIN,SPINRA,TMPSCL,GTIM(16),BETA(16),BDOT(16),NGAM(16)
        COMMON/SYSCOM/ ITK,NL
C
        PRINT 9
    9   FORMAT(//30X,22H ***  NAVIGATION  ***    /)
        ITK=1
    5   PRINT 810
  810   FORMAT(22X,'**  NAVIGATION SOLUTION **')
        IWD=1
   13   GO TO (14,100,200),IWD
   14   CALL LOADMK
   25   CALL LSORT(NLAND,PTIME,XLIN,XELE,XLAT,XLON,ICODE)
   16   NDAY=LDAY
        MID=(NLAND+1)/2
        HOUR=PTIME(MID)
        CALL GETORB(LDAY,HOUR)
   18   SPINRA=100.
        TMPSCL=SPINRA/3600000.0
        CALL PREPOS
        KBAND=1
        CALL SETSCN(KBAND)
        IJK=3
        PRINT 999,IJK,PCLN,PICLIN
        IJK=9
        PRINT 999,IJK,PCLN,PICLIN
  999   FORMAT(I10,2E20.8)
        NAVN=1
        PRINT 35, NAVN
   35   FORMAT(18X,  '**  SPIN ATTITUDE SOLUTION NO. ',I4,'    **',/2X,
       1   'DECLINATION  RT. ASCEN.  CENTERLINE    LANDMARKS    SEARCH ITER
       2ATIONS')
        CALL SPINAX(LANDN ,DEC,RAS,PCLN,NIT,MIT)
        PRINT 40, DEC,RAS,PCLN,LANDN,NIT,MIT
   40   FORMAT(2F12.5,F6.0,' FIXED',I7,' USED',I6,' TOTAL',I4,'TURNS',4X)
        DECLIN=DEC
        RASCEN=RAS
        PICLIN=PCLN
        CALL PRESAT
        CALL RESIDU
   70   CALL GAMCAL
        GO TO 787
  100   CONTINUE
        CALL PREPOS
        CALL PRESAT
        GO TO 787
  200   CONTINUE
        GO TO 787
  787   CONTINUE
        STOP
```

```
      SUBROUTINE FLTIME(INT,IDAY,HOUR)
      DIMENSION INT(4),MDAY(12)
      DATA MDAY/0,31,59,90,120,151,181,212,243,273,304,334/
      IYR=INT(1)/100
      MON=MOD(INT(1), 100)
      IF(MON.LE.12) GOTO 6
      JYR=(MON-1)/12
      IYR=IYR+JYR
      MON=MON-12*JYR
    6 IDAY= INT(2)/100
      IDAY = IDAY+MDAY(MON)
      IF (MON.LT.3) GO TO 7
      IF(MOD(IYR,4).EQ.0)IDAY=IDAY+1
    7 IDAY=IDAY+1000*(IYR-70)
      HOUR= MOD(INT(2),100)
      FMIN= INT(3)/100
      SEC = MOD(INT(3),100)
      FSEC= INT(4)
      HOUR=HOUR+(FMIN+(SEC+FSEC/10000.0)/60.0)/60.0
      PRINT 20
   20 FORMAT(//2X, 'FLTIME: IDAY,FMIN,FSEC,SEC,HOUR')
      PRINT 21, IDAY,FMIN,FSEC,SEC,HOUR
   21 FORMAT(/2X,I6,4F12.6)
      RETURN
      END
```

```
      FUNCTION TIMDIF(IYRDA1,HOUR1,IYRDA2,HOUR2)

      IY1=MOD(IYRDA1/1000,100)
      ID1=MOD(IYRDA1,1000)
      IFAC1=(IY1-1)/4+1
      D1=365*(IY1-1)+IFAC1+ID1-1
      IY2=MOD(IYRDA2/1000,100)
      ID2=MOD(IYRDA2,1000)
      IFAC2=(IY2-1)/4+1
      D2=365*(IY2-1)+IFAC2+ID2-1
      T1=1440.0*D1+60.0*HOUR1
      T2=1440.0*D2+60.0*HOUR2
      TIMDIF=T2-T1
      PRINT 10
 10   FORMAT(//2X,'TIMDIF: IYRDA1,HOUR1,IYRDA2,HOUR2,D1,D2,T1,T2,
     1TIMDIF')
      PRINT 11,IYRDA1,HOUR1,IYRDA2,HOUR2,D1,D2,T1,T2,TIMDIF
 11   FORMAT(/2X,I10,F10.4,I10,3E20.4,/2X,3E20.4)
      RETURN
      END
```

```
      FUNCTION IROUND(X)
      IF(X)1,2,3
    1 IROUND=X-0.5
      RETURN
    2 IROUND=0
      RETURN
    3 IROUND=X+0.5
      RETURN
      END
```

```
      SUBROUTINE SATPOS(NAVDAY,TIME,X,Y,Z)
      COMMON/GDATA/PI,RDPDG,RE,A,B,AB,ASQ,BSQ,ATMHGT,GRACON,EMEGA,SOLSID
     * ,SHA,IYR,IHR
      COMMON/SATORP/IORB,IXD,XHR,XI(3),        SLAT,SLON,SHGT,ARIES,
     * IEDAY,EPHR,SEMIMA,OECCEN,ORBINC,EMANOM,PERHEL,ASNODE,
     * XMMC,SROME2,PX,PY,PZ,QX,QY,QZ
C
C        COMPUTE MEAN ANOMALY
C
      DIFTIM=TIMDIF(IEDAY,EPHR,NAVDAY,TIME)
      XMANOM=XMMC*DIFTIM
      ECANM1=XMANOM
      EPSILN=1.0E-8
C
C        SOLVE FOR ECCENTRIC ANOMALY
C
      DO 2 I=1,20
      ECANOM=XMANOM+OECCEN* SIN(ECANM1)
      PRINT 20
   20 FORMAT(//2X,'SATPOS:XMMC,XMANOM,ECANOM')
      PRINT 21,XMMC,XMANOM,ECANOM
   21  FORMAT(/2X,3E20.4)
      IF ( ABS(ECANOM-ECANM1).LT.EPSILN) GO TO 3
      ECANM1=ECANOM
    2 CONTINUE
C
C        COMPUTE CARTESIAN COMPONETS
C
    3 XOMEGA=COS(ECANOM)-OECCEN
      YOMEGA=SROME2* SIN(ECANOM)
      XS=XOMEGA*PX+YOMEGA*QX
      YS=XOMEGA*PY+YOMEGA*QY
      ZS=XOMEGA*PZ+YOMEGA*QZ
C
      PRINT 30
   30 FORMAT(//2X,'SATPOS:XOMEGA,YOMEGA,XS,YS,ZS')
      PRINT 31,XOMEGA,YOMEGA,XS,YS,ZS
   31 FORMAT(/2X,5F15.7)
C        ROTATE TO GEOGRAPHIC COORDINATES
C
      THR=IHR
      DIFTIM=TIMDIF(IYR,THR,NAVDAY,TIME)
      RA=DIFTIM*SOLSID*PI/720.0D0+SHA
      RAS=AMOD(RA,2.0*PI)
      CRA=COS(RAS)
      SRA=SIN(RAS)
      PRINT 40
   40 FORMAT(//2X,'SATPOS:DIFTIM,SHA,RA,RAS,CRA,SRA')
      PRINT 41,DIFTIM,SHA,RA,RAS,CRA,SRA
   41 FORMAT(/2X,6F20.4)
      X=CRA*XS+SRA*YS
      Y=-SRA*XS+CRA*YS
      Z=ZS
      XI(1)=XS
      XI(2)=YS
      XI(3)=ZS
      SLAT=ATAN(Z/SQRT(X**2+Y**2))/RDPDG
      SLON=ATAN2(Y,X)/RDPDG
```

```
      SHGT=SQRT(X**2+Y**2+Z**2)
      PRINT 10
 10   FORMAT(2X,'SATPOS:X,Y,Z,XI(J) WHERE J=1,3,SLAT,SLON,SHGT')
      PRINT 11,X,Y,Z,(XI(J),J=1,3),SLAT,SLON,SHGT
 11   FORMAT(/2X,9F13.5)
      RETURN
      END
```

```
      FUNCTION FLALO(M)
      INTEGER*4 M,N
      IF(M.LT.0) GO TO 1
      N=M
      X=1.0
      GO TO 2
    1 N=-M
      X=-1.0
    2 FLALO=FLOAT(N/10000)+FLOAT(MOD(N/100,100))/60.0+FLOAT(MOD(N,100))/
     13600.0
      FLALO=X*FLALO
      PRINT 10
   10 FORMAT(//2X,'FLALO: M,N,X,FLALO')
      PRINT 11,M,N,X,FLALO
   11 FORMAT(/2X,2I8,2F13.6)
      RETURN
      END
```

```
      FUNCTION  ILALO(XDEG)
      INTEGER*4 ILALO,IDEG,MIN,ISEC
      ZN=XDEG
      IF(XDEG.LT.0.0) ZN=-ZN
    2 IDEG=ZN
      ZD=IDEG
      ZN=(ZN-ZD)*60.0
      PRINT 10,XDEG,IDEG,ZD,ZN
   10 FORMAT(//2X,'ILALO: XDEG,IDEG,ZD,ZN',F13.6,I8,2F13.6)
      MIN=ZN
      ZM=MIN
      ZN=(ZN-ZM)*60.0+0.5
      ISEC=ZN
      ILALO=10000*IDEG+100*MIN+ISEC
      IF(XDEG.LT.0.0) ILALO=-ILALO
      PRINT 20,MIN,ZM,ZN,IDEG,ILALO
   20 FORMAT(//2X,'ILALO: MIN,ZM,ZN,IDEG,ILALO',I8,2F13.6,2I8)
      RETURN
      END
```

```
      SUBROUTINE LOADMK
      COMMON/XLAND/NLAND,LDAY,ICODE(32),PTIME(32),XLIN(32),XELE(32),
     1XLAT(32),XLON(32),DLIN(32),DELE(32),TIMEL(32)
      COMMON/BUFFER/LMKNO,LMKID,                        ITIME(4),LCODE
      DIMENSION JDAY(25)
      INTEGER*4 LAT,LONG
      NLAND=LMKNO
      MDAY=32700
      N=0
      LMKID=-777
      IF(LMKID.EQ.-777) GO TO 200
      DO 100 L=1,LMKNO
      READ  50,       LMKNO,LMKID,LAT,LONG,XMP,XML,(ITIME(J),J=1,4),LCODE
 0    FORMAT(2I3,2I8,2F10.2,5I5)
      PRINT  77,      LMKNO,LMKID,LAT,LONG,XMP,XML,(ITIME(J),J=1,4),LCODE
 7    FORMAT(' LMK=',2I3,2I8,2F10.2,5I5)
      IF(LCODE.LT.0) GO TO 100
 0    N=N+1
      XLAT(N)=FLALO(LAT)
      XLON(N)=FLALO(LONG)
      XELE(N)=XMP
      XLIN(N)=XML
      CALL FLTIME(ITIME,JDAY(N),PTIME(N))
      IF(JDAY(N).LT.MDAY) MDAY=JDAY(N)
      ICODE(N)=LCODE*100+LMKID
 00   CONTINUE
      NLAND=N
      LDAY=MDAY
      DO 150 J=1,NLAND
      PTIME(J)=PTIME(J)+24.0*(JDAY(J)-MDAY)
 50   CONTINUE
      GO TO 250
 00   LMKNO=9
      LMKID=5
      LCODE=0
      DO 5 I=1,4
 5    ITIME(I)=I
      CALL TESTMK
      PRINT 40
 40   FORMAT(//2X,'LOADMK:LMKNO,LMKID,,LCODE,ITIME(I) WHERE I=1,4')
      PRINT 41,LMKNO,LMKID,LCODE,(ITIME(I),I=1,4)
 41   FORMAT(/2X,7I8)
 50   RETURN
      END
```

```
      SUBROUTINE TESTMK
       COMMON/XLAND/NLAND,LDAY,ICODE(32),PTIME(32),XLIN(32),XELE(32),
     1XLAT(32),XLON(32),DLIN(32),DELE(32),TIMEL(32)
      LDAY=4212
      NLAND=9
      TLAT=14.65833333
      TLON=-17.44166667
      TIME=12.0
      DO 20 I=1,NLAND
      ICODE(I)=1
      XLAT(I)=TLAT
      XLON(I)=TLON
      PTIME(I)=TIME
      TIME=TIME+0.5
   20 CONTINUE
      XLIN(1)=5140
      XLIN(2)=5088
      XLIN(3)=5041
      XLIN(4)=5002
      XLIN(5)=4972
      XLIN(6)=4950
      XLIN(7)=4936
      XLIN(8)=4930
      XLIN(9)=4934
      XELE(1)=11462
      XELE(2)=11440
      XELE(3)=11430
      XELE(4)=11420
      XELE(5)=11409
      XELE(6)=11400
      XELE(7)=11391
      XELE(8)=11383
      XELE(9)=11375
      PRINT 30
   30 FORMAT(//2X,'TESTMK:LDAY,NLAND,TLAT,TLON,(XLAT(I),XLON(I),PTIME(I)
     1,XLIN(I),XELE(I),WHERE I=1,9')
      PRINT 31,LDAY,NLAND,TLAT,TLON,(XLAT(I),XLON(I),PTIME(I),XLIN(I),
     1XELE(I),I=1,9)
   31 FORMAT(/2X,2I8,2F10.6,10F8.2,/2X,15F8.2,/2X,15F8.2,/2X,5F8.2)
      RETURN
      END
```

```
      SUBROUTINE  LSORT(NL,TJ,A,B,C,D,IC)
      DIMENSION TJ(1),A(1),B(1),C(1),D(1),IC(1)
      L=1
 10   TK=TJ(L)
      MV=L
      DO 30 K=L,NL
      IF(TJ(K).GE.TK) GO TO 30
      TK=TJ(K)
      MV=K
 30   CONTINUE
      TS=TJ(L)
      SA=A(L)
      SB=B(L)
      SC=C(L)
      SD=D(L)
      IS=IC(L)
      TJ(L)=TK
      A(L)=A(MV)
      B(L)=B(MV)
      C(L)=C(MV)
      D(L)=D(MV)
      IC(L)=IC(MV)
      TJ(MV)=TS
      A(MV)=SA
      B(MV)=SB
      C(MV)=SC
      D(MV)=SD
      IC(MV)=IS
      L=L+1
      IF(L.LT.NL) GO TC 10
 77   RETURN
      END
```

```
      SUBROUTINE PREPOS
      COMMON/GDATA /PI,RDPDG,R,A,B,AB,ASQ,BSQ,ATMHGT,GRACON,EMEGA,SOLSID
     1 ,SHA,IYR,IHR
      COMMON/SATORB/IORB,IXD,XHR,XS(3),       SLAT,SLON,SHGT,ARIES,
     1 IEDAY,EPHR,SEMIMA,OECCEN,ORBINC,XMANOM,PERHEL,ASNODE,
     2 XMMC,SROME2,PX,PY,PZ,QX,QY,QZ
      PI=3.14159265
      RDPDG=PI/180.0
      R=6371.221
      A=6378.388
      B=6356.912
      AB=A*B
      ASQ=A**2
      BSQ=B**2
      ATMHGT=8.0
      SOLSID=1.00273791
      EMEGA=PI*SOLSID/12.0
      SHA=100.26467
      SHA=RDPDG*SHA
      IYR=4001
      IHR=0
      GRACON=0.07436574
      RE=A
      XMMC=GRACON*RE* SQRT(RE/SEMIMA)/SEMIMA
      SROME2=SQRT(1.0-OECCEN)*SQRT(1.0+OECCEN)
      O=RDPDG*ORBINC
      SO=SIN(O)
      CO=COS(O)
      P=RDPDG*PERHEL
      SP=SIN(P)*SEMIMA
      CP=COS(P)*SEMIMA
      S=RDPDG*ASNODE
      SA=SIN(S)
      CA=COS(S)
      PX=CP*CA-SP*SA*CO
      PY=CP*SA+SP*CA*CO
      PZ=SP*SO
      QX=-SP*CA-CP*SA*CO
      QY=-SP*SA+CP*CA*CO
      QZ=CP*SO
      PRINT 10
   10 FORMAT(/2X,'PREPOS:EMEGA,XMMC,SROME2,O,P,S,PX,PY,PZ,QX,QY,QZ')
      PRINT 20,EMEGA,XMMC,SROME2,O,P,S,PX,PY,PZ,QX,QY,QZ
   20 FORMAT(/2X,3F12.8,4E20.4,/2X,5E20.4)
      RETURN
      END
```

```
      FUNCTION LD(IYR)
      LD=0
      IF(MOD(IYR,4).EQ.0) LD=1
      RETURN
      END
```

```
      SUBROUTINE PRESAT
      COMMON/SCANR/ISCAN                    ,NUMSEN,NOPCLN,TOTLIN,DEGLIN,RADLIN
     1 ,PICLIN,TOTELE,DEGELE,RADELE,PICELE,EF,PITCH ,YAW,ROLL,SKEW,ROTM11
     2,ROTM13,ROTM21,ROTM23,ROTM31,ROTM33,RFACT,RCASIN,SD,CD,PDIR,PRAT
      COMMON/GDATA/PI,RDPDG,RE,A,E,AB,ASQ,BSQ,ATMHGT,GRACON,EMEGA,SOLSID
     1 ,SHA,IYR,IHR
      COMMON/NAVSLN/INAV,NAVN,LANDN,NIT,MIT,NORB,NDAY,EL,EP,ET,SPIN(3)
     1,RASCEN,DECLIN,SPINRA,TMPSCL,GTIM(16),BETA(16),BDOT(16),NGAM(16)
      DEC=DECLIN*RDPDG
      SINDEC=SIN(DEC)
      COSDEC=COS(DEC)
      RAS=RASCEN*RDPDG
      SINRAS=SIN(RAS)
      COSRAS=COS(RAS)
      SPINAX=COSDEC*COSRAS
      SPINAY=COSDEC*SINRAS
      SPIN(1)=SPINAX
      SPINAZ=SINDEC
      SPIN(2)=SPINAY
      SPIN(3)=SPINAZ
      CPITCH=RDPDG*PITCH
      CYAW=RDPDG*YAW
      CROLL=RDPDG*ROLL
      PSKEW=ATAN2(SKEW,RADLIN/RADELE)
      PRINT 5
    5 FORMAT(//2X,'PRESAT: DEC,RAS,TMPSCL,PSKEW,SPINAX,SPINAY,SPINAZ')
      PRINT 6,DEC,RAS,TMPSCL,PSKEW,SPINAX,SPINAY,SPINAZ
    6 FORMAT(/2X,7E17.8)
      STP=SIN(CPITCH)
      CTP=COS(CPITCH)
      STY=SIN(CYAW-PSKEW)
      CTY=COS(CYAW-PSKEW)
      STR=SIN(CROLL)
      CTR=COS(CROLL)
      ROTM11=CTR*CTP
      ROTM13=STY*STR*CTP+CTY*STP
      ROTM21=-STR
      ROTM23=STY*CTR
      ROTM31=-CTR*STP
      ROTM33=CTY*CTP-STY*STR*STP
      RFACT=ROTM31**2+ROTM33**2
      ROASIN=ATAN2(ROTM31,ROTM33)
      PRINT 10
   10 FORMAT(2X,'PRESAT: SPIN(I) WHERE I=1,3,ROTM11,ROTM13,
     1ROTM21,ROTM23,ROTM31,ROTM33')
      PRINT11,(SPIN(I),I=1,3),ROTM11,ROTM13,ROTM21,ROTM23,ROTM31,
     1ROTM33
   11 FORMAT(2X,9F13.6)
      RETURN
      END
```

```
      SUBROUTINE GETORB(LDAY,HOUR)
      COMMON/BUFFER/KBAND,MDAY
      COMMON/SATORB/IORB,IXD,XHR,XS(3),SLAT,SLON,SHGT,ARIES,
     1IEDAY,EPHR,SEMIMA,OECCEN,ORBINC,XMANOM,PERHEL,ASNODE,
     2XMMC,SROME2,PX,PY,PZ,QX,QY,QZ
      IORB=-1
      IF(IORB) 10,70,30
   10 IEDAY=4216
      EPHR =0.0
      SEMIMA=42168.86
      OECCEN=0.001207
      ORBINC=1.920
      XMANOM= 181.235
      PERHEL=247.316
      ASNODE=198.189
      GO TO 70
   30 READ 33,IEDAY,EPHR ,SEMIMA,OECCEN,ORBINC,XMANOM,PERHEL,ASNODE
   33 FORMAT(I6,7F15.6)
      IEDAY=MDAY
      PRINT 65
   65 FORMAT(//2X,'GETORB: IEDAY,EPHR,SEMIMA,OECCEN,ORBINC,XMANOM,PERHEL
     1,ASNODE')
   70 PRINT80,    IEDAY,EPHR,SEMIMA,OECCEN,ORBINC,XMANOM,PERHEL,ASNODE
      CALL EPOCH(IEDAY,EPHR,SEMIMA,OECCEN,XMANOM)
      PRINT80,    IEDAY,EPHR,SEMIMA,OECCEN,ORBINC,XMANOM,PERHEL,ASNODE
   80 FORMAT(5X,'ORBIT',I6,7F15.6)
      RETURN
      END
```

```
      SUBROUTINE SETSCN(KBAND)
      COMMON/SCANR/ISCAN                    ,NUMSEN,NOPCLN,TOTLIN,DEGLIN,RADLIN
     1 ,PICLIN,TOTELE,DEGELE,RADELE,PICELE,EF,PITCH ,YAW,ROLL,SKEW,ROTM11
     2,ROTM13,ROTM21,ROTM23,ROTM31,ROTM33,REACT,ROASIN,SD,CD,PDIR,PRAT
      COMMON/GDATA/PI,RDPDG,RE,A,B,AB,ASQ,BSQ,ATMHGT,GRACON,EMEGA,SOLSID
     1 ,SHA,IYR,IHR
      NOPCLN=0
      PRERAT=0.0
      PREDIR=0.0
      PITCH=0.0
      YAW=0.0
      ROLL=0.0
      SKEW=0.0
      PDIR=0.0
      PRAT=0.0
      SD=SIN(PDIR)
      CD=COS(PDIR)
      IF (KBAND.EQ.2) GO TO 30
      NUMSEN=8
      GO TO 45
 30   NUMSEN=2
      GO TO 45
  45  SENSOR=NUMSEN
      TOTLIN=1821.0*SENSOR
      DEGLIN=20.0
      TOTELE=1911.0*SENSOR
      DEGELE=18.375
      PICLIN=(TOTLIN+1.0)/2.0
      RADLIN=RDPDG*DEGLIN/(TOTLIN-1.0)
      RADELE=RDPDG*DEGELE/(TOTELE-1.0)
      PICELE=(1.0+TOTELE)/2.0
      EF=RADELE/(2.0*PI)
 52   PRINT 53, KBAND,    SENSOR ,TOTLIN,DEGLIN,TOTELE,DEGELE,PICLIN,SD
 53.  FORMAT(/ 16H SCAN CONSTANTS.  ,I5    ,2F13.1,F13.4,F13.1,F13.4,
     1 2F13.1)
      IJK=1
      PRINT 999,IJK,PCLN,PICLIN
999   FORMAT(' PCLN,PICLIN PRINT NO.',I7,2(1PG20.10))
      RETURN
      END
```

```
      SUBROUTINE EPOCH(IETIMY,EPHR,SEMIMA,OECCEN,XMEANA)
      PI=3.14159265
      RDPDG=PI/180.0
      RE=6378.388
      GRACCN=0.07436574
      XMMC=GRACCN*SQRT(RE/SEMIMA)**3
      XMANOM=RDPDG*XMEANA
      TIME=(XMANOM-OECCEN*SIN(XMANOM))/(60.0*XMMC)
      PRINT 20
   20 FORMAT(//2X,'EPOCH: XMMC,XMANOM,XMEANA,TIME')
      PRINT 21,XMMC,XMANOM,XMEANA,TIME
   21 FORMAT(/2X,4F15.7)
      TIME1=EPHR
      TIME=TIME1-TIME
      IDAY=TIME/24.0
      PRINT 30,TIME,IDAY
   30 FORMAT(/2X,'EPOCH: TIME,IDAY',/2X,F12.6,I6)
      IF(TIME.LT.0.0) IDAY=IDAY-1
      TIME=TIME-24.0*IDAY
 4    EPHR=TIME
      XMEANA=0.0
      PRINT 40,EPHR,XMEANA
   40 FORMAT(/2X,'EPOCH: EPHR,XMEANA',2X,2F12.6)
      IF(IDAY.EQ.0) GO TO 12
      JYEAR=MOD(IETIMY/1000,100)
      JDAY=MOD(IETIMY,1000)
      JDAY=JDAY+IDAY
      IF(JDAY.LT.1) GO TO 5
      JTOT=365+LD(JYEAR)
      IF(JDAY.GT.JTOT) GO TO 6
      GO TO 7
 5    JYEAR=JYEAR-1
      JDAY=365+LD(JYEAR)+JDAY
      GO TO 7
 6    JYEAR=JYEAR+1
      JDAY=JDAY-JTOT
 7    IETIMY=1000*JYEAR+JDAY
 12   RETURN
      END
```

```
      SUBROUTINE SPINAX(NUMSPN,DEC,RAS,PCLN,NIT,MIT)
       COMMON/XLAND/NLAND,LDAY,ICODE(32),PTIME(32),XLIN(32),XELE(32),
     1XLAT(32),XLON(32),DLIN(32),DELE(32),TIMEL(32)
      COMMON/GDATA/PI,RDPDG,R ,A,B,AB,ASQ,BSQ,ATMHGT,GRACON,EMEGA,SOLSID
     1 ,SHA,IYR,IHR
      COMMON/SCANR/ISCAN                  ,NUMSEN,NOPCLN,TOTLIN,DEGLIN,RADLIN
     1 ,PICLIN,TOTELE,DEGELE,RADELE,PICELE,EF,PITCH ,YAW,ROLL,SKEW,ROTM11
     2,ROTM13,ROTM21,ROTM23,ROTM31,ROTM33,RFACT,RCASIN,SD,CD,PDIR,PRAT
      DIMENSION  D(15)
      DOUBLE PRECISION ZERCT,XLAM,S1,S2,S3,PARM1,PARM2,PARM3,SA,CA,SB,CB
     1,SP,CP,GA,GM,G1,G2,G3,XA,XB,XP,COSA,GB,GP
      DOUBLE PRECISION DSQRT,DSIN,DCOS
      DEC=90.0
      RAS=0.0
      PCLN=PICLIN
      DO 2 I=1,15
    2 D(I)=0.0
      NUMSPN=0
      DO 3 I=1,NLAND
      ICODEN=MOD(ICODE(I)/100,10)
      IF (ICODEN.NE.0.AND.ICODEN.NE.1) GO TO 3
      NUMSPN=NUMSPN+1
      PICTIM=PTIME(I)
      SAMTIM=VTIME(PICTIM,XLIN(I),XELE(I))
      EARROT=EMEGA*SAMTIM
      ST=SIN(EARROT)
      CT=COS(EARROT)
      PRINT 100,EMEGA,SAMTIM,EARROT,ST,CT
  100 FORMAT(//2X,'SPINAX:EMEGA,SAMTIM,EARROT,ST,CT',/2X,5E20.5)
      CALL SATPOS(LDAY,SAMTIM,XSAT,YSAT,ZSAT)
      YLAT=XLAT(I)*RDPDG
      YLON=XLON(I)*RDPDG
      SINLAT=SIN(YLAT)
      COSLAT=COS(YLAT)
      SINLON=SIN(YLON)
      COSLON=COS(YLON)
      X=COSLAT*COSLON
      Y=COSLAT*SINLON
      Z=SINLAT
      TANLAT=(SINLAT/COSLAT)**2
      RR=SQRT((1.0+TANLAT)/(BSQ+ASQ*TANLAT))*AB
      PRINT 20,X,Y,Z,TANLAT,RR
   20 FORMAT(//2X,'SPINAX: X,Y,Z,TANLAT,RR',/2X,5F15.7)
      X=RR*X
      Y=RR*Y
      Z=RR*Z
      X1=X-XSAT
      X2=Y-YSAT
      X3=Z-ZSAT
      XFACT=1.0/SQRT(X1**2+X2**2+X3**2)
      X1=X1*XFACT
      X2=X2*XFACT
      X3=X3*XFACT
      UX=CT*X1-ST*X2
      UY=ST*X1+CT*X2
      UZ=X3
      YLIN=(XLIN(I)-PCLN)*RADLIN
      PRINT 30,XFACT,UX,UY,UZ,YLIN
```

```
30 FORMAT(//2X,'SPINAX: XFACT,UX,UY,UZ,YLIN',/2X,5F13.5)
   SINLIN=SIN(YLIN)
   COSLIN=COS(YLIN)
   D(1)=D(1)+UX**2
   D(2)=D(2)+UX*UY
   D(3)=D(3)+UX*UZ
   D(4)=D(4)+UY**2
   D(5)=D(5)+UY*UZ
   D(6)=D(6)+UZ**2
   D(7)=D(7)+UX*COSLIN
   D(8)=D(8)+UX*SINLIN
   D(9)=D(9)+UY*COSLIN
   D(10)=D(10)+UY*SINLIN
   D(11)=D(11)+UZ*COSLIN
   D(12)=D(12)+UZ*SINLIN
   D(13)=D(13)+COSLIN**2
   D(14)=D(14)+SINLIN**2
   D(15)=D(15)+COSLIN*SINLIN
   PRINT50
50 FORMAT(2X,'SPINAX:X1,X2,X3,D(J) WHERE J=1,15')
   PRINT 51,X1,X2,X3,(D(J),J=1,15)
51 FORMAT(2X,9F12.8,/2X,9F12.8)
 3 CONTINUE
   IF (NUMSPN.EQ.0)RETURN
   IF (NUMSPN.EQ.1)GOTO13
   NITLIM=5000
   MITLIM=5000
   XLAM=0.01
   ZEROT=1.E-7
   S1=0.0
   S2=PI/2.0
   S3=PI/2.0
   PARM1=0.5
   PARM2=0.75
   PARM3=-0.5
   N=1
   I=0
   J=0
 4 I=I+1
 5 IF(XLAM.LT.ZEROT)GO TO 11
   SA=DSIN(S1)
   CA=DCOS(S1)
   SB=DSIN(S2)
   CB=DCOS(S2)
   SP=DSIN(S3)
   CP=DCOS(S3)
   GA=D(1)*CA*SA+D(2)*CB*(2.0*CA**2-1.0)+D(3)*(2.0*CA**2-1.0)*SB-D(4)
  1*CA*SA*CB**2-D(5)*2.0*SA*CA*SB*CB-D(6)*SA*CA*SB**2-D(7)*CA*CP+D(8)
  2*CA*SP+D(9)*SA*CB*CP-D(10)*SA*CB*SP+D(11)*SA*SB*CP-D(12)*SA*SB*SP
   GB=-D(2)*CA*SA*SB+D(3)*SA*CA*CB-D(4)*CA**2*CB*SB+D(5)*CA**2*(2.0*C
  1B**2-1.0)+D(6)*CA**2*SB*CB+D(9)*CA*SB*CP-D(10)*CA*SB*SP-D(11)*CA*C
  2B*CP+D(12)*CA*CB*SP
   IF(NOPCLN.EQ.0.OR.NUMSPN.EQ.2) GO TO 6
   GP=D(7)*SA*SP+D(8)*SA*CP+D(9)*CA*CB*SP+D(10)*CA*CB*CP+D(11)*CA*SB*
  1SP+D(12)*CA*SB*CP-D(13)*SP*CP+D(14)*SP*CP+D(15)*(2.0*SP**2-1.0)
   PRINT 60
60 FORMAT(2X,'SPINAX:GA,GB,GP')
   PRINT 61, GA,GB,GP
```

```
 51   FORMAT(2X,3F12.8)
      GO TO 7
  6   GP=0.0
  7   GM=DSQRT(GA**2+GB**2+GP**2)
      GA=GA/GM
      GB=GB/GM
      GP=GP/GM
      GO TO(8,10),N
  8   N=2
  9   G1=GA
      G2=GB
      G3=GP
      XA=S1
      XB=S2
      XP=S3
      S1=XA-XLAM*GA
      S2=XB-XLAM*GB
      S3=XP-XLAM*GP
      IF(I.EQ.NITLIM) GO TO11
      GO TO 4
 10   COSA=G1*GA+G2*GB+G3*GP
      XLAM=XLAM*(COSA*PARM1+PARM2)
      IF(COSA.GT.PARM3) GO TO 9
      S1=XA
      S2=XB
      S3=XP
      J=J+1
      IF(J.EQ.MITLIM)GO TO 11
      GO TO 5
 11   PRINT 70
 70   FORMAT(2X,'SPINAX:COSA,XLAM')
      PRINT 71, COSA,XLAM
 71   FORMAT(2X,2F15.7)
      NIT=I
      MIT=J
      SPAX1=DSIN(S1)
      SPAX2=DCOS(S1)*DCOS(S2)
      SPAX3=DCOS(S1)*DSIN(S2)
      DEC=90.0-ATAN(SQRT(SPAX1**2+SPAX2**2)/SPAX3)/RDPDG
      RAS=0.0
      IF(SPAX3.GT.0.99999999) GO TO 12
      RAS=ATAN2(SPAX2,SPAX1)/RDPDG
 12   PCLN=PCLN-(S3-PI/2.0)/RADLIN
      PRINT 80
 80   FORMAT(2X,'SPINAX: DEC,RAS,PCLN')
      PRINT 81, DEC,RAS,PCLN
 81   FORMAT(2X,3F15.7)
 13   CONTINUE
      RETURN
      END
```

```
      SUBROUTINE  SATEAR(PICTIM,XLIN,XELE,XLAT,XLON,ITYPE,NERR,BETAIN,BET
     1DOT,ATFRAC)
:REATE RDG:(350,6)SATEAR.FIN/NV
      SATEAR COMPUTES SATELLITE COOR * EARTH COOR * EARTH EDGES * SUB POINTS
      T(0) IS DEFINED TO BE GREENWICH HOUR 0 OF NAVIGATION
      LATITUDE RANGES FROM +90TO-90 SOUTH
      LONGITUDE RANGES FROM +180TO-180 WEST
      *****
      INPUT PARAMETERS
      *****
      PICITIM = PICTURE START TIME ( HOUR FROM T(0) )
      XLIN = SATELLITE COORDIINATE ( LINE )
      XELE = SATELLITE COORDINATE ( ELEMENT )
      XLAT = EARTH COORDINATE ( DEGREES LATITUDE )
       XLON = EARTH COORDINATE ) DEGREES LONGITUDE )
      ITYPE = 1 FOR SATELLITE COORDINATE TO EARTH COORDINATE TRANSFROM
            = 2 FOR EARTH COORDINATE TO SATELLITE COODINATE TRANSFORM
            = 3 FOR LEFT-RIGHT OBLATE EARTH EDGE ( XLAT = LEFT , XLON = RIGHT )
            = 4 FOR SUB-POINT ( XLIN=LINE , XELE=ELE.  ,XLAT=LAT. , XLON=LON. )
C           = 5 FOR ROTATION ANGLE ( XLIN = ROTATION ANGLE )
      NERR= ERROR FLAG (=0 FOR NORMAL RETURN, = 2 THRU 9 FOR ERRORS)
      BETAIN = BETA ANGLE AT T(0) ( ELEMENTS )
      BETDOT = RATE OF CHANGE OF BETA ( ELEMENTS PER HOUR )
      ATFRAC = CLOUD HEIGHT COEFFICIENT ( RANGES FROM 0 TO 1 )
C     ITER =  ITERATION COUNT
      GAMMA = BETA ANGLE AT SAMPLE POINT TIME ( RADIANS )
      SAMTIM = SAMPLE POINT TIME ( HOURS FROM T(0) )
         C.T. MOTTERSHEAD/CSC
         Z13 OCT 1975
---------------------------------------------------------------------------
      COMMON/GDATA/PI,REDEG,R  ,A,B,AB,ASQ,BSQ,ATMHGT,GRACON,EMEGA,SOLSID
     1 ,SHA,IYR,IHR
    . COMMON/SCANR/ISCAN              ,NUMSEN,NOPCLN,TOTLIN,DEGLIN,RADLIN
     1,PCLN ,TOTELE,DEGELE,RADELE,PICELE,EF,PITCH,YAW,ROLL,SKEW,ROTM11,
     2ROTM13,ROTM21,ROTM23,ROTM31,ROTM33,RFACT,ROASIN,SO,CO,PDIR,PRAT
      COMMON/NAVSLN/INAV,NAVN,LANDN,NIT,MIT,NORB,NDAY,EL,EP,ET,SPIN(3),
     1 RASCEN,DECLIN,SPINRA,TMPSCL,GTIM(16),BETA(16),BDOT(16),NGAM(16)
      COMMON/SATVEC/XSAT,YSAT,ZSAT,HEIGHT,XVEC1,XVEC2,XVEC3,THETA,
     1AROT11,AROT12,AROT13,AROT21,AROT22,AROT23,AROT31,AROT32,AROT33
      LIMIT=3
      NERR=0

         BRANCH ON TRANSFORM TYPE

      GO TO (12,9,12,9,9),ITYPE

         INITALIZE FOR LATLONG OR SUBSATELLITE POINT CALCULATION

9     XLIN=PCLN
      XELE=PICELE
      ITER=0

      COMPUTE TIME DEPENDENTS PARAMETERS

 12   SAMTIM=VTIME(PICTIM,XLIN,XELE)
      GAMMA=RADELE*(BETAIN+BETDOT*SAMTIM)
      CALL SATCOR(NDAY,SAMTIM,GAMMA,SPIN)
```

```
      PRINT 10,SAMTIM,PICTIM,XLIN,XELE,GAMMA,BETAIN,BETOOT,SPIN
   10 FORMAT(//2X,'SATEAR: SAMTIM,PICTIM,XLIN,XELE,GAMMA,BETAIN,BETOOT,
     1SPIN',/2X,4E20.6,/2X,4E20.6)
C
C     CHECK FOR TRANSFORM DIRECTION
C
      GO TO(14,16,20,22,22),ITYPE
C     *****
C     TRANSFORM FROM SATELLITE COORDINATES TO EARTH COORDINATES
C     *****
   14 CALL LATLON(ATFRAC,XLIN,XELE,XLAT,XLON,NERR)
      PRINT 30
   30 FORMAT(2X,'SE: XLAT,XLON,NERR')
      PRINT 31,XLAT,XLON,NERR
   31 FORMAT(2X,2F15.7,I8)
      GO TO 77
C-----------------------------------------------------------------------
C
C     TRANSFORM FROM EARTH COORDINATES TO SATELLITE COORDINATES
C
   16 ITER=ITER+1
      IF(ITER.GT.LIMIT)GOTO 18
      IF(ITER.GT.1) GOTO 17
C     *****
C     COMPUTE EARTH COORDINATE VECTOR
C     *****
      CALL VCLALO(ATFRAC,XLAT,XLON,XE,YE,ZE,NERR)
      PRINT 40
   40 FORMAT(2X,'EARTH COOR. VEC.: XE,YE,ZE,NERR')
      PRINT 41, XE,YE,ZE,NERR
   41 FORMAT(2X,3E20.4,I8)
      IF(NERR.GT.0) GOTO 77
   17 CALL LINELE(XE,YE,ZE,XLIN,XELE)
      PRINT 50
   50 FORMAT(2X,'LINELE1: XLIN,XELE')
      PRINT 51,XLIN,XELE
   51 FORMAT(2X,2F15.7)
      GO TO 12
C
C     CHECK IF POINT IS OFF FRAME AND IF SO SET ERROR FLAG
C
   18 IF(XLIN.LT.1.0.OR.XLIN.GT.TOTLIN) NERR=4
      IF(XELE.LT.1.0.OR.XELE.GT.TOTELE) NERR=5
      GO TO 77
C-----------------------------------------------------------------------
C     *****
C     EARTH EDGE COMPUTATION
C     COMPUTE POINTING VECTOR IN SATELLITE COORDINATE SYSTEM AT ELEMENT 0
C
C     SUBROUTINE  HORIZON NOT USED
   20 CONTINUE
      GO TO 77
C-----------------------------------------------------------------------
C
C     SUB-SATELLITE POINT COMPUTATION
C
   22 ITER=ITER+1
      IF(ITER.GT.LIMIT) GO TO 21
```

```
      CALL LINELE(0.0,0.0,0.0,XLIN,XELE)
      PRINT 60
   60 FORMAT(2X,'LINELE2: XLIN,XELE')
      PRINT 61, XLIN,XELE
   61 FORMAT(2X,2F15.7)
      GO TO 12
C
C     COMPUTE SUB-SATELLITE POINT FROM SATELLITE POSITION VECTOR
C
   23 XLAT=ATAN(XVEC3/SQRT(XVEC1**2+XVEC2**2))/RDPDG
      XLON=ATAN2(XVEC2,XVEC1)/RDPDG
      PRINT 70
   70 FORMAT(2X,'SUB-SAT PT.: XLAT,XLON')
      PRINT 71, XLAT,XLON
   71 FORMAT(2X,2F15.7)
      IF(ITYPE.EQ.4) GO TO 77
   77 RETURN
      END
```

```
      SUBROUTINE SATCOR (NDAY,SAMTIM,GAMMA,SPIN)
C     SATOR USES THE NAVIGATION SOLUTION (ORBIT,SPINATTITUDE,GAMMA)
C      TO CALCULATE THE SATELLITE COORDINATE ROTATION MATRIX AROT
C      AT THE SAMPLE TIME, AND STORE IT IN THE COMMON/SATVEC/
C     SG = SIN ( GAMMA )
C     CG = COS ( GAMMA)
C     EARROT = EARTH ROTATION FROM T(0) (RADIANS )
C     ST = SIN ( EARROT )
C     CT  = COS ( EARROT )
C
C       C.T. MOTTERSHEAD/CSC
C     10 OCT. 1975
C
      COMMON/GDATA/PI,RDPDG,R,A,B,AB,ASQ,BSQ,ATMHGT,GRACON,EMEGA,SOLSID
     * ,SHA,IYR,IHR
      COMMON/SATVEC/XSAT,YSAT,ZSAT,HEIGHT,XVEC1,XVEC2,XVEC3,THETA,
     *AROT11,AROT12,AROT13,AROT21,AROT22,AROT23,AROT31,AROT32,AROT33
      DIMENSION SPIN(3)
      SG=SIN(GAMMA)
      CG=COS(GAMMA)
      PRINT 30,GAMMA,SG,CG
   30 FORMAT(//2X,'SATCOR: GAMMA,SG,CG',/2X,3E20.8)
      EARROT=EMEGA*SAMTIM
      ST=SIN(EARROT)
      CT=COS(EARROT)
C
C     REPOINT SPIN AXIS AS FUNCTION OF PRECESSION
C
      SPAX1=SPIN(1)
      SPAX2=SPIN(2)
      SPAX3=SPIN(3)
      CALL PRECES(SAMTIM,SPAX1,SPAX2,SPAX3)
C
C  .  COMPUTE DISPLACEMENT VECTOR FROM ORBIT INFORMATION ( KEPLERIAN MODEL )
C
      CALL SATPOS(NDAY,SAMTIM,XSAT,YSAT,ZSAT)
      PRINT 50
   50 FORMAT(2X,'PRECES SATPOS: SPAX1,SPAX2,SPAX3,XSAT,YSAT,ZSAT')
      PRINT 51, SPAX1,SPAX2,SPAX3,XSAT,YSAT,ZSAT
   51 FORMAT(2X,6F15.7)
C
C     COMPUTE UNIT POINTING VECTOR
C
      HEIGHT=SQRT(XSAT**2+YSAT**2+ZSAT**2)
      XVEC1=XSAT/HEIGHT
      XVEC2=YSAT/HEIGHT
      XVEC3=ZSAT/HEIGHT
      THETA=R/HEIGHT
C
C     COMPUTE NOMINAL SATELLITE POSITION ROTATIONAL MATRIX
C
      AROT31=CT*SPAX1+ST*SPAX2
      AROT32=-ST*SPAX1+CT*SPAX2
      AROT33=SPAX3
      COSA=XVEC1*AROT31+XVEC2*AROT32+XVEC3*AROT33
      YVEC1=XVEC1-COSA*AROT31
      YVEC2=XVEC2-COSA*AROT32
      YVEC3=XVEC3-COSA*AROT33
```

```
      YNOR=-1.0/SQRT(YVEC1**2+YVEC2**2+YVEC3**2)
      PRINT 40
   40 FORMAT(//2X,'SATCOR: EARRCT,HEIGHT,SAMTIM,COSA,YVEC1,YVEC2,YVEC3,
     1YNOR')
      PRINT 41,EARRCT,HEIGHT,SAMTIM,COSA,YVEC1,YVEC2,YVEC3,YNOR
   41 FORMAT(/2X,8F13.5)
      AROT11=YVEC1*YNOR
      AROT12=YVEC2*YNOR
      AROT13=YVEC3*YNOR
      AROT21=AROT32*AROT13-AROT33*AROT12
      AROT22=AROT33*AROT11-AROT31*AROT13
      AROT23=AROT31*AROT12-AROT32*AROT11
      AROT=AROT11
      AROT11=AROT*CG-SG*AROT21
      AROT21=AROT*SG+CG*AROT21
      AROT=AROT12
      AROT12=AROT*CG-SG*AROT22
      AROT22=AROT*SG+CG*AROT22
      AROT=AROT13
      AROT13=AROT*CG-SG*AROT23
      AROT23=AROT*SG+CG*AROT23
      PRINT 60
   60 FORMAT(2X,'SATCOR: AROT11,AROT12,AROT13,AROT21,AROT22,AROT23
     1,AROT31,AROT32,AROT33')
      PRINT 61,AROT11,AROT12,AROT13,AROT21,AROT22,AROT23,AROT31,
     1AROT32,AROT33
   61 FORMAT(2X,9F13.6)
      RETURN
      END
```

```
      SUBROUTINE LATLON(ATFRAC,XLIN,XELE,XLAT,XLON,NERR)
      COMMON/GDATA/PI,RDPDG,R,A,B,AB,ASQ,BSQ,ATMHGT,GRACON,EMEGA,SOLSID
     * ,SHA,IYR,IHR
      COMMON/SCANR/ISCAN                ,NUMSEN,NOPCLN,TOTLIN,DEGLIN,RADLIN
     1,PICLIN,TOTELE,DEGELE,RADELE,PICELE,EF,PITCH,YAW,ROLL,SKEW,ROTM11,
     *ROTM13,ROTM21,ROTM23,ROTM31,ROTM33,RFACT,ROASIN,SO,CO,PDIP,PRAT
      COMMON/SATVEC/XSAT,YSAT,ZSAT,HEIGHT,XVEC1,XVEC2,XVEC3,THETA,
     *AROT11,AROT12,AROT13,AROT21,AROT22,AROT23,AROT31,AROT32,AROT33
      YLIN=(XLIN-PCLN)*RADLIN
      YELE=(XELE-PICELE)*RADELE
      SINLIN=SIN(YLIN)
      COSLIN=COS(YLIN)
      SINELE=SIN(YELE)
      COSELE=COS(YELE)
C
C       COMPUTE POINTING VECTOR IN SATELLITE COORDINATE SYSTEM AT ELEMENT 0
C
      ELI=ROTM11*COSLIN-ROTM13*SINLIN
      EMI=ROTM21*COSLIN-ROTM23*SINLIN
      ENI=ROTM31*COSLIN-ROTM33*SINLIN
C
C     ADJUST POINTING VECTOR FOR ELEMENT COUNT
C
      FLI=COSELE*ELI+SINELE*EMI
      FMI=-SINELE*ELI+COSELE*EMI
      FNI=ENI
C
C     COMPUTE POINTING VECTOR IN EARTH COORDINATE SYSTEM
C
      ELO=AROT11*FLI+AROT21*FMI+AROT31*FNI
      EMO=AROT12*FLI+AROT22*FMI+AROT32*FNI
      ENO=AROT13*FLI+AROT23*FMI+AROT33*FNI
      PRINT 10
   10 FORMAT(//2X,'LATLON: YLIN,YELE,ELI,EMI,ENI,FLI,FMI,FNI,ELO,EMO,
     1ENO')
      PRINT 11,YLIN,YELE,ELI,EMI,ENI,FLI,FMI,FNI,ELO,EMO,ENO
   11 FORMAT(/2X,11F10.3)
C
C     ADJUST FOR CBLATENESS OF EARTH SPHERE AND CLOUD HEIGHT
C
      CLDHGT=ATFRAC*ATMHGT
      AHGTSQ=(A+CLDHGT)**2
      BHGTSQ=(B+CLDHGT)**2
      BASQ=BHGTSQ/AHGTSQ
      CNEMSQ=1.0-BASQ
      AQ=BASQ+CNEMSQ*ENO**2
      BQ=2.0*((ELO*XSAT+EMO*YSAT)*BASQ+ENO*ZSAT)
      CQ=(XSAT**2+YSAT**2)*BASQ+ZSAT**2-BHGTSQ
      RAD=BQ**2-4.0*AQ*CQ
C
C     CHECK IF POIT IS CFF EARTH AND IF SO LET REJECTION VALUES
C
      IF(RAD.LT.1.0) GO TO 32
C
C     FIND POINT ALONG POINTING VECTOR INTERSECTING EARTH SURFACE
C
      S=-(BQ+SQRT(RAD))/(2.0*AQ)
      X=XSAT+ELO*S
```

```
      Y=YSAT+EMO*S
      Z=ZSAT+ENO*S
      PRINT 20
   20 FORMAT(//2X,'LATLON: CLDHGT,BASQ,AQ,BQ,CQ,RAD,S,X,Y,Z')
      PRINT 21,CLDHGT,BASQ,AQ,BQ,CQ,RAD,S,X,Y,Z
   21 FORMAT(/2X,10F11.4)
C
C       CONVERT TO EARTH COORDINATES
C
      XLAT=ATAN(Z/SQRT(X**2+Y**2))
      XLON=ATAN2(Y,X)
      XLAT=XLAT/RDPDG
      XLON=XLON/RDPDG
      GO TO 40
   32 NERR=2
   40 RETURN
      END
```

```
      SUBROUTINE PRECES (SAMTIM,SPAX1,SPAX2,SPAX3)
      COMMON/SCANP/ISCAN                  ,NUMSEN,NOPCLN,TOTLIN,DEGLIN,RADLIN
     1 ,PICLIN,TOTELE,DEGELE,RADELE,PICELE,EF,PITCH ,YAW,ROLL,SKEW,ROTM11
     2,ROTM13,ROTM21,ROTM23,ROTM31,ROTM33,REACT,RCASIN,SD,CD,PDIR,PRAT
      IF (PRAT.EQ.0.0) GO TO 10
      PTOT=SAMTIM*PRAT
      SA=SIN(PTOT)
      CA=COS(PTOT)
      X1=SQRT(1.0/(1.0+(SPAX1/SPAX3)**2))
      Y1=0.0
      Z1=-(SPAX1*X1/SPAX3)
      X2=SPAX2*Z1
      Y2=SPAX3*X1-SPAX1*Z1
      Z2=-SPAX2*X1
      X1=CD*X1+SD*X2
      Y1=CD*Y1+SD*Y2
      Z1=CD*Z1+SD*Z2
      PRINT 20,X1,Y1,Z1,X2,Y2,Z2
   20 FORMAT(//2X,'PRECES: X1,Y1,Z1,X2,Y2,Z2',/2X,6F15.7)
      SPAX1=CA*SPAX1+SA*X1
      SPAX2=CA*SPAX2+SA*Y1
      SPAX3=CA*SPAX3+SA*Z1
   10 RETURN
      END
```

```
      SUBROUTINE LINELE(XE,YE,ZE,XLIN,XELE)
      COMMON/SATVEC/XSAT,YSAT,ZSAT,HEIGHT,XVEC1,XVEC2,XVEC3,THETA,
     *AROT11,AROT12,AROT13,AROT21,AROT22,AROT23,AROT31,AROT32,AROT33
      COMMON/SCANR/ISCAN                ,NUMSEN,NOPCLN,TOTLIN,DEGLIN,RADLIN
     *,PCLN   ,TOTELE,DEGELE,RADELE,PICELE,FF,PITCH,YAW,ROLL,SKEW,ROTM11,
     *ROTM13,ROTM21,ROTM23,ROTM31,ROTM33,RFACT,ROASIN,SD,CD,PDIR,PRAT
      Y1=XE-XSAT
      Y2=YE-YSAT
      Y3=ZE-ZSAT
      YFACT=1.0/SQRT(Y1**2+Y2**2+Y3**2)
      Y1=Y1*YFACT
      Y2=Y2*YFACT
      Y3=Y3*YFACT
      X1=AROT11*Y1+AROT12*Y2+AROT13*Y3
      X2=AROT21*Y1+AROT22*Y2+AROT23*Y3
      X3=AROT31*Y1+AROT32*Y2+AROT33*Y3
      UMV=ATAN2(X3,SQRT(RFACT-X3**2))-ROASIN
      XLIN=PCLN-UMV/RADLIN
      SLIN=SIN(UMV)
      CLIN=COS(UMV)
      U=ROTM11*CLIN+ROTM13*SLIN
      V=ROTM21*CLIN+ROTM23*SLIN
      PRINT 5,U,V,UMV
    5 FORMAT(/2X,'LINELE: U,V,UMV',/2X,3E20.8)
      IF(V.EQ.0.0) GO TO 6
      UV=ATAN2(V,U)
      GO TO 7
    6 UV=0.0
    7 UMV=UV-ATAN2(X2,X1)
      XELE=PICELE+UMV/RADELE
      PRINT 10
   10 FORMAT(//2X,'LINELE: YFACT,Y1,Y2,Y3,X1,X2,X3,UMV,U,V')
      PRINT 11,YFACT,Y1,Y2,Y3,X1,X2,X3,UMV,U,V
   11 FORMAT(/2X,7F11.4,/2X,3E20.8)
      RETURN
      END
```

```
      SUBROUTINE VCLALO(ATFRAC,XLAT,XLCN,XE,YE,ZE,NERR)
CREATE RDO=(350,6)SATPAK,FTN/NV
C
C     XE,YE,ZE - COMPONENTS OF EARTH COORDINATES VECTOR
C     YLAT = XLAT CONVERTED TO RADIANS
C     YLON = XLON CONVERTED TO RADIANS
C     SINLAT = SIN ( YLAT )
C     COSLAT = COS ( YLAT )
C     SINLON = SIN ( YLON )
C     COSLON = COS ( YLON )
C        C. T. MOTTERSHEAD/CSC
C
      COMMON/GDATA/PI,RCPDG,R,A,B,AB,ASQ,BSQ,ATMHGT,GRACON,EMEGA,SOLSID
     * ,SHA,IYR,IHR
      COMMON/SATVEC/XSAT,YSAT,ZSAT,HEIGHT,XVEC1,XVEC2,XVEC3,THETA,
     *AROT11,AROT12,AROT13,AROT21,AROT22,AROT23,AROT31,AROT32,AROT33
      YLAT=XLAT*RCPDG
      YLCN=XLCN*RCPDG
      SINLAT=SIN(YLAT)
      COSLAT=COS(YLAT)
      SINLCN=SIN(YLON)
      COSLON=COS(YLON)
      X=COSLAT*COSLON
      Y=COSLAT*SINLCN
      Z=SINLAT
C
C     CHECK IF POINT IS OUT OF SATELLITE VIEW AND IF SO SET ERROR FLAG
C
      IF((X*XVEC1+Y*XVEC2+ Z*XVEC3).LT.THETA) NERR=3
C
C     ADJUST FOR OBLATENESS OF EARTH SPHERE AND CLOUD HEIGHT
C
      TANLAT=(SINLAT/COSLAT)**2
      RR=SQRT((1.0+TANLAT)/(BSQ+ASQ*TANLAT))*AB+ATMHGT*ATFRAC
      XE=RR*X
      YE=RR*Y
      ZE=RR*Z
      RETURN
      END
```

```
      FUNCTION VTIME(PICTIM,XLIN,XELE)
      COMMON/NAVSLN/INAV,NAVN,LANDN,NIT,MIT,NORB,NDAY,EL,EP,ET,SPIN(3),
     1 RASCEN,DECLIN,SPINRA,TMPSCL,GTIM(16),BETA(16),BDOT(16),NGAM(16)
      COMMON/SCANR/ISCAN          ,NUMSEN,NOPCLN,TOTLIN,DEGLIN,RADLIN
     *,PICLIN,TOTELE,DEGELE,RADELE,PICELE,EF,PITCH,YAW,ROLL,SKEW,ROTM11,
     *ROTM13,ROTM21,ROTM23,ROTM31,ROTM33,RFACT,ROASIN,SD,CD,PDIR,PRAT
      ILIN=XLIN+0.5
      PARLIN=(ILIN-1)/NUMSEN
      PARELE=(XELE-1.0)*EF
      FRAMET=TMPSCL*(PARLIN+PARELE)
      VTIME=PICTIM+FRAMET
      PRINT 10,PARLIN,PARELE,FRAMET,VTIME
   10 FORMAT(//2X,'VTIME: PARLIN,PARELE,FRAMET,VTIME',/2X,4E20.8)
      RETURN
      END
```

```
      SUBROUTINE RESIDU
      COMMON/SYSCOM/ ITK,NL
      COMMON/XLAND/NLAND,LDAY,ICODE(32),PTIME(32),XLIN(32),XELE(32),
     1XLAT(32),XLON(32),DLIN(32),DELTA(32),TIMEL(32)
      COMMON/NAVSLN/INAV,NAVN,LANDN,NIT,MIT,NORB,NDAY,EL,EP,ET,SPIN(3),
     1 RASCEN,DECLIN,SPINRA,TMPSCL,GTIM(16),BETA(16),BDOT(16),NGAM(16)
      DIMENSION          NUM(16),AVG(16),VAR(16)
      GAMA=0.0
      GDOT=0.0
      ATER=0.0
      DO 10 L=1,16
            NUM(L)=0
            AVG(L)=0.0
            VAR(L)=0.0
   10 CONTINUE
      LMAX=1
      PRINT 17, NDAY
   17 FORMAT(//20X,    48HLANDMARK RESIDUALS AT ZERO GAMMA SHIFT FOR DA
     1TE     ,I6)
      PRINT 18
   18 FORMAT(2X,110H LMK RETURN  TIME(HMS)  LATITUDE  LONGITUDE  MEA
     1S.LINE  CALC.LINE  LINE ERR MEAS.PIXEL  CALC.PIXEL  DPIXEL)
      SUMSQ=0.0
      ZLSQ=0.0
      PRINT 37
   37 FORMAT(16X,'LANDMARK RESIDUALS AT ZERO GAMMA SHIFT',/2X,' LMK GMT
     1    LATITUDE LONGITUDE    CALC.LINE, ERROR  CALC.PIXEL,SHIFT RET')
      DO 50 I=1,NLAND
      PICTIM=PTIME(I)
      TIMEL(I)=VTIME(PICTIM,XLIN(I),XELE(I))
      NERR=0
      MSER=10
      CALL SATEAR(PICTIM,YLIN,YELE,XLAT(I),XLON(I),2,NERR,GAMA,
     1 GDOT,ATER)
      IF(NERR.GT.0) MSER=20
      DELTA(I)=YELE-XELE(I)
      DLIN(I)=YLIN-XLIN(I)
      PRINT 23,I,MSER,PTIME(I),XLAT(I),XLON(I),XLIN(I),YLIN,DLIN(I),
     1 XELE(I),YELE,DELTA(I)
   23 FORMAT(2X,I4,2X,I4,   3F12.5,6F12.3)
      ICODEN=MOD(ICODE(I)/100,10)
      IF(ICODEN.NE.0.AND.ICODEN.NE.1) GO TO 40
      SUMSQ=SUMSQ+DELTA(I)*DELTA(I)
      ZLSQ=ZLSQ+DLIN(I)*DLIN(I)
      LMK=MOD(ICODE(I),100)
      IF(LMK.LT.0.OR.LMK.GT.32) LMK=1
      AVG(LMK)=AVG(LMK)+DLIN(I)
      VAR(LMK)=VAR(LMK)+DLIN(I)**2
      IF(LMK.GT.LMAX) LMAX=LMK
      NUM(LMK)=NUM(LMK)+1
   40 PRINT 47, I,PTIME(I),XLAT(I),XLON(I),YLIN,DLIN(I),YELE,
     1 DELTA(I),NERR
   47 FORMAT(I6,F7.2,2F10.3,4F20.4,I4)
   50 CONTINUE
      FNUM=LANDN
      ZMS=SQRT(ZLSQ/FNUM)
      RMS=SQRT(SUMSQ/FNUM)
      PRINT 57,RMS,ZMS
```

```
 57   FORMAT(16H  RMS PIXEL ERR=  ,F8.2,16H  RMS LINE ERR=  ,F8.2)
      PRINT 61,ZMS
 61   FORMAT('   SUMMARY OF SPIN ATTITUDE FIT: OVERALL RMS LINE ERROR='
     1 ,F8.2,8X)
            DO 90 LMK=1,LMAX
            IF (NUM(LMK).EQ.0) GO TO 90
            FNUM=NUM(LMK)
            DLAV=AVG(LMK)/FNUM
            VSQ=VAR(LMK)/FNUM-DLAV**2
            VSQ=SQRT(VSQ)
      PRINT 71, LMK,DLAV,VSQ,NUM(LMK)
 71   FORMAT('   LANDMARK',I4,'MEAN LINE ERROR=',F8.2,'+/-',F8.2,',ON,',
     1 I4,',IMAGES.',5X)
 90   CONTINUE
      EL=ZMS
      RETURN
      END
```

```
      SUBROUTINE GAMCAL
      COMMON/XLAND/NLAND,LDAY,ICODE(32),PTIME(32),XLIN(32),XELF(32),
     1XLAT(32),XLON(32),DLIN(32),DELF(32),TIMEL(32)
      COMMON/NAVSLN/INAV,NAVN,LANDN,NIT,MIT,NORB,NDAY,EL,EP,ET,SPIN(3),
     1 RASCEN,DECLIN,SPINRA,TMPSCL,GTIM(16),BETA(16),BDOT(16),NGAM(16)
      CALL GCODER
      RETURN
      END
```

```
      SUBROUTINE GSHIFT(NUMGAM)
      COMMON/XLAND/NLAND,LDAY,ICODE(32),PTIME(32),XLIN(32),XELE(32),
     1XLAT(32),XLON(32),CLIN(32),DELE(32),TIMEL(32)
      COMMON/NAVSLN/INAV,NAVN,LANCN,NIT,MIT,NORB,NDAY,EL,EP,ET,SPIN(3),
     1 RASCEN,DECLIN,SPINRA,TMPSCL,GTIM(16),BETI(16),BETD(16),NUMG(16)
      INAV=1
      NUMGAM=0
      ISTART=1
      IF(ISTART.GT.NLAND) GO TO 6
      SUMG=0.0
      SUMGT=0.0
      SUMT=0.0
      SUMTSQ=0.0
      NUM=0
      N=0
      DO 5 I=ISTART,NLAND
      IF(I.NE.ISTART) GO TO 13
      PTIM=PTIME(I)
      ICODEN=MOD(ICODE(I)/100,10)
      ICODEG=MOD(ICODE(I)/1000,100)
      IF(ICODEN.NE.0.AND.ICODEN.NE.2) GO TO 2
      NUM=NUM+1
      GAMMA=DELE(I)
      SAMTIM=TIMEL(I)
      SUMG=SUMG+GAMMA
      SUMGT=SUMGT+GAMMA*SAMTIM
      SUMT=SUMT+SAMTIM
      SUMTSQ=SUMTSQ+SAMTIM**2
      PRINT 40
      FORMAT(2X,'NUM,GAMMA,SAMTIM,SUMG,SUMGT,SUMT,SUMTSQ')
      PRINT 41,NUM,GAMMA,SAMTIM,SUMG,SUMGT,SUMT,SUMTSQ
      FORMAT(2X,I8,3E20.4,/2X,3E20.4)
      IF(I.EQ.NLAND) GO TO 20
      NCODE=MOD(ICODE(I+1)/1000,100)
      IF(NCODE.EQ.ICODEG) GO TO 5
      N=I
      IF(NUM.EQ.0) GO TO 10
      NUMGAM=NUMGAM+1
      GTIM(NUMGAM)=PTIM
      NUMG(NUMGAM)=NUM
      IF(NUM.GT.1) GO TO 4
      BETI(NUMGAM)=GAMMA
      BETD(NUMGAM)=0.0
      GO TO 10
      XNUM=NUM
      DENOM=XNUM*SUMTSQ-SUMT**2
      BETI(NUMGAM)=(SUMTSQ*SUMG-SUMT*SUMGT)/DENOM
      BETD(NUMGAM)=(XNUM*SUMGT-SUMG*SUMT)/DENOM
      PRINT 50
      FORMAT(2X,'GSHIFT:XNUM,DENOM,BETI,BETD')
      PRINT 51, XNUM,DENOM,BETI(NUMGAM),BETD(NUMGAM)
      FORMAT(2X,I8,3F15.7)
      GO TO 10
      CONTINUE
      ISTART=N+1
      GO TO 1
      RETURN
      END
```

```
      SUBROUTINE GCODER
      COMMON/SYSCOM/ ITK,NL
      COMMON/XLAND/NLAND,LDAY,ICODE(32),PTIME(32),XLIN(32),XELF(32),
     1XLAT(32),XLON(32),DLIN(32),DELF(32),TIMEL(32)
      COMMON/NAVSLN/INAV,NAVN,LANDN,NIT,MIT,NORB,NDAY,EL,EP,ET,SPIN(3),
     1 RASCEN,DECLIN,SPINRA,TMPSCL,GTIM(16),BETI(16),BETD(16),NUMG(16)
      DIMENSION BFIT(32),ROLD(32),RNEW(32),IMID(32),LMKID(32),IWD(16)
      DIMENSIONRMS(16),JCODE(32),LAST(16)
      INTEGER*4 ITIME,ILALO
      NLP = 20
      EP=0.0
      NPAGE=1+NLAND/NLP
      IMG=1
      TIMAG=PTIME(1)+0.01
      DO 10 I=1,NLAND
      IF(PTIME(I).LT.TIMAG) GO TO 6
      LAST(IMG)=I-1
      IMG=IMG+1
      TIMAG=PTIME(I)+0.01
    6 IMID(I)=IMG
      LMKID(I)=MOD(ICODE(I),100)
      BFIT(I)=0.0
      JCODE(I)=ICODE(I)
      ROLD(I)=0.0
      RNEW(I)=0.0
      IWD(I)=NLAND+1
   10 CONTINUE
      EP=0.0
      IGP=1
      MAXIM=IMID(NLAND)
      LAST(MAXIM)=NLAND
      IWD(1)=MAXIM
   60 NBGN=1
      DO 90 N=1,NLAND
      IM=IWD(N)
      IF(IM.GT.MAXIM) IM=MAXIM
      IF (IM.GT.0) GO TO 70
      PRINT 20
   20 FORMAT(//'NEGATIVE ENTRY TO GAMMA CODE ENCOUNTERED')
   70 NEND=LAST(IM)
      DO 80 I=NBGN,NEND
      ICODE(I)=JCODE(I)+1000*N
   80 CONTINUE
      NBGN=NEND+1
      IF(NBGN.GT.NLAND) GO TO 95
   90 CONTINUE
   95 CALL GSHIFT (NUMGAM)
      NUMG(32)=NUMGAM
      NTOT=0
      DO 99 IGP=1,NUMGAM
      NTOT=NTOT+NLMG(IGP)
      RMS(IGP)=0.0
   99 CONTINUE
      KBGN=1
      KEND=0
      TOTSQ=0.0
      PRINT 701
  701 FORMAT(16X,41H** LANDMARK PIXEL SHIFT COMPENSATION   **   ,17X)
```

```
      PRINT 707
707   FORMAT(' TO CONTROL THE EAST-WEST ALIGMENT OF THIS SET OF MASTER
     1 IMAGES,',/2X,'EXAMINE THE MEASURED LANDMARK PIXEL SHIFTS,AND DEF
     2INE IMAGE GROUPS',/2X,'FOR A TRIAL LINEAR FIT OF SHIFT VS. TIME. T
     3HE PARAMETERS AND FINAL',1X,'(NEW) RESIDUALS FOR THE CURRENT GROUP
     4ING ARE LISTED BELOW:')
      PRINT 702
702   FORMAT(' MASTER IMAGE     LANDMARK  SCAN  PIXEL SHIFTS  FIN
     1AL PIXEL ERROR  ')
      PRINT 703
703   FORMAT(' ID  GMT  GROUP NO. ID  TIME  MEASURED  FITTED  '
     1,'   NEW    OLD  ')
      N=1
18    LEND=0
      KPAGE=0
19    LBGN=LEND+1
      LEND=LEND+NLP
      KPAGE=KPAGE+1
      IF(LEND.GT.NLAND) LEND=NLAND
      IGP=0
22    DO 50 I=LBGN,LEND
      ITIME=ILALO(PTIME(I))
      IGOLD=IGP
      IGP=MOD(ICODE(I)/1000,100)
      BETA=BETI(IGP)
      BETDOT=BETD(IGP)
30    ROLD (I)=RNEW(I)
      GCALC=BETA+BETDOT*TIMEL(I)
      BFIT(I)=GCALC
      DIFF=DELE(I)-GCALC
      RNEW(I)=DIFF
      ICODEN=MOD(ICODE(I)/100,10)
      IF(ICODEN.NE.0.AND.ICODEN.NE.2) GO TO 40
      DSQ=DIFF**2
      RMS(IGP)=RMS(IGP)+DSQ
      TOTSQ=TOTSQ+DSQ
40    PRINT 704, IMID(I),ITIME,IGP,I,LMKID(I),TIMEL(I),
     1DELE(I),BFIT(I),RNEW(I),ROLD(I)
704   FORMAT(I4,I8,I4,I6,I4,5F18.4)
50    CONTINUE
      TOTSQ=SQRT(TOTSQ/FLOAT(NTCT))
      PRINT 708, TOTSQ,EP
708   FORMAT(32X,'FINAL RMS PIXEL ERROR=',2E20.4)
      EP=TOTSQ
      ETN=SQRT((EL**2+EP**2)/2.0)
      PRINT 709, ETN,ET
709   FORMAT(12X,'CORRESPONDING OVERALL NAVIGATION ACCURACY ',2E20.4)
      ET=ETN
      PRINT 219
219   FORMAT(74X)
      PRINT 77
77    FORMAT(/5X,'GAMMA SHIFT CALCULATION')
      PRINT 230
230   FORMAT(44H GROUP  SIZE  BASETIME   BETA  BETADOT  RMS )
      DO 250 N=1,NUMGAM
      RMS(N)=SQRT(RMS(N)/FLOAT(NUMG(N)))
      PRINT 240, N,NUMG(N),GTIM(N),BETI(N),BETD(N),RMS(N)
240   FORMAT(2I6,4E20.4)
```

```
 250 CONTINUE
 700 RETURN
     END
```

APPENDIX E

Landmark Scanning Program

by

Neil R. Guard

Rufus E. Bruce

Sandra K. Weaver

```
6-15:28:55 (,0)


 CODE(1) 000647; DATA(0) 004130; BLANK COMMON(2) 000000

RENCES (BLOCK, NAME)

P
S


S


NMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

1 141G        0001     000123 144G      0001     000214 172G      0001     000222 200G
4 217G        0001     000312 236G      0001     000456 277G      0001     000463 303G
6 331G        0001     000550 343G      0001     000566 354G      0001     000636 377G
0 750L        0001     000403 775L      0001     000613 810L      0001     000617 850L
3 910F        0000     004042 920F      0000     004034 930F      0000     004036 940F
6 960F        0000     004012 970F      0000 I 003773 I         0000 I 003766 IAFC
4 IDMP        0000 I 003636 IELE      0000 I 003771 IEL1      0000 I 003772 IEL2
7 IPAR        0000 I 003740 ISKIP     0000 I 004001 ISLP      0000 I 004002 ISLP1
0 ITOS        0000 I 004005 IVAL      0000 I 003744 IWD1      0000 I 003752 IWD2
5 IXIT        0000 I 003774 J         0000 I 003765 JDUMP     0000 I 003775 JX
4 LINE        0000 I 001344 NATA      0000 I 004000 NDX       0000 I 004003 NLINE
2 NWORDI      0000 I 003761 NWORDS    0000 R 000214 T         0000 R 002474 X


  C ****  THIS PROGRAM READS A SECTORED VERSION OF AN SMS DATA TAPE
  C       AND PROCESSES A USER CHOSEN AREA BY USING A PATTERN RECOG-
  C       NITION SCHEME TO LOCATE A PREDETERMINED LANDMARK FOR USE
  C       IN CALCULATING REGISTRATION TRANSFORMATION PARAMETERS
  C ****
  C     INITIAL STORAGE
  C        ITOS(134)     - DATA RETURN FROM FLOTAP
  C        K(6)          - STATUS RETURN FROM FLOTAP
  C        T(60,10)      - COASTLINE OUTPUT ARRAY
  C        NATA(60,10)   - WORKING STORAGE ARRAY
  C        X(60,10)      - SLOPE CONTRAST ARRAY
  C        LINE(10)      - CRITICAL LINE NO. STORAGE
  C        IELE(10)      - CRITICAL ELEMENT NO. STORAGE
  C        ICRTEL(60)    - COASTAL ELEMENT STORAGE NO.
  C        IWD1(6)       - CHARACTER COMPUTATION STORAGE
  C        IWD2(6)       - CHARACTER COMPUTATION STORAGE
  C ****
        DIMENSION ITOS(134),K(6),T(60,10),NATA(60,10),X(60,10),LINE(10),
       1IELE(10),ICRTEL(60),IWD1(6),IWD2(6)
  C ****
  C     INITIAL PARAMETERS
```

```
C         ISKIP     - NO. OF LINES ON TAPE TO SKIP
C         NWORDS    - NO. OF WORDS PER LINE
C         NLINES    - NO. OF LINES IN ARRAY
C         IDMP      - NO. OF WORDS TO SKIP AT BEGINNING OF EACH LINE
C         JDMP      - NO. OF WORDS LEFT TO SKIP AT END OF EACH LINE
C         IAFC      - FOR SAVING NO. OF ABNORMAL FRAME COUNTS
C         IPAR      - FOR SAVING NO. OF PARITY ERRORS
C ....
      ISKIP= 200
      NWORDS= 10
      NWORD1=NWORDS-1
      NLINES= 60
      IDMP=71
      JDUMP=IDMP+NWORD1-1
      IAFC= 0
      IPAR= 0
      ILINE= ISKIP + NLINES
      IEL1= IDMP*6
      IEL2= IEL1 + NWORD1*6
C * SKIP A PAGE ON OUTPUT
      WRITE (6,900)
  900 FORMAT(1H1)
C * ESTABLISH TAPE WITHEN PROGRAM
      CALL FLDTAP(11,'VISIBLEDATA1')
      CALL FLDTAP(6)
      CALL FLDTAP(5)
      CALL FLDTAP(1)
C * SKIP ISKIP LINES ON TAPE
      CALL FLDTAP(9,ISKIP)
C * LOOP TO READ DATA AND STORE IT
      WRITE (6,970)
 *970 FORMAT (1X,'RAW DATA ARRAY AS READ FROM TAPE',/)
      WRITE (6,950) ISKIP,ILINE,IEL1,IEL2
  950 FORMAT (1X,'LINE',I6,' TO',I6,', ELEMENT',I6,' TO',I6,//)
      DO 100 I=1,NLINES
C * CLEAR FLDTAP STATUS RETURN ARRAY
      DO 200 J=1,6
      K(J)=0
  200 CONTINUE
C * PICK UP DATA LINE
      CALL FLDTAP(7,134,ITOS,K)
C * CHECK TAPE READ STATUS
      IF (K(3).NE.0) STOP
      IF (K(4).NE.0) STOP
      IF (K(5).NE.0) STOP
      IF (K(1).EQ.0) STOP
      IF (K(2).NE.0) IAFC=IAFC+1
      IF (K(6).NE.0) IPAR=IPAR+1
      IF (K(2).NE.0.AND.K(6).NE.0.AND.K(1).EQ.1) STOP
C * OUTPUT DATA LINE READ
      WRITE (6,930) (ITOS(JX),JX=IDMP,JDUMP)
  930 FORMAT (1X,9A6)
C * STORE DESIRED ELEMENTS
      DO 400 J=1,NWORDS
      JX=IDMP+J-1
      NATA(I,J)=ITOS(JX)
  400 CONTINUE
```

```
  100 CONTINUE
      WRITE (6,900)
C * LOOP THROUGH NLINE LINES TO PROCESS DATA
      DO 500 I=1,NLINES(6c)
      IXIT= 0
C * STORE SINGLE ELEMENT VALUES
      DO 600 J=1,NWORDI9
      IWD1(1)=FLD(00,6,NATA(I,J))
      IWD1(2)=FLD(06,6,NATA(I,J))
      IWD1(3)=FLD(12,6,NATA(I,J))
      IWD1(4)=FLD(18,6,NATA(I,J))
      IWD1(5)=FLD(24,6,NATA(I,J))
      IWD1(6)=FLD(30,6,NATA(I,J))
      IWD2(1)=FLD(18,6,NATA(I,J))
      IWD2(2)=FLD(24,6,NATA(I,J))
      IWD2(3)=FLD(30,6,NATA(I,J))
      IWD2(4)=FLD(00,6,NATA(I,J+1))
      IWD2(5)=FLD(06,6,NATA(I,J+1))
      IWD2(6)=FLD(12,6,NATA(I,J+1))
C * FIND SLOPE ACROSS FOUR ELEMENTS
      DO 700 IX=1,6
      NDX= 6*(IX-1)
      ISLP= ABS(IWD1(IX)-IWD2(IX))
C * SET OCEAN VALUE IF SLOPE .LT. 3
      IF (ISLP.LT.3) GO TO 725
C * SET CLOUD VALUE IF SLOPE .GT. 4 .OR. ELEMENT .GT. 22
      IF(ISLP.GT.4.OR.IWD1(IX).GT.22) GO TO 750
C * SET COASTAL VALUE
      FLD(NDX,6,T(I,J))=29
      IXIT=IXIT+1
      GO TO 775
  750 FLD(NDX,6,T(I,J))=8
      GO TO 775
  725 FLD(NDX,6,T(I,J))=5
C * STORE SLOPE VALUE FOR OUTPUT
  775 FLD(NDX,6,X(I,J))= ISLP + 48
      IF (IXIT.EQ.1) ICRTEL(I)=6*J+IX+2                6*(J-1)+
  700 CONTINUE                                          6*J+Ix
  600 CONTINUE                        6*1+1+2
  500 CONTINUE                           9
C * OUTPUT COASTAL OUTLINE ARRAY
      WRITE (6,940)
  940 FORMAT (1X,'PREDICTED COASTAL OUTLINE ARRAY',/)
      WRITE (6,950) ISKIP,ILINE,IEL1,IEL2
      DO 110 I=1,NLINES
      WRITE (6,930) (T(I,J),J=1,NWORDI)
  110 CONTINUE
      WRITE (6,900)
C * OUTPUT SLOPES ARRAY
      WRITE (6,960)
  960 FORMAT(1X,'COMPUTED SLOPE VALUES',/)
      WRITE (6,950) ISKIP,ILINE,IEL1,IEL2
      DO 120 I=1,NLINES
      WRITE (6,930) (X(I,J),J=1,NWORDI)
  120 CONTINUE
      WRITE (6,900)
      WRITE (6,910) (ICRTEL(I),I=1,40)
```

```
  910 FORMAT (1X,'CRITICAL ELEMENTS',/,6(1X,I5))
C * CALCULATE LINE AND ELEMENT NUMBERS FOR UP TO TEN COASTAL
C     PROJECTION POINTS.
      ISLP1= ICRTEL(1)-ICRTEL(3)
      J=0
      NLINE1=NLINES-2
      DO 800 I=2,NLINE1
      ISLP2= ICRTEL(I)-ICRTEL(I+2)
      IVAL= ISLP1*ISLP2
      IF (IVAL.GT.0) GO TO 810
      IF(J.GE.10) GO TO 850
      J=J+1
      LINE(J)=I+1
      IELE(J)=ICRTEL(I+1)
  810 ISLP1=ISLP2
  800 CONTINUE
  850 JX=J
C * OUTPUT CRITICAL LINE AND ELEMENT NUMBERS
      WRITE (6,900)
      WRITE (6,920) (LINE(I),IELE(I),I=1,JX)
  920 FORMAT (1X,'COASTAL PROTRUSION POINTS PREDICTED AT : ',
     110(/,41X,'LINE ',I2,'  ELEMENT 'I2))
      STOP
      END

:OMPILATION:          NO  DIAGNOSTICS.



 03/16/76 15:29:05               WSMR 32K VERSION

   001000 012001       4610 IBANK WORDS DECIMAL
   040000 050373       4348 DBANK WORDS DECIMAL
;S  011133



:GMENT $MAINS          001000 012001      040000 050373

         $(1)      001000 001024
         $(1)      001025 001047
         $(1)      001050 001157        $(2)     040000 040012
         $(1)      001160 001365        $(2)     040013 040032
K)                                           040033 040034
         $(1)      001366 001513        $(2)     040035 040077
         $(1)      001514 001536
         $(1)      001537 001760        $(2)     040100 040174
         $(1)      001761 002021
         $(1)      002022 002316        $(2)     040175 040200
         $(1)      002317 003473        $(2)     040201 040237
         $(1)      003474 004645        $(2)     040240 040274
         $(1)      004646 004757
         $(1)      004760 005642        $(2)     040275 040351
```

```
        $(1)     005643 005676
                                      $(2)     040352 042553
        $(1)     005677 006126        $(2)     042554 042601
        $(1)     006127 007113        $(2)     042602 042752
        $(3)     007114 007114        $(4)     042753 043024
        $(1)     007115 007141        $(2)     043025 043034
        $(1)     007142 007320        $(2)     043035 043153
        $(1)     007321 007540        $(2)     043154 043356
                                      $(2)     043357 043415
        $(1)     007541 007601
        $(1)     007602 010403        $(0)     043416 043757
        $(1)     010404 011027        $(2)     043760 044164
        $(1)     011030 011132        $(2)     044165 044232
        $(3)     OVF                  $(4)     044233 044242
OMMONBLOCK)                                 044243 044243
        $(1)     011133 012001        $(0)     044244 050373
                                      $(2)     BLANKSCOMMON

VEL 71
```