MODIS DATA STUDY TEAM PRESENTATION

April 20, 1990

AGENDA

1. Discussion with the University of Miami on MODIS Ocean Product Sizing (Gregg)
2. Comparison of Ocean Processing Estimates (Gregg)
3. Estimates of MODIS SDST Computer Use Requirements (Ardanuy)
4. Storage Considerations for MODIS Ocean Color Data (Gregg)
5. Discussion of CDOS Requirement Tradeoffs (McKay)
6. Simulation of MODIS-T Stare-Mode Coverage (Riggs)

Discussion with Robert Evans, U. Miami
on Ocean Products Sizing for MODIS

We discussed our estimates of the processing requirements for MODIS and estimated lines of computer code with Robert Evans, of the University of Miami on April 12, 1990. Since the University of Miami has extensive experience designing code and processing remote sensing data for oceanography, we felt that their opinions of our estimates for MODIS would be useful.

Generally, Dr. Evans felt that we had underestimated the sizing requirements, based on his experience with CZCS processing. He felt that we could make a better estimate MODIS requirements by using the CZCS as a model. Some details of our discussion follow.

Lines of Computer Code (LOC)

Evans estimated 500,000 total LOC in DSP (Miami's display and processing package) for the CZCS. These break down into the following categories.

35,000	Level 1
50,000	Level 2
25,000	Level 3
300,000	Tools
70,000	Flow Control

Tools are decision-making, analysis aids, re-formatting ancillary data (e.g., ozone, etc), coefficient calculations. Evans noted that this was an underestimate; it included no data sets required for the computations.

Operations

CZCS experience showed that it took 20 minutes to process sub-sampled (every 4th pixel) 2-min scene on a MicroVax II, from Level-0 to Level-4. Since the CZCS had 4 channels, Evans suggested we estimate MODIS processing requirements by scaling the CZCS estimates to MODIS channels and orbital times, then multiply by 10 to account for new products and anticipated snags.

The CZCS estimates do not include Quality Control, except that which may easily be checked in the algorithms (e.g., negative radiances, absurd tilts, bad gains, etc.)

Evans noted that we should consider possible developments of products that do not exist at this time (e.g., a coupled physical/biological/optical model incorporating MODIS data to estimate primary production)

Broken down in a different manner, Evans said

of the 20 min to process 2 min. scene,
10 were Level-1 to Level-3
10 were projections and global product production

A further breakdown, along levels of processing was

25% Level-1
50% Level-2
25% command/control

UMiami's Goals

Evans said the University of Miami's desires regarding MODIS data was to occasionally require 1 km water-leaving radiance data for calibrations (data that coincide with ships, planes, other sampling). However, generally they will require sub-sampled (4 km) global data, to test the implications of the algorithms, performance of bio-optics, comparison of results with expectations, and as a check against CDHF.

Otherwise all processing is to be done at CDHF.

Comparison of Ocean Processing Estimates
Based on CZCS Code to Data Study Team's
Independent Estimates

In this report we compare our estimates of lines of code and processing requirements for MODIS with those based on a discussion with Dr. Robert Evans at the University of Miami, which were derived from operational CZCS code.

Lines of Code (LOC)

In this week's report we present a revised estimate of required LOC for MODIS processing based on discussions at the previous meeting (April 6, 1990). Comparison of these revised values to the estimates for CZCS processing are shown in Table 1.

Table 1. Comparison of estimated lines of code for MODIS with those for CZCS.

	MODIS	CZCS
Level-1	65,000	35,000
Level-2 (oceans only)	12,000	50,000
Level-3	12,000	25,000

The increase in Level-1 LOC for MODIS is expected due to the increased number of bands, pixels, the addition of higher resolution detectors, ancillary data requirements, and number of products involved. However, the difference in estimates of Level-2 processing is difficult to reconcile. Our estimate was based on some knowledge of the algorithms and reference to NMFS CZCS code. However, the algorithms themselves were developed by Miami and have been in operation there for nearly 10 years.

CPU Requirements

According to Evans, it required 20 minutes to process a 2-minute CZCS scene on a MicroVax II. This processing included atmospheric corrections and generation of water-leaving radiances, and production of pigment concentrations. A 2-minute scene involved 970 scan lines (single detector), thus it required 1.237 seconds to process a single CZCS scan. Note that this estimate includes all levels of processing. From a series of computer timing tests using LINPACK (Dongarra, 1989), the speed of the MicroVax II is taken as 0.13 MFLOPS. Thus we derive 0.16 MFLOP/scan for CZCS processing.

Since about half of the processing time is spent on Level-3 algorithms in the CZCS, and Level-1 requires about 25% of the other half, the CZCS requires about 0.06 MFLOP/scan for Level-2 processing. Dividing by the number of pixels and bands, we arrive at 7.62 operations/band/pixel for the CZCS.

Evans recommended we scale these values to MODIS bands and wavelengths and multiply by 10 to obtain an estimate for MODIS processing requirements. Accordingly, we arrive at 74 MFLOP/scan for MODIS-T and 19 MFLOP/scan for MODIS-N. These estimates include cloud filters, so our estimates must account for clouds. We assume a 50% reduction in processing due to clouds. Results are shown in Table 2.

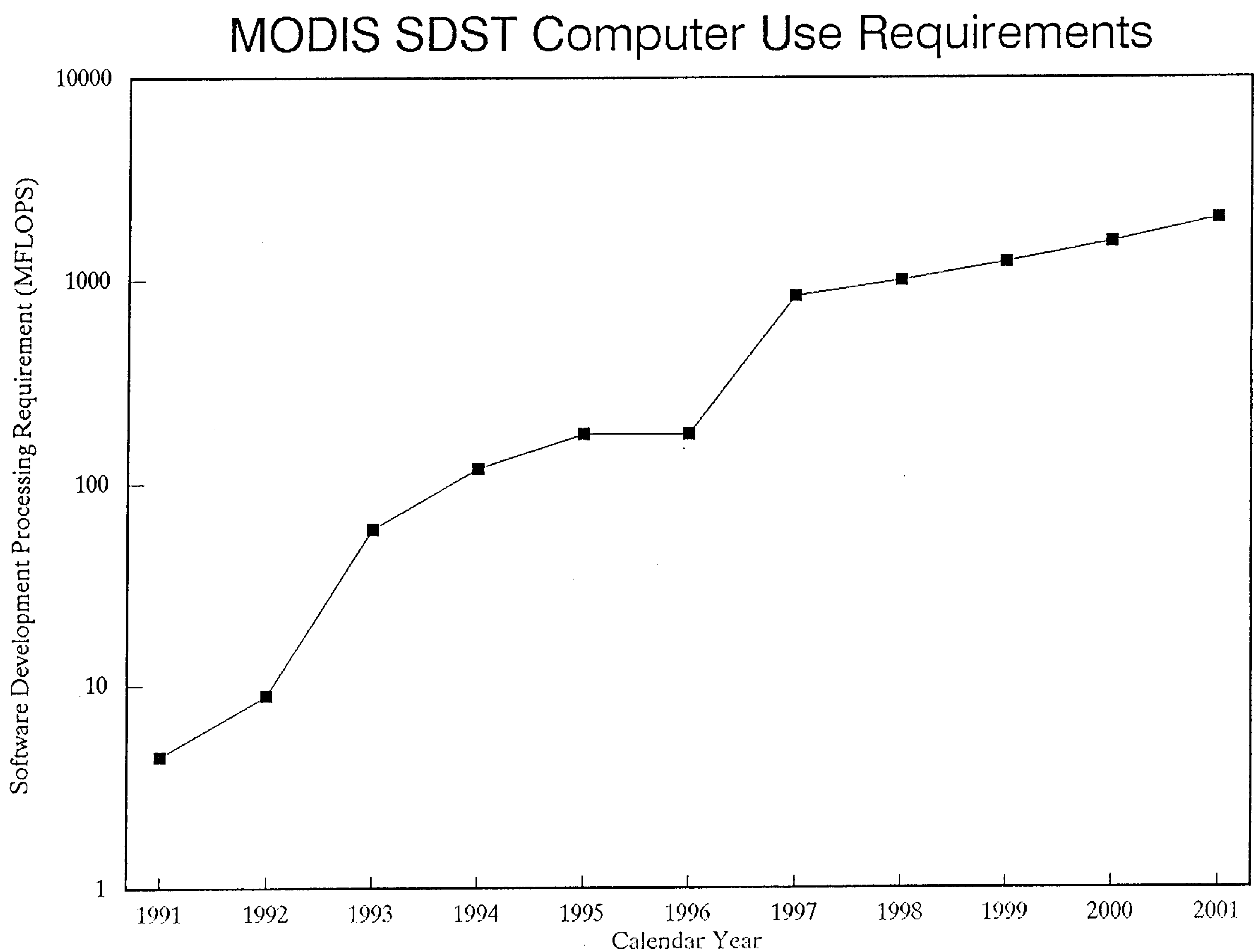
Table 2. Comparison of processing requirements for MODIS using the MODIS Data Study Team's (MDST) estimates and those derived from UMiami's CZCS processing for atmospheric correction and pigment concentration.

	MDST	Derived from CZCS	
MODIS-N	40	19	MFLOP/scan
MODIS-T	156	74	MFLOP/scan

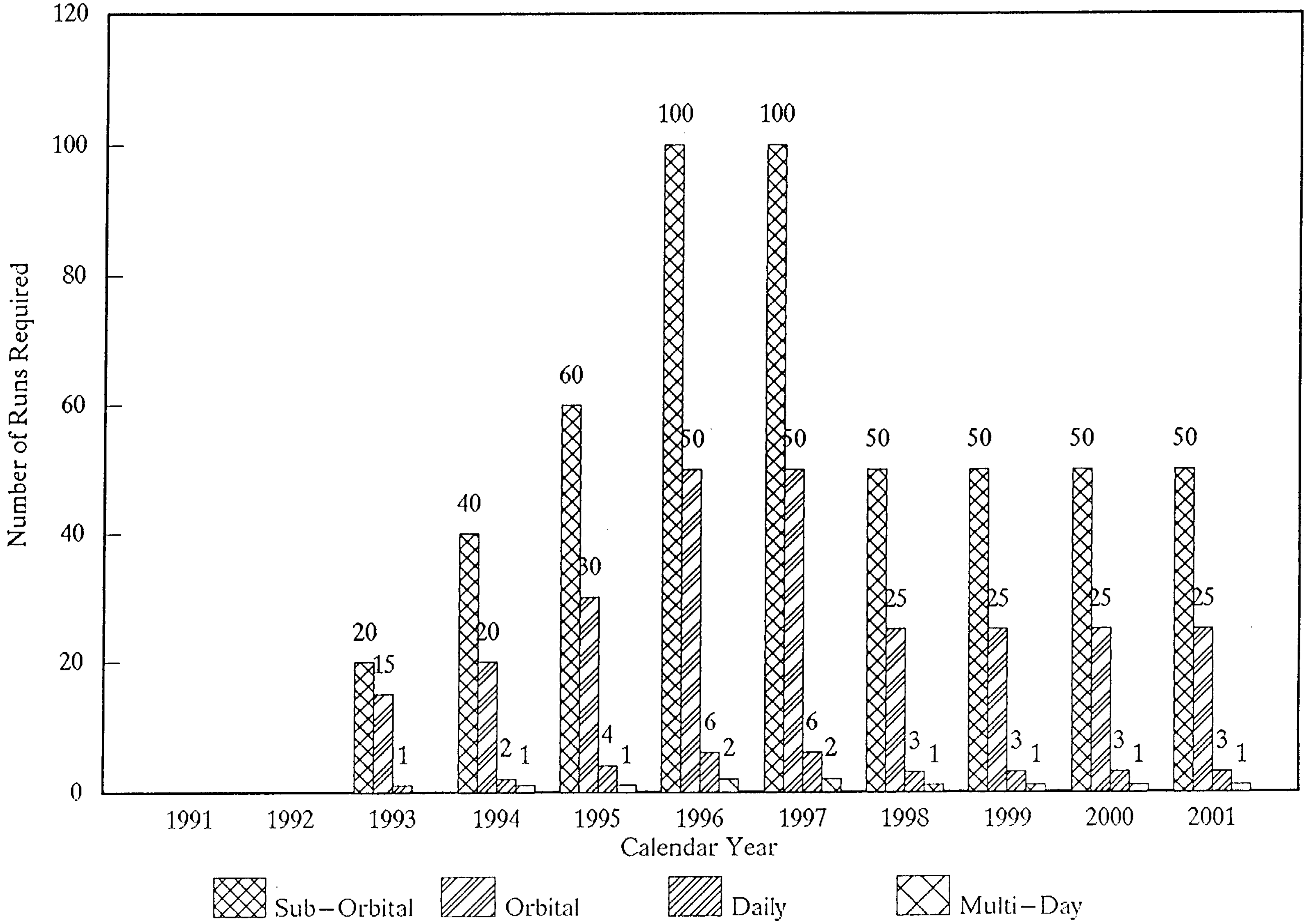
The MDST estimates exceed those based on the CZCS by about a factor of 2. MODIS ocean processing requires generation of new data products, for which algorithms have not been formalized, and a new pixel-by-pixel atmospheric correction procedure. Thus this difference is small considering the uncertainty involved. Therefore, we consider these estimates roughly in agreement.

Reference

Dongarra, J.J., 1989. Performance of various computers using standard linear equations software in a Fortran environment. Tech. Mem. 23, Argonne Nat. Lab.

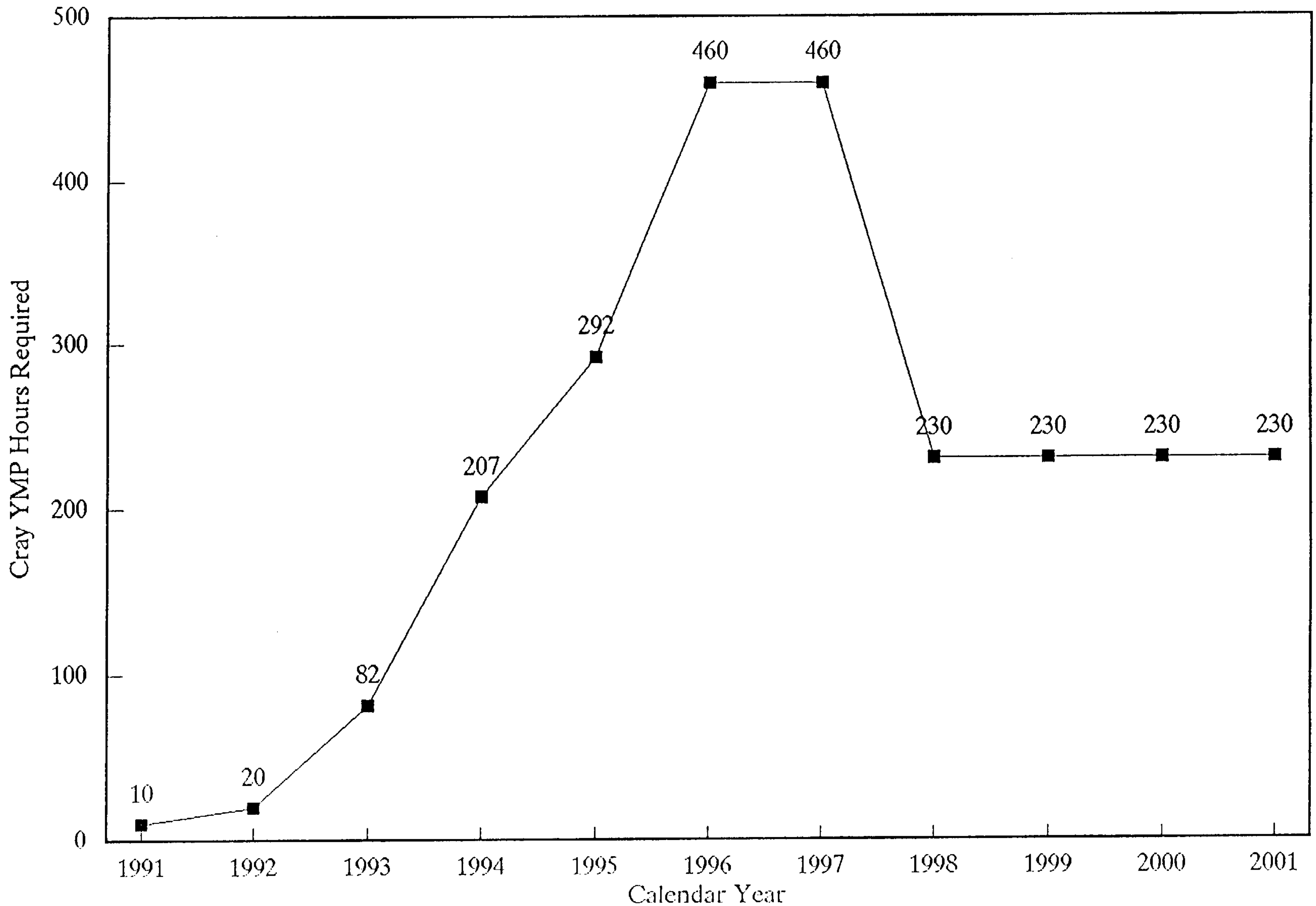

MODIS SDST Computer Use Requirements
10000
1000
100
10
1
Software Development Processing Requirement (MFLOPS)
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Calendar Year

MODIS SDST Anticipated Test Runs



MODIS SDST CRAY/YMP Use Requirements

CRAY YMP With 4 CPUs Assumed



Storage Considerations for MODIS Ocean Color Data

Processing of MODIS ocean color data products requires and produces several data sets and look-up tables. It is important to estimate the size of these data sets and tables in order to estimate storage requirements for MODIS. These data sets will be divided into four categories: 1) external data sets and look-up tables, 2) ancillary data, 3) internally computed and held data sets, and 4) scratch data.

External data sets and look-up tables (e.g., extraterrestrial solar irradiance, ozone absorption coefficients) are generated prior to launch and remain unchanged in processing. Ancillary data (e.g., pressure, wind speeds, and ozone) are data required to produce MODIS ocean color products and may be obtained from sources external to MODIS. These data may change from scan to scan or even pixel to pixel. Internally computed and held data sets (e.g., instantaneous extraterrestrial solar irradiance corrected for ozone absorption, solar and spacecraft zenith and azimuth angles) are computed in the course of MODIS processing and are retained for use in later processing. Finally scratch data sets are those needed for temporary computations. For example, cubic spline interpolations require small arrays, which must be created as the need arises. These data sets are usually small compared to the other types.

More external data sets and look-up tables may be required than listed here as the algorithms become more refined. Secondly, more internally-computed and scratch arrays may be utilized in order to maximize vector processing, if vector computers are used for MODIS processing. This list then serves as a rough estimate of the storage requirements for MODIS ocean color processing, representing our present knowledge of the algorithms.

Symbols Table

	MODIS-N	MODIS-T
I = number of pixels along scan	1582	1007
J = number of pixels along track	8	30
IA = number of anchor points along scan	94	80
JA = number of anchor points along track	2	5
L = number of wavelengths	9	32

Water-Leaving Radiances

A. External Data Sets	Dimensions
Mean extraterrestrial irradiance	L
Ozone absorption coefficients	L
Rayleigh optical thickness, standard	L
Fourier coefficients look-up table	40,39,L,3
Anchor point array counter	IA
Anchor point array counter	JA
Lambda	L

B. Ancillary Data Sets	Dimensions
Pressure	IA,JA
Wind speeds	I,J
Ozone	I,J

C. Internally Computed Data Sets	Dimensions
Instantaneous extraterrestrial irrad.	L
... corrected for ozone absorption	L
Rayleigh optical thickness	I,J,L
Rayleigh radiance intensity	I,J,L
Total radiance	I,J,L
Normalized water-leaving radiance	I,J,L
Single-scattering aerosol radiance	I,J,L
Solar zenith	I,J
Solar azimuth	I,J
Spacecraft zenith	I,J
Spacecraft azimuth	I,J
Cloud/error flag	I,J

D. Scratch Data Sets	Dimensions
	L (12)
	IA (9)
	JA (9)

MODIS-N 7.0×10^5 values
2.8 Megabytes (4-byte words)

MODIS-T 5.2×10^6 values
20.8 Megabytes

Case 2 Chlorophyll

A. External Data Sets	Dimensions
Chlorophyll	13,15
Gelbstoff	13,15

MODIS-N&T 390 values
1.56 kilobytes

Discussion of CDOS Requirement Trade-offs

1. Background.

The MODIS Data Study Team (under the direction of Daesoo Han, Code 636) is addressing issues relating to the optimum MODIS data packet structure for use in returning data from the instruments (MODIS-N and MODIS-T) to the ground data system. Besides those issues relating to processing convenience in the on-board and ground segments of the data system, an issue relating to data completeness has emerged. Initially, to facilitate the rapid distribution of MODIS Level-0 data to processing facilities that require data only for certain selected bands, the data study team recommended that each instrument data packet contain data only from a single spectral band. This packet structure would allow the selection of data based on information in the packet header without the need to access the contents of each packet and selectively retrieve data for the required spectral bands.

Since that initial recommendation, it has been pointed out that the generation of many MODIS products requires concurrent instrument data from several spectral bands, and if randomly-distributed data packet losses occur, product losses will be increased by the proposed packet structure (compared to product losses with a band-interleaved data packet structure). Analysis has shown that, in the limit for a small packet loss rate, product losses for band-unique packets are n times those for band-interleaved packets, where n is the number of concurrent spectral bands required to compute the product.

Note that only random packet losses are significant in determining the relative merits of the two data packetization strategies, i.e. neither data packetization strategy can compensate for data dropouts or systematic data losses lasting more than a few milliseconds. If random data packet losses occur, the band-interleaved packet structure tends to confine data product losses to a mimimal area, while a band-unique packet structure spreads product losses over a wider area.

2. Instrument design, processing, and science product tradeoffs.

MODIS data packet structure will affect instrument design requirements, CDOS service requirements, EOSDIS/MODIS processing requirements, and also (potentially) the quality of the final MODIS data products. Except for CDOS requirements, the factors involved have been discussed with the appropriate responsible groups and a high-level overview of the situation, as we percieve it, is presented in Table 1.

Discussions with the MODIS-T instrument design team support the conclusion that, from the instrument design standpoint, a band-interleaved data packet structure is simpler to support.

TABLE 1

Comparison of packet structures for Real-Time, Near-Real-Time, and Routine Data Priorities

		CDOS Requirements		EOSDIS Requirements		
	Instrument design	Real-time Near-R/T	Routine	Real-Time Near-R/T	Routine	Product Quality
Band-interleaved packet structure	Simpler	100% MODIS data access required	Data loss less significant	Band de-commutation required	Negligible difference	Relative product integrity for data dropouts.
Band-unique packet structure	Additional complexity	Selective access adequate	Stringent completeness requirement	Band selection required	Negligible difference	Increased product losses for random packet losses or dropouts 1 ms or less. Equivalent losses >> 1 ms.

Specifically, it appears that, for some instrument operation schemes at least, on-board memory requirements might be reduced using a band-interleaved packet structure, and on-board processing complexity may also be somewhat reduced with this packet structure (no need to selectively route detector data to multiple buffer areas, one for each instrument spectral band).

From the EOSDIS/MODIS processing perspective, it appears that processing requirements are slightly more difficult for the band-interleaved packet structure, primarily for real-time and near-real-time data. As defined here, real-time data is data delivered directly to EOSDIS as the data is received at the ground station during tape playback from the on-board recorders or (for direct transmission) as the data are generated by the instrument. Delays for data buffering to smooth data flows are permissible but are assumed to be minimal. Such data may be useful for instrument control; they are needed for MODIS performance characterization at the MODIS Characterization System (MCS). It is understood that such data is delivered "as is" and may contain duplicate or missing data segments that will be corrected in subsequent CDOS processing.

Near-real-time data are data needed within 3-8 hours after instrument overpass. Near-real-time data will usually support field experiments; specific data requirements will be adapted to the experiments in progress at the time in question. One constantly occurring need for near-real-time data has been identified. For the purpose of detecting new volcanic eruptions worldwide, the IDS volcanology team requires near-real-time instrument data for six spectral bands delivered to the EOSDIS within 6 hours of data acquisition at the instrument. Screening for volcanic events will be done as a part of MODIS processing at the appropriate active archive.

CDOS processing of near-real-time data would be helpful in the creation of quality near-real-time products and it is presumed that near-real-time data delivered from CDOS will receive all the corrective processing that it is possible to apply within the required time constraints. If a band-interleaved MODIS data packet structure is used, CDOS would be required to make three deliveries of the complete MODIS data stream; the first delivery would meet the "real-time" requirement defined above and would occur as soon as the delivery could be completed, the second delivery would meet the "near-real-time" defined immediately above, and would occur (by present planning) within 6 hours of the original observation, and the third delivery would be fully CDOS-processed data delivered for routine EOSDIS processing within the much-discussed 24 hour routine data delivery constraint. Since real-time and near-real-time processing will nearly always use data only for a few spectral bands, data delivery requirements could potentially be reduced using if a band-unique MODIS packet structure were employed, i.e. band selection could potentially be done (based on header information) as a part of CDOS processing, and only required real-time and near-real-time information would need to be transmitted EOSDIS. Routine data transmission requirements would not be much affected by data packet structure.

Because of concerns about potentially increased data product losses using a band-unique packet structure, the MODIS Science Team has strongly advocated a band-interleaved MODIS packet structure. Data completeness is of utmost concern to the researchers, and the studies completed thus far have not definitively demonstrated that the TDRSS and CDOS designs will not permit the sort of random data packet loss that is exacerbated by the band-unique packet structure. A portion of the minutes for the MODIS Technical Team Meeting of April 12 is reproduced below:

"W. Esaias recommended using BIL (Band Interleaved by Line) for data packetization. He had shown in a previous meeting that this approach will usually result in less data loss from communication link bit errors than the BSQ (Band Sequential) data packets. W. Barnes said that he will recommend that this approach be used in the MODIS-T Phase C/D Specifications. T. Magner said that it will be easier from the instrument point-of-view to send BIL packets. In addition, W. Esaias said that for some geophysical parameters, "quick look" of BIL as opposed to BSQ is needed. Thus, even the need for quick look products does not necessarily translate to a requirement for Band Sequential packets."

3. <u>CDOS tradeoffs.</u>

It appears that the CDOS tradeoff is between a requirement to provide 100 percent of the MODIS data for the real-time service, the near-real-time service, and routine service and a very stringent data completeness requirement that could assure investigators that undue data product losses would not occur using a band-unique packet structure. MODIS data packet discussions have thus far not included representatives from the CDOS. Since the decisions made affect CDOS requirements, it is now time to include CDOS representation in the discussions; since the band-interleaved packet structure would simplify the instrument design and assure maximum data product completeness under any operating conditions, the great preponderance of opinion outside the CDOS is that the band-interleaved packet structure is preferrable.

A Simulated MODIS-T Tilting Strategy for Stare Mode over Land

With MODIS-T in composite mode both ocean and land surfaces can be imaged within the same scan. This may increase the potentially usable MODIS-T coverage of land surfaces for determining surface directional characteristics, yet this coverage will be constrained to the ocean tilt strategy of MODIS-T. Thus, there may be more MODIS-T coverage of land surfaces but this coverage may be confined to a limited range of viewing geometries. The change in mode from dual to composite does not alter the tilt strategy which is assumed to remain in a "CZCS tilt strategy" unless there are no ocean pixels in a scan. This restricts the locations at which the MODIS-T tilt could be changed to a land tilt strategy, and in this case, the land coverage of selected sites given in Table 1 of the 6 April, 1990 MODIS Data Study Team Presentation, now represent potential land surface coverage of those sites by MODIS-T with the possible option of viewing at different tilts.

Simulations

For the purpose of determining land surface directional reflectance characteristics and building a BRDF imaging of the same location from many different sun-sensor-target viewing geometries is required, thus a separate MODIS-T tilting strategy for land is desirable. It is assumed that the priority tilt strategy for MODIS-T will be for ocean coverage, i.e. a "CZCS tilt strategy", and that the tilt can only be changed to a land tilt strategy when there are no ocean pixels in a scan. Changing the MODIS-T tilt from ocean tilt to land tilt and back to ocean tilt, without losing any ocean coverage while maximizing the collection of land directional reflectance data for the purpose of building a BRDF, requires that locations that tilt changes can be performed be determined.

Determination of locations where tilt can be changed, given ocean tilt and coverage are priority one, and what land area is potentially imaged requires that location limits of tilt changes be determined. First it must be determined at what point along an orbit that an ocean is no longer imaged, and at that point, switching MODIS-T to a land tilt, at what location does the land coverage then begin. Second at what location must the tilt be switched back to ocean tilt in order to image the first upcoming ocean pixel in a scan. This will determine the last land location imaged in land tilt before MODIS-T is tilted back for ocean coverage.

Although many tilting strategies are possible for obtaining data on surface directional reflectance for building a BRDF only a ±50° tilt has been simulated here. The specific questions that this simulation was designed to answer are:

What land surface areas can be imaged at a tilt of + and - 50° tilt by MODIS-T when it is not required to tilt for ocean coverage? And, what land areas could potentially be imaged in stare mode? In stare mode MODIS-T stares at specific location from a forward tilt angle rolling over to a backward tilt angle as the platform passes over the location. Simulations were performed for a + and - 50° tilt, the tilt limit for MODIS-T, and for a ±50° tilt stare mode.

Simulation Results

Land surface coverage for +50° and -50° tilts, 16 day repeat coverage, (Figures 1 and 2, respectively) show that different regions of continents are covered by either a + or - 50° tilt. With a +50°, forward tilt, the more northerly areas of continents are covered and with a -50°, backward tilt, the more southerly areas are covered, e.g. North America in Figures 1 and 2. Extension of coverage over the oceans, in all figures, is the result of the increased field of view along the ground swath at a ±50° tilt angle; at an ocean tilt of 20° only land would be viewed along the satellite swath. To show the extent of land coverage possible with a ±50° tilt the union of the + and - 50° tilt was determined (Figure 3) and it shows that nearly all earth's land surface could be imaged if the + and - tilt coverages were composited over a 16 day repeat cycle. This (Figure 3) does not indicate the land surface areas for which a BRDF could be built, it only shows the extent of land surface for which a limited amount of data, limited to either ±50° tilt could be collected for a BRDF. Assuming that both +50° and -50° tilts are required to build up a BRDF, then the land areas for which both views could exist are given by the intersection of the +50° and -50° simulations (Figure 4). The intersection of these simulations occur over interior continental areas, for the most part, and represent for what regions data for a BRDF could possibly be built up. Australia and Greenland are entirely excluded from having this coverage.

Stare mode simulation results for a 50° tilt (Figure 5) show that only the interior areas of the continents of North America, South America, Africa, Asia, and a small portion of Antarctica could be imaged. It would not be possible to image any other land areas in this stare mode scenario. If building a surface BRDF is restricted to only regions over which data sets are acquired in stare mode, then BRDF's may only be constructed for these limited regions of the earth's surface. But, if BRDF's can be built from data sets of ±50° tilts from any orbits then it may be possible to build up BRDF's for the regions shown in Figure 4. Surprisingly, it appears by comparing Figure 5 with Figure 4, that by either means of building up a BRDF that the same continental land regions are covered.

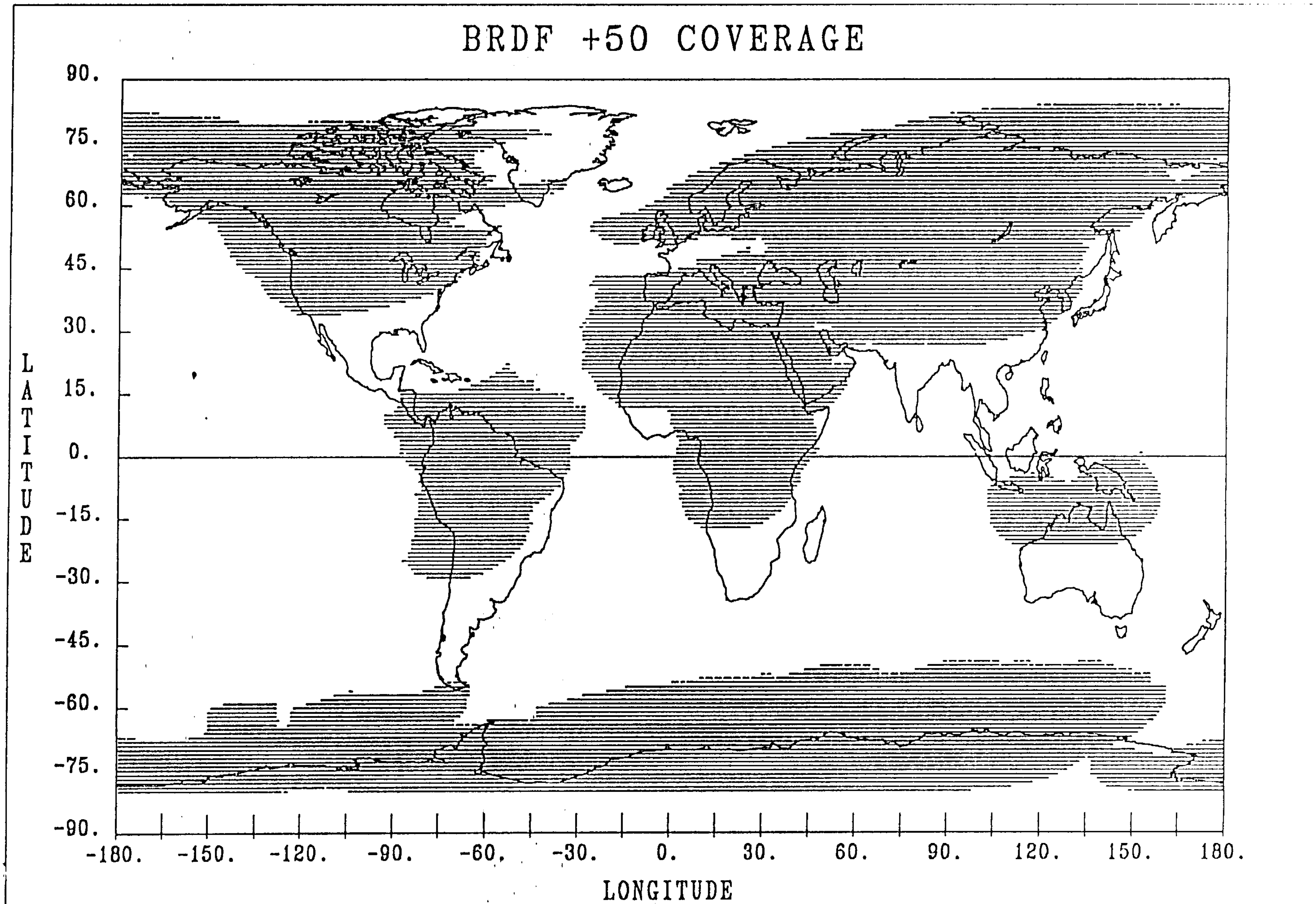

BRDF +50 COVERAGE
90.
75.
60.
45.
30.
15.
0.
-15.
-30.
-45.
-60.
-75.
-90.
LATITUDE
-180.
-150.
-120.
-90.
-60.
-30.
0.
30.
60.
90.
120.
150.
180.
LONGITUDE

FIGURE 1

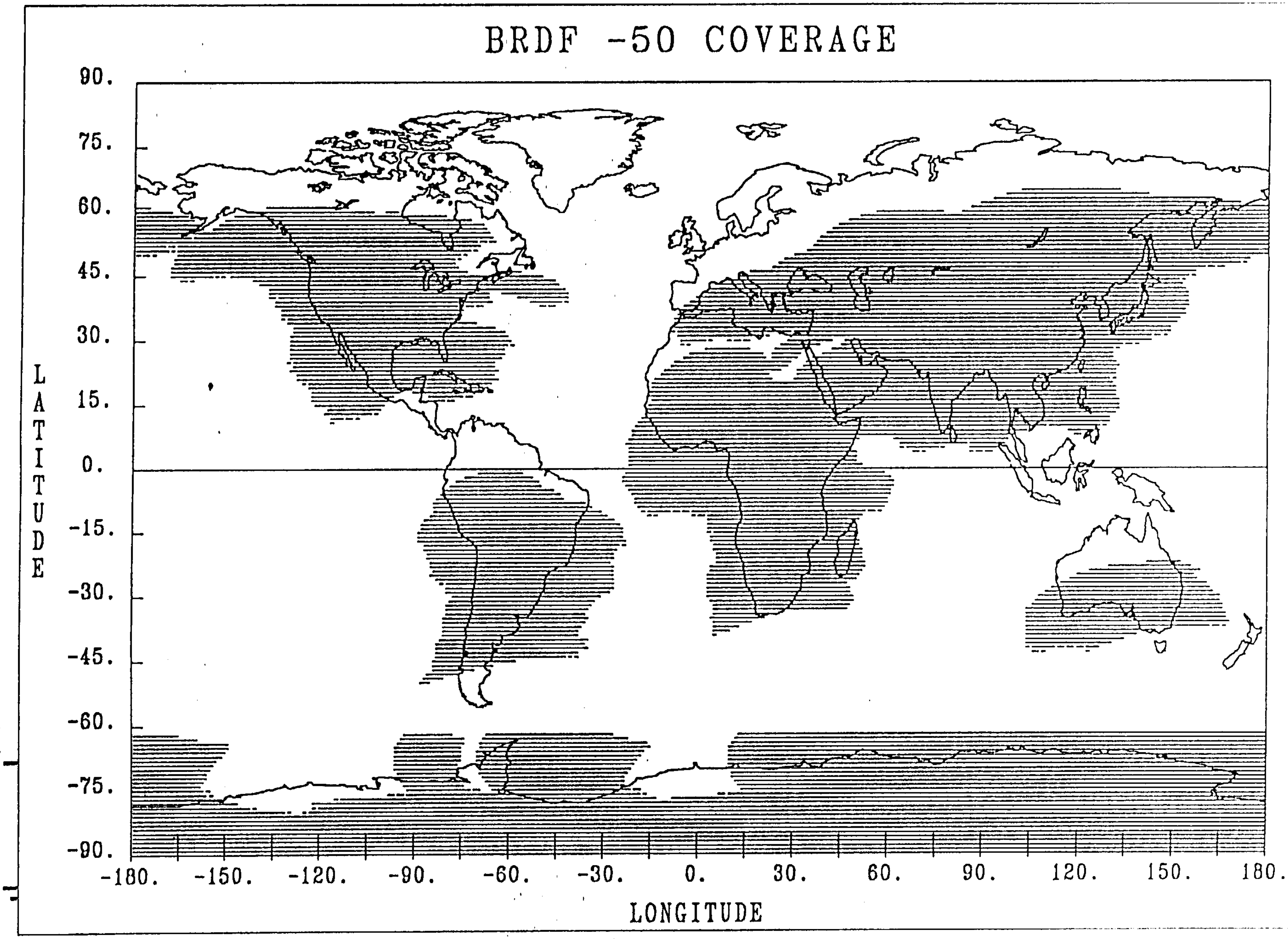

BRDF -50 COVERAGE
90.
75.
60.
45.
30.
15.
0.
-15.
-30.
-45.
-60.
-75.
-90.
LATITUDE
-180.
-150.
-120.
-90.
-60.
-30.
0.
30.
60.
90.
120.
150.
180.
LONGITUDE

FIGURE 2

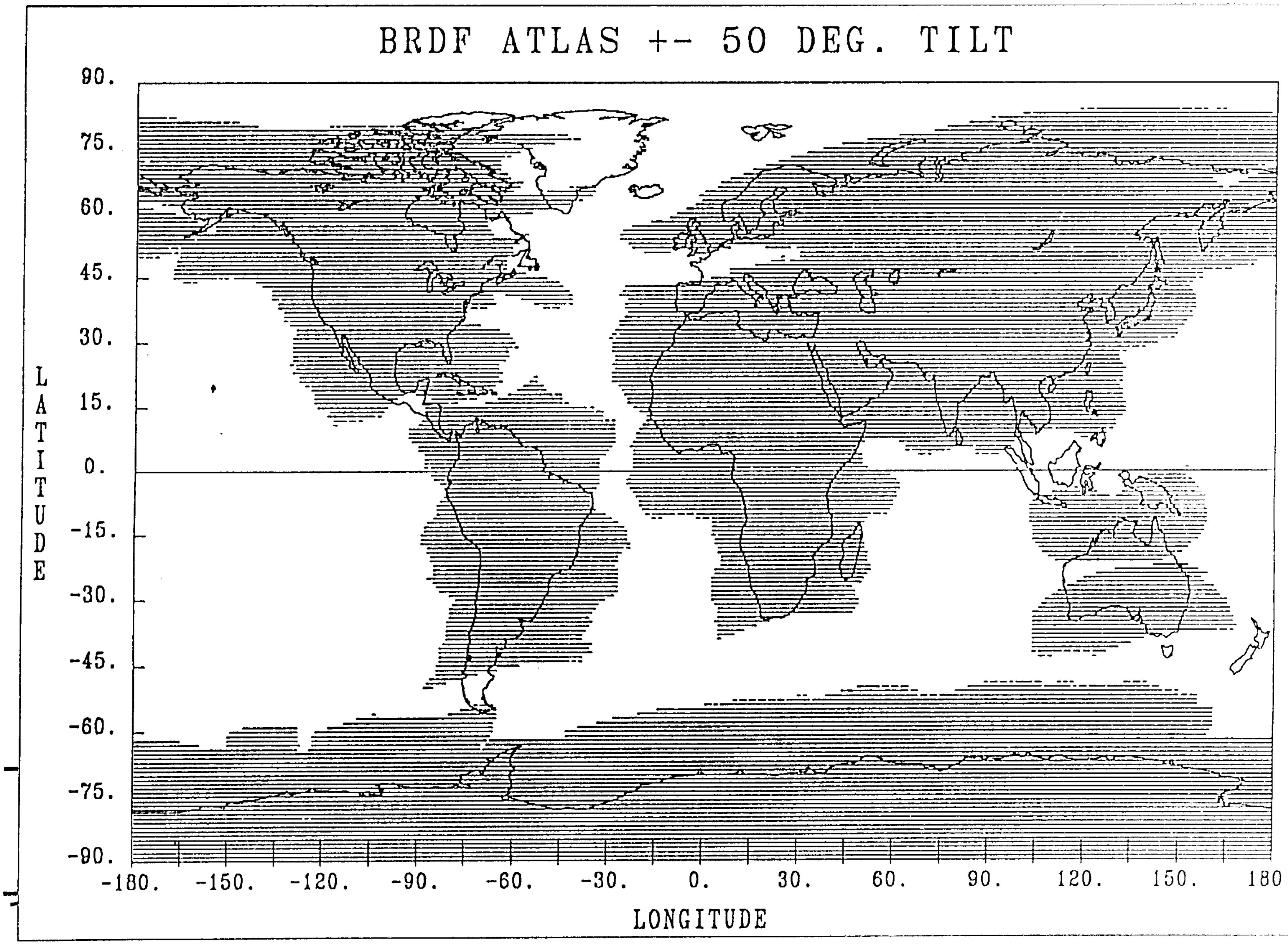
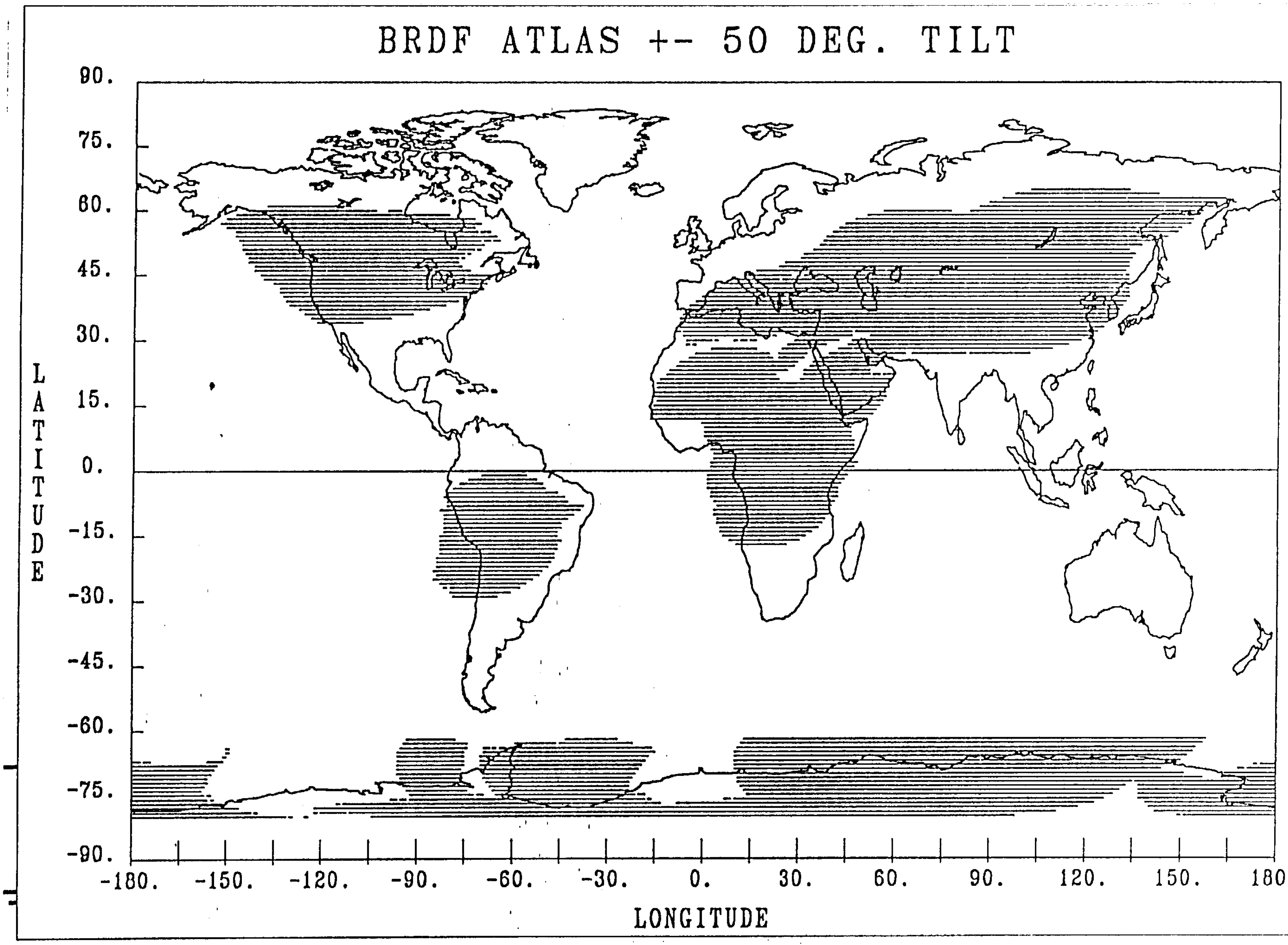

BRDF ATLAS +- 50 DEG. TILT
90.
75.
60.
45.
30.
15.
0.
-15.
-30.
-45.
-60.
-75.
-90.
LATITUDE
-180.
-150.
-120.
-90.
-60.
-30.
0.
30.
60.
90.
120.
150.
180.
LONGITUDE

FIGURE 3



BRDF ATLAS +- 50 DEG. TILT
90.
75.
60.
45.
30.
15.
0.
-15.
-30.
-45.
-60.
-75.
-90.
LATITUDE
-180.
-150.
-120.
-90.
-60.
-30.
0.
30.
60.
90.
120.
150.
180.
LONGITUDE

FIGURE 4

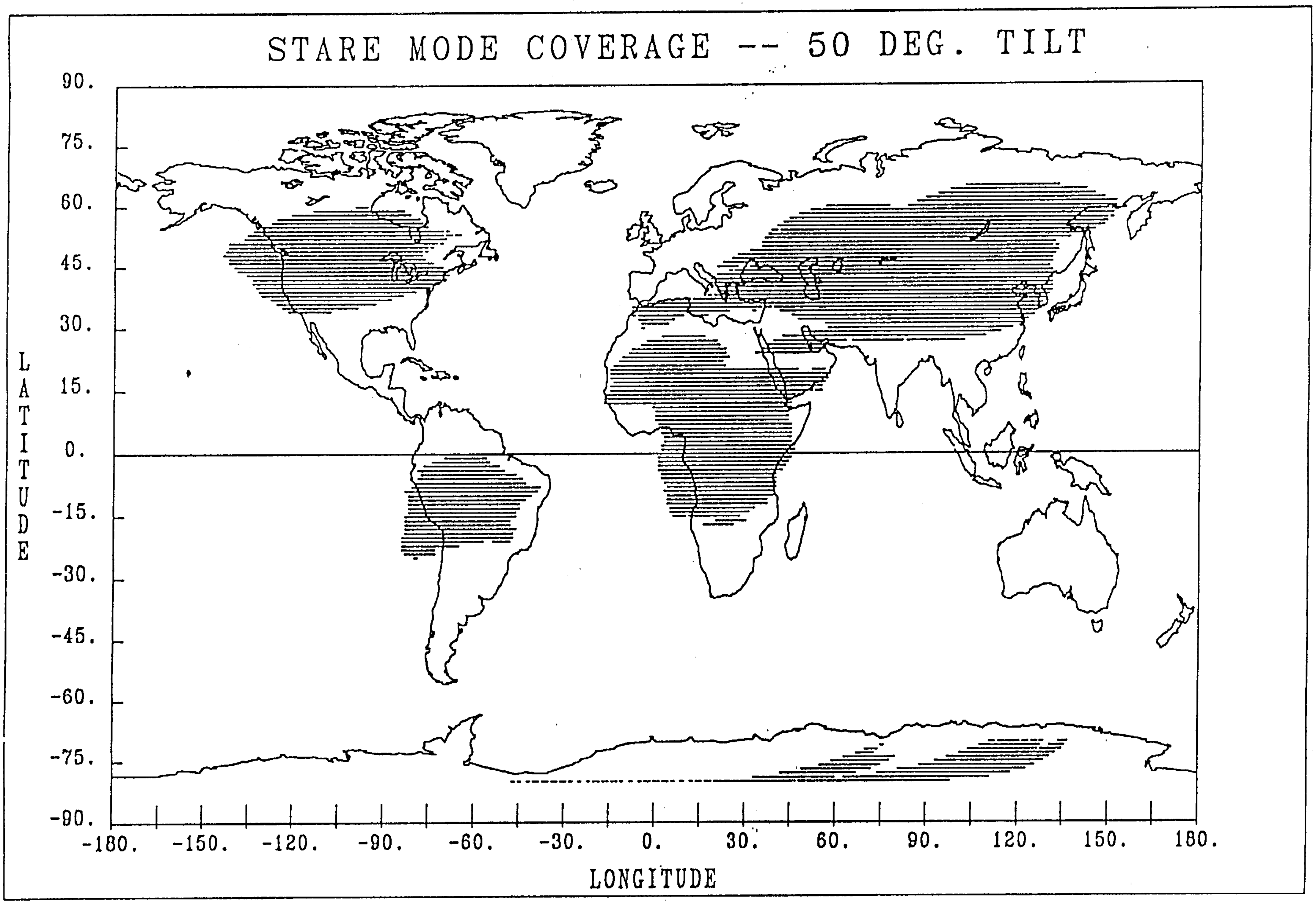

STARE MODE COVERAGE -- 50 DEG. TILT
90.
75.
60.
45.
30.
15.
0.
-15.
-30.
-45.
-60.
-75.
-90.
LATITUDE
-180.
-150.
-120.
-90.
-60.
-30.
0.
30.
60.
90.
120.
150.
180.
LONGITUDE

FIGURE 5