MODIS DATA STUDY
TEAM PRESENTATION

January 26, 1990

AGENDA

1. Major Ancillary and Correlative Data Sets Required for the Generation of MODIS Core Data Products (Ardanuy)
2. MODIS Science Team and Data Study Team Working Group Requirements (Ardanuy)
3. The UARS Data System Experience: An Interview with Dr. Skip Reber (McKay)
4. Recent Digital Elevation Model Developments (Hoyt)
5. Potential Atmospheric Correction Data Requirements for Reflective MODIS-N Bands (Riggs)
6. Update to MODIS-N and MODIS-T Spectral and IFOV Parameters (Ardanuy)
7. Update to MODIS-N and MODIS-T Data Rate and Volume Estimates (Ardanuy)
8. MODIS Data Flows for Levels-1 through -4 (Ardanuy)
9. Sizing and Evaluation of MODIS Anchor Point Earth Location Algorithms (Gregg, Ardanuy, McKay)
10. Two Aerosol Size Distribution Estimates: Reasons for Differences (Hoyt, Andrews)
11. Timing Tests on the IBM 3081 (Hoyt)
12. Processing Estimates of Optical Depth Effective Radius (Andrews, Hoyt)
13. Accuracy Requirements for Wind Speeds for Ocean Color Data Processing (Gregg)

MAJOR ANCILLARY AND CORRELATIVE DATA SETS REQUIRED FOR THE GENERATION OF MODIS CORE DATA PRODUCTS

Below is a list of major ancillary and correlative data sets, as we understand them at this time, required for the generation of MODIS core data products. Note that we have differentiated ancillary data (required to generate and perform quality control on data products) from correlative data (required to develop or validate geophysical algorithms).

1. AMSU and AIRS/AMSU level-2 products

Total column ozone: potentially required as ancillary data for atmospheric correction (especially over oceans). if accuracy (but not spatial resolution) exceeds that of MODIS (on the order of 5 DU accuracy required). The AIRS/AMSU total column ozone is not likely to be more accurate than the TOMS ozone, but may be more easily collocated with MODIS than TOMS (Fleig, personal communication).

Temperature and moisture profiles: may be required as ancillary data for synergistic Level-2 processing of standard core products and specialized product development by Joel Susskind.

Surface pressure: potentially desirable as ancillary data if the accuracy exceeds that available from NMC over certain regions of the Earth (e.g., southern hemisphere, tropical/subtropical oceans) (on the order of 1 mb accuracy required for Rayleigh scattering correction, particularly over the oceans).

Surface and cloud-top temperature: useful as correlative data for validating and improving the MODIS data products.

2. NMC and ECMWF (preferably both)

Surface pressure: required as ancillary data for atmospheric correction globally; 1 mb accuracy desired wherever possible.

Surface wind speeds: ancillary data required to absolutely the highest possible accuracy for removal of sun-glint contamination to the water-leaving radiances (an accuracy of 1 m/sec desired, but perhaps only 5 m/sec possible).

Upper-air and surface analyses: correlative data to be used to validate and develop MODIS atmospheric products.

Radiosonde profiles: correlative data to be used to validate and develop MODIS atmospheric products, particularly profiles (may require routine stripping of profiles nearest to the radiosonde locations).

3. Other Eos Instruments

CERES surface incident fluxes: incident solar and infrared

radiation, ideally diurnally averaged, preferably narrow-band (400 to 700 nm) but broad-band acceptable; required as ancillary data to compute primary productivity over the ocean and over land (present accuracies of oceanic shortwave are about 20 W/m**2, but the required accuracy is not known (ISCCP also has a surface incident solar radiation program, which uses geostationary and polar-orbiter data).

SCANSCAT near-surface winds: the 10% accuracy of SCANSCAT wind speed near the surface makes it an ideal data source for sun-glint correction (over most regions, the error would be less than 1 m/sec)(conservative estimates of error are 2 m/sec, which is still a potential improvement over NMC conventional data away from surface stations).

LAWS winds: the 1 m/sec stated accuracy implies that LAWS winds may be useful as ancillary data for sun-glint correction over the oceans; however, the LAWS data may likely be incorporated into improved NMC operational analyses (possibly applies to SCANSCAT as well).

LAWS aerosols: not required at present, but their 1999 availability may yield a useful ancillary data set for atmospheric corrections, both over land and ocean (accuracy TBD by LAWS science team).

Passive microwave (Source TBD): potentially could be used as ancillary data, and will be used as correlative data for the validation of sea-ice observations from MODIS.

4. <u>In-situ validation observations</u>

Radiosondes (see NMC above)

Ship and buoy data (ephemeral): useful as correlative data for validating and developing MODIS ocean products; potentially required as ancillary data for QC of standard products prior to archival, which more stringent availability requirements. Also, as with radiosonde data, comparisons lend themselves to the routine stripping of collocated MODIS data as the products are generated to facilitate comparisons. However, the general (with unconstrained timeliness) use of this ancillary data for QC prior to archive makes sense, but is not consistent with the current orthodoxy (Fleig, personal communication)[1]. Members of the MODIS science

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[1]GSFCMAIL comments of Al Fleig (January 23, 1990): As the current HQ dictated view goes (to the extent that I understand it) standard products are archived as soon as they are made (within specified timeliness goals). That means that validation and quality control that takes more than two days from time of observation must occur after archival. The implication is that a scientist can change a quality flag through various states,

team have proposed that moored or drifting buoy data (primarily sea surface temperature (SST) and measured water leaving radiances) be transmitted from the buoys to land via GOES.[2]

5. Digital Elevation Model

Required as ancillary data to accurately navigate MODIS terrestrial observations, as well as to apply illumination/slope corrections. The precise requirements must be refined by the MODIS science team.

6. Ecological Descriptions and Miscellaneous

Land/Ocean Masks and Biome types are required as ancillary data for

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including hypothetical examples such as (the science community will have to identify a more realistic set sometime in the next eight years):

1. Unvalidated and unchecked preliminary data
2. Preliminary data that has been casually checked
3. Preliminary data that has been quality controlled
4. Validated data from a qualified algorithm

The above discussion applies to the time period after a product becomes standard. There should be some start-up time for a new product before it must be released, but this will have to be worked out in the next eight years.

[2]GOES is a low data rate system, but most data would be received within one hour of observation. At present, buoy data data goes by land line to the World Weather Building in Suitland, MD where it is routinely made available within a short time.

It would be quite feasible to quality control the ground truth data and determine its geographic position within 48 hours for use with MODIS products. Dr. Dennis Clark has proposed the use of about 15 buoys. SST observations from ships are routinely combined with other synoptic observations and automatically plotted on weather maps for routine use (within about 6 hours). This implies that some MODIS products could have ground truth data applied before release (perhaps during processing) and archiving. Every time a product is produced, the quality controlled ground truth values could be collocated with the appropriate pixels.

Alternaively, validation efforts could be scheduled periodically, or in association with major or other natural events. This scenario would not require ground truth data to always be used within 24 to 48 hours of the MODIS observations. Any ground truth data available could be appended to the records in the archive (possibly by updating the metadata and browse data) or just added to the archive as an additional data source.

Land/Ocean Masks and Biome types are required as ancillary data for product generation (e.g., aerosol optical depth).

Terrestrial aerosol climatologies: useful as ancillary data for atmospheric correction over land.

Extraterrestrial solar spectral irradiance: required either one time (modulated by Earth-Sun distance) or as a function of time (perhaps with ACRIM/SOLSTICE).

7. Other Potential Data Sets (all correlative data)

ISCCP or equivalent cloud data

NOAA free-flyer and geostationary satellite data sets

Other EOS instrument and non-EOS satellite data sets

Other conventional and in-situ data sets

8. Look-up Tables

Efficient MODIS data product generation will require the use of look-up tables to access pre-computed constants. Some of these tables will be massive, with millions of entries, and will require megabytes of memory. Examples include Rayleigh scattering (a function of three variables) and the reflection function for an infinite cloud (a function of six variables).

9. Existing MODIS Data Sets

Many MODIS products will be compared with the existing product from preceding time periods. Significant differences may be flagged and subject to careful scrutiny and explaination. Candidate data products of this type might include snow cover maps, sea ice, and SST fields (e.g., we detect a snow covered pixel north of 50°N in December, it will remain snow covered through April).

MODIS SCIENCE TEAM AND DATA STUDY TEAM WORKING GROUP REQUIREMENTS

1. Terrestrial Science Working Group

Already in existance.

2. Oceanography Working Group

Already in existance.

3. Atmospheric Science Working Group

Already in existance.

4. Instrument Characterization Working Group

Already in existance as the Instrument Characterization Team (ICT)?

5. Ancillary Data Working Group

Responsible for:

- Identifying ancillary and correlative data requirements (timeliness, completeness, accuracy, resolution, etc.)
- Developing "interfaces" at personal and project levels to ensure that the data sets are developed and made available

3. Scene Identification Working Group

Responsible for:

- Cloud/no cloud (each algorithm has its own definition of what a cloud is and how much contamination is acceptable; multiple definitions of clouds will be required).
- Snow/ice (discrimination of sea-ice and snow over land from uncovered surfaces and from low and high altitude clouds).
- Case-1/Case-2 waters (different bio-optical retrieval algorithms will be required; this is a relatively complex test that depends on atmospherically corrected water-leaving radiances, e.g., a Level-2 test).
- Land/Ocean (how accurate spatially are present surface geomaps? if not to 1 km or better, MODIS radiances will be used for the fine discrimination near coastal regions).
- Land biomes (can specify different surface coverage regions so that specific retrieval algorithms may be

applied, e.g., aerosol optical depth over desert or dark-green vegetation).

4. Standard Algorithm and Data Product Peer Review Working Group

The functions of this group may in fact be divided into the three discipline working groups.

5. Atmospheric Correction Working Group

Both the terrestrial and the ocean science team members have identified algorithms that will require atmospheric corrections. There is the opportunity for substantial commonality between the two sets of requirements (which are not yet adequately defined).

6. Time and Space Averaging and Rectification Working Group

There are many techniques for generating Level-3 products, e.g.:

- Averages of sparsely or densely sampled parameters
- Selection of a single pixel within a region/period to represent the whole
- Pixel intervals, i.e., using every second, third or fourth pixel in time or space, etc.
- Empirical Orthogonal Functions (EOF's)
- Low/high/bandpass filters

The vast set of compositing techniques employed by present-day algorithms (e.g., NDVI, SST, ocean color, cloud parameters) implies that many MODIS-era Level-3 algorithms will be required. A diverse, yet self-consistent, suite of Level-3 averaging algorithms must be developed (this won't happen by accident).

7. Simulation (and Prototyping) Data Working Group

Simulated MODIS data will play a key role in the development of geophysical retrieval algorithms and in the evolution of MODIS data processing from its earliest concepts to an integrated functioning system. Substantial coordination withi and between the science and data study teams will be required.

12. Communications Working Group

Responsible for defining more precisely:

- the data needs of the MODIS science team members.
- the data needs of the interdisciplinary investigators and other EOS instrument science teams.

THE UARS DATA SYSTEM EXPERIENCE:

An interview with Dr. Skip Reber

On Wednesday morning, January 17, Phil Ardanuy, Doug Hoyt, and Al McKay of RDC and Mike Andrews of GSC met with Dr. Skip Reber of the UARS project to discuss the UARS experience with ground data system requirements. The group was anxious to benefit from any "lessons learned" during UARS data system development, and it was particularly anxious to learn about the data system sizing techniques that were applied for that effort and the degree of success that the techniques achieved.

Dr. Reber began by noting that he serves UARS as project scientist and is not primarily responsible as a data system developer and coordinator. Tom Taylor and Ellen Herring both have extensive experience with the UARS data system. They can provide additional, more specific information relating to the UARS data system.

The overall data rate for all UARS instruments is about 32 kb/s, or approximately 2-3 kb/s for each instrument. Because the EOS (and MODIS) data rate is orders of magnitude larger, Dr. Reber felt that the UARS experience may not be directly applicable to MODIS.

The basic data system size estimates that the UARS team used were developed from a poll of the UARS science team members. Beginning in 1983, with informal annual updates afterwards, each research group was asked to estimate its data processing resource requirements. Estimates were to be a best guess, stated in terms of required operations using the VAX 780 or 785 as a standard unit of required data processing capacity. Processing requirements for each 24 hours of data were tallied, multiplied by two to allow for reprocessing, and again multiplied by 1.5 to allow for computer overhead and data management tasks.

Between 1983, when the initial system sizing estimates were prepared, and the present, estimated UARS data processing requirements have grown by a factor of ten. System memory requirements have also been estimated, and these have also grown, although not by such a large factor. Although there was some apparent confusion among the team members about the nature of computer "operations" as they were defined, the primary source of the large error in estimating requirements seems to have been a simple underestimation of the size of the required processing task. As actual coding has begun, nearly all groups have been forced to increase their processing estimates; some of the most experienced groups have had the largest increases. Besides simple underestimation, some of the increases are due to an increased sophistication of algorithms that was not anticipated in initial sizing estimates.

In October of 1988 the individual UARS instrument groups delivered simulated data for their respective instruments. The initial data simulations assumed perfect performance of the data transmission system. Data simulation was assigned to the individual instrument groups at least partially as an exercise to aid in the task of preparing algorithms and code for data interpretation, i.e. beginning with assumed physical parameters and deriving instrument outputs is the natural inverse to the problem of taking observed

instrument outputs and determining the physical conditions that correspond to the observed outputs. All data simulation activities have contributed to a deeper understanding of instrument function and processing requirements for data recovery. The next step in data simulation will include the introduction of actual data transmission formats and the introduction of potential data transmission anomalies and glitches in the simulation data. Three days of simulated observation data will be produced. Three cycles of simulated data and data product algorithm software delivery and integration are anticipated.

The production of simulation data is being directed by an appropriate working group selected from interested UARS science team members and UARS supporting contractors. Generally, UARS has had good experience with working groups selected in this manner from the larger scientific community. Generally, working groups composed of all members of the science team are unwieldy. Nearly all integration of data system activities has been accomplished under the direction of appropriately selected working groups.

In the development of the UARS data system it was initially thought that primary user access would be to Level-3 data, so that the formats used for Level-1 and -2 data could be left to investigator discretion. In retrospect, this thinking appears flawed. Users will be concerned with the quality of the data they have received, and will often want to examine the Level-1 and -2 products that most clearly reflect basic instrument function. Integrated Level-1 and -2 data formats are needed so that a single data access system can support all user requests.

RECENT DIGITAL ELEVATION MODEL DEVELOPMENTS

There are two recent developments regarding Digital Elevation Models (DEM's) which are of interest to MODIS data processing. First, there is now a CD-ROM, called "Geophysics of North America", which has a DEM for all of North America. The data set was developed starting with the Defense Mapping Agency DEM, which has a 3 second spatial resolution, obtained by digitizing from one degree latitude by two degree longitude coverage topographic maps. Every tenth pixel was selected from this DEM to obtain a 30 second resolution (about 2700 feet or 0.8 km.). Elevations were rounded to the nearest 20 feet. Next each corner of the cells thus generated were averaged to obtain the elevation of cell to the nearest 10 meters. This data set was then transferred to the CD-ROM. It consists of about 45 megabytes of data.

The second DEM development concerns plans to develop a global Digital Chart of the World by December 1991. This effort, by ERSI with Defense Mapping Agency funding, will start with the 270 Operational Navigational Charts as source material. The final data product will use a CD-ROM as the distribution medium. The December 1989 issue of Photogrammetric Engineering and Remote Sensing reports on this effort.

It remains to be seen if these digital elevation models have the resolution and accuracy required for the MODIS data processing.

POTENTIAL ATMOSPHERIC CORRECTION DATA REQUIREMENTS
FOR REFLECTIVE MODIS-N BANDS

In the following table is listed data, and the accuracies currently considered necessary, that may be required by MODIS Science Team members for making atmospheric corrections over land surfaces in reflective MODIS-N bands. Accuracies listed are those suggested by Dr. Kaufman (Y. Kaufman, personal communication).

These accuracy requirements for ancillary data for use in making atmospheric corrections over land surfaces are currently less stringent than the accuracies required for the same data for making atmospheric corrections over the oceans by the ocean scientists. The less stringent demands for accuracy of ancillary data for terrestrial studies, as compared to ocean studies, may allow for the possibility of the needed data to come from other MODIS bands through interdisciplinary exchange of data, e.g. ozone and aerosol data from the atmospheric science discipline for use in making atmospheric corrections over land by the terrestrial discipline. Data exchange among disciplines is a topic that the MODIS Science Team members need to address.

Also, the scientists involved with developing atmospheric corrections over land need to provide a tentative algorithm for making the corrections which can be used in developing estimates of processing requirements.

TABLE 1
Data Required and Possible Sources of that Data for Atmospheric Corrections in the Reflective bands over Land Surfaces

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The basic relationship between radiance measured at the satellite, reflectance from a surface, and the atmosphere may be expressed as:

$$L = L_s\ t_s + L_p$$

L - radiance measured at sensor, radiometrically corrected ($Wm^{-2}\mu m^{-1}sr^{-1}$)

L_s - is radiation reflected from the surface; the component of L that contains information about the surface.

t_s - is transmittance of direct beam through the atmosphere.

L_p - is path radiance, the contribution of scattering by Rayleigh and aerosols to L.

L_s - radiation reflected from the surface. Some studies and data products may require that L_s only be determined, while other studies may require more data on factors affecting L_s, specifically measurements of F_o and ρ. These last data may also be used in determining L_p.

DATA NEEDED:

F_o - total irradiance (direct + diffuse) on surface.
Data source: Solar extraterrestrial radiation

TABLE 1
Data Required and Possible Sources of that Data for Atmospheric Corrections in the Reflective bands over Land Surfaces
(continued)

ρ - surface reflectivity
Data source: ρ may be known for specific locations and referenced in a look up table, or ρ may be determined from relationships among factors affecting reflectivity.
Accuracies: not specified at this time

t_s - transmittance of direct beam through the atmosphere.
DATA NEEDED:

τ_R - Rayleigh optical thickness; determined from surface pressure measurements.
Data source: National Meteorologic Center (NMC) surface pressure maps.
Accuracy: ± 10 mb (approximately 1%) in surface pressure.

τ_A - Aerosol optical thickness; determined by the amount of aerosols present at time of image acquisition.
Data source: Aerosol climatology
Surface visibility measurements, NMC
Atmospheric sampling
MODIS-N, Aerosol Optical Depth; a listed core data product in the Atmospheric Core Data Product Analysis
Accuracy: Not specified. Whatever data is available will be used in the correction. At present, determination of aerosols is the greatest unknown in atmospheric corrections over land surfaces.

τ_O - Ozone optical thickness; determined from the amount of ozone present.
Data source: MODIS-N, Total Column Ozone, a listed core data product in the Atmospheric Core Data Product Analysis
Other satellites; Total Ozone Mapping Spectrometer (TOMS)
Accuracy: Ozone amount measured to about 5% would probably be satisfactory.

L_p -is path radiance, the contribution of scattering by Rayleigh and aerosols to L.
DATA NEEDED:

τ_R - same as above
Data source: same as above
τ_A - same as above
Data source: same as above
F_o - same as above
Accuracies: same as above

UPDATE TO MODIS-N AND MODIS-T SPECTRAL AND IFOV PARAMETERS

MODIS-T Channel Parameters[1]

Band	Center Wavelength (micron)	Band Pass (micron)	IFOV (m)
1	0.410	0.015	1000
2	0.425	0.015	1000
3	0.440	0.015	1000
4	0.455	0.015	1000
5	0.470	0.015	1000
6	0.485	0.015	1000
7	0.500	0.015	1000
8	0.515	0.015	1000
9	0.530	0.015	1000
10	0.545	0.015	1000
11	0.560	0.015	1000
12	0.575	0.015	1000
13	0.590	0.015	1000
14	0.605	0.015	1000
15	0.620	0.015	1000
16	0.635	0.015	1000
17	0.650	0.015	1000
18	0.665	0.015	1000
19	0.680	0.015	1000
20	0.695	0.015	1000
21	0.710	0.015	1000
22	0.725	0.015	1000
23	0.740	0.015	1000
24	0.755	0.015	1000
25	0.770	0.015	1000
26	0.785	0.015	1000
27	0.800	0.015	1000
28	0.815	0.015	1000
29	0.830	0.015	1000
30	0.845	0.015	1000
31	0.860	0.015	1000
32	0.875	0.015	1000

MODIS-N Channel Parameters[2]

Band	Center Wavelength (micron)	Band Pass (micron)	IFOV (m)
1	0.659	0.020	214
2	0.865	0.050	214
3	0.470	0.020	428
4	0.555	0.020	428
5	1.240	0.020	428
6	1.640	0.020	428
7	2.130	0.050	428
8	0.415	0.015	856
9	0.443	0.010	856
10	0.490	0.010	856
11	0.531	0.010	856
12	0.565	0.010	856
13	0.653	0.015	856
14	0.681	0.010	856
15	0.745	0.010	856
16	0.865	0.015	856
17	0.908	0.030	856
18	0.936	0.010	856
19	0.950	0.050	856
20	3.750	0.180	856
21	3.750	0.180	856
22	3.959	0.050	856
23	4.050	0.050	856
24	4.465	0.050	856
25	4.515	0.050	856
26	4.565	0.050	856
27	6.715	0.360	856
28	7.325	0.300	856
29	8.550	0.300	856
30	9.730	0.300	856
31	11.030	0.500	856
32	12.020	0.500	856
33	13.335	0.300	856
34	13.635	0.300	856
35	13.935	0.300	856
36	14.235	0.300	856

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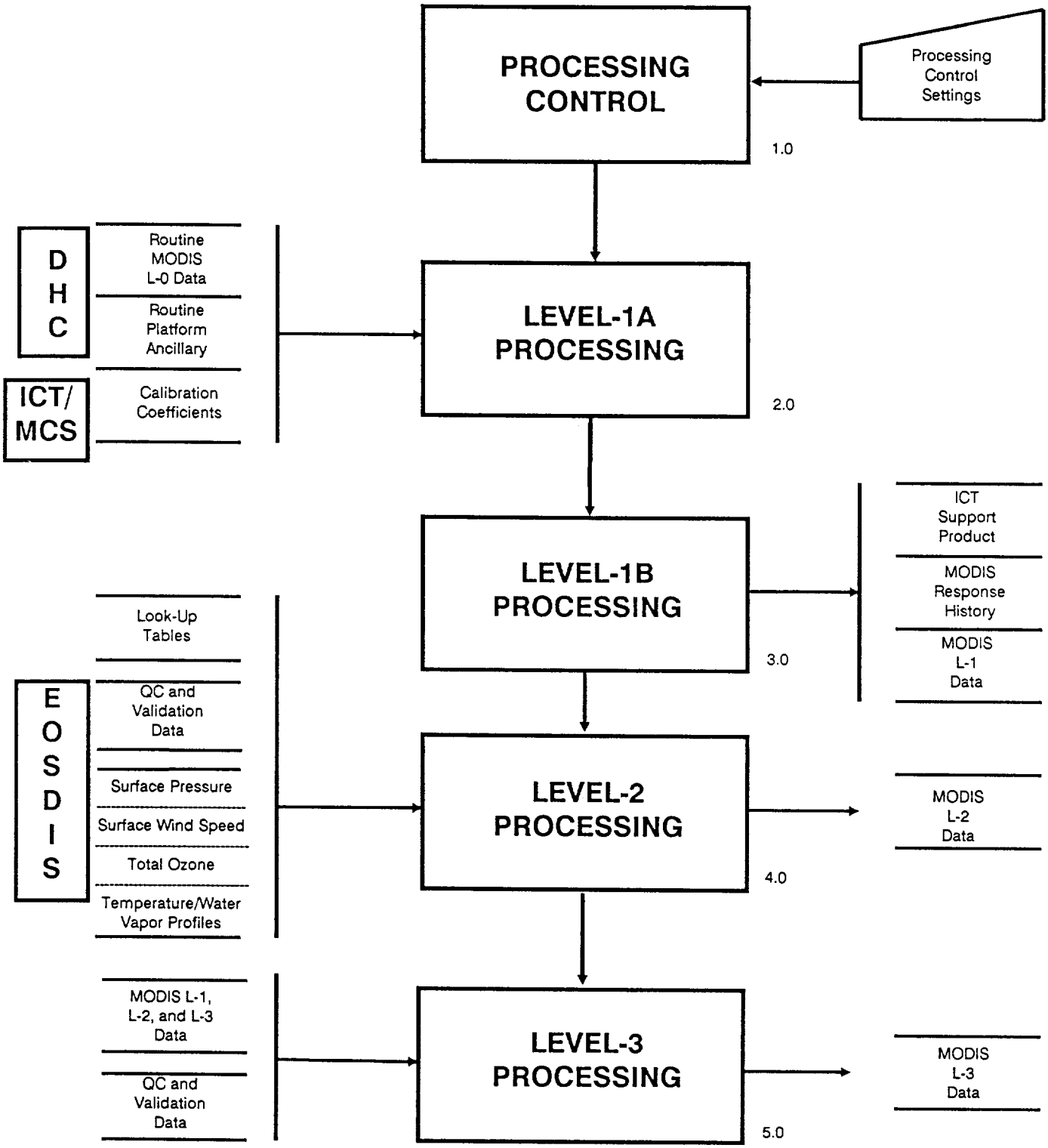
[1]In the final design, the MODIS-T field of view may be 1.1 km. This revision will reduce the number of across track observations from 1107 to 1007, may reduce the number of along track detectors from 32 to 30, and may reduce the scan period from 4.75 to 4.62 seconds (Tom Magner, personal communication, September 15, 1989).

[2]Channel information updated to include the deletion of the 2.06 μm, 428 m band (old band 7) and the addition of a second 3.75 μm, 856 m band (new band 21) with an extended temperature range.

UPDATE TO MODIS-N AND MODIS-T DATA RATE AND VOLUME ESTIMATES

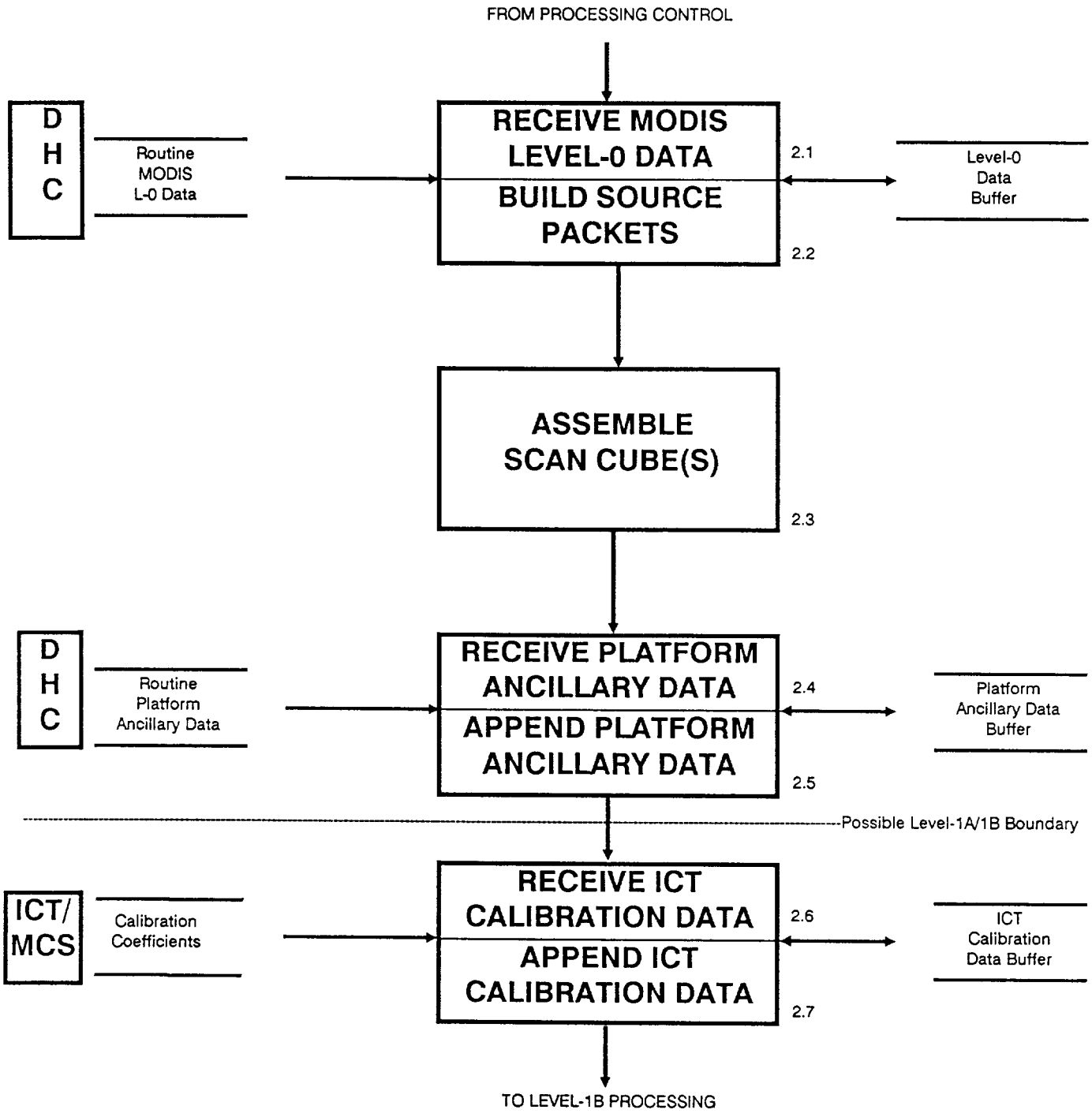
Earth Radius (km)	6371		
Satellite Altitude (km)	705		
Orbital Period (min)	98.9		
MODIS-N # 856 m REF channels	12		
MODIS-N # 428 m REF channels	5		
MODIS-N # 214 m REF channels	2		
MODIS-N # 856 m TIR channels	17		
MODIS-T # 1 km REF channels	32		
MODIS-N # bits/REF channel	12		
MODIS-N # bits/TIR channel	12		
MODIS-T # bits/REF channel	12		
MODIS-N REF Duty Cycle	50%		
MODIS-N TIR Duty Cycle	100%		
MODIS-T REF Duty Cycle	50%		
MODIS-N # Along-track IFOVs	8		
MODIS-T # Along-track IFOVs	32		
MODIS-N # Along-track detectors	648		
MODIS-T # Along-track detectors	32		
MODIS-N Maximum scan angle (deg)	55		
MODIS-T Maximum scan angle (deg)	45		
MODIS-N IFOV FWHM (deg)	6.95E-02		
MODIS-T IFOV FWHM (deg)	8.13E-02		
MODIS-N # pixels along-scan/on-Earth	1582		
MODIS-T # pixels along-scan/on-Earth	1107		
MODIS-N Scan Period (sec)	1.02		
MODIS-T Scan Period (sec)	4.75		
MODIS-N VIS Data (megabits/scan)	9.7		
MODIS-N TIR Data (megabits/scan)	2.6		
MODIS-N Daytime Data (megabits/scan)	12.3		
MODIS-T Daytime Data (megabits/scan)	13.6		
MODIS-N # Scans/Orbit	5841		
MODIS-T # Scans/Orbit	625		
		Contingency 10%	Total
MODIS-N Daytime Data Rate (mbps)	12.1	1.2	13.3
MODIS-N Nighttime Data Rate (mbps)	2.5	0.3	2.8
MODIS-T Daytime Data Rate (mbps)	2.9	0.3	3.2
MODIS-N Orbital Ave Data Rate (mbps)	7.3	0.7	8.1
MODIS-T Orbital Ave Data Rate (mbps)	1.4	0.1	1.6
MODIS-N Daily Data Volume (gigabits)	632.8	63.3	696.1
MODIS-T Daily Data Volume (gigabits)	123.8	12.4	136.2
Total MODIS Data Volume (gigabits)	756.6	75.7	832.3

DATA FLOWS FOR ROUTINE LEVEL-1 TO LEVEL-4 MODIS DATA PROCESSING



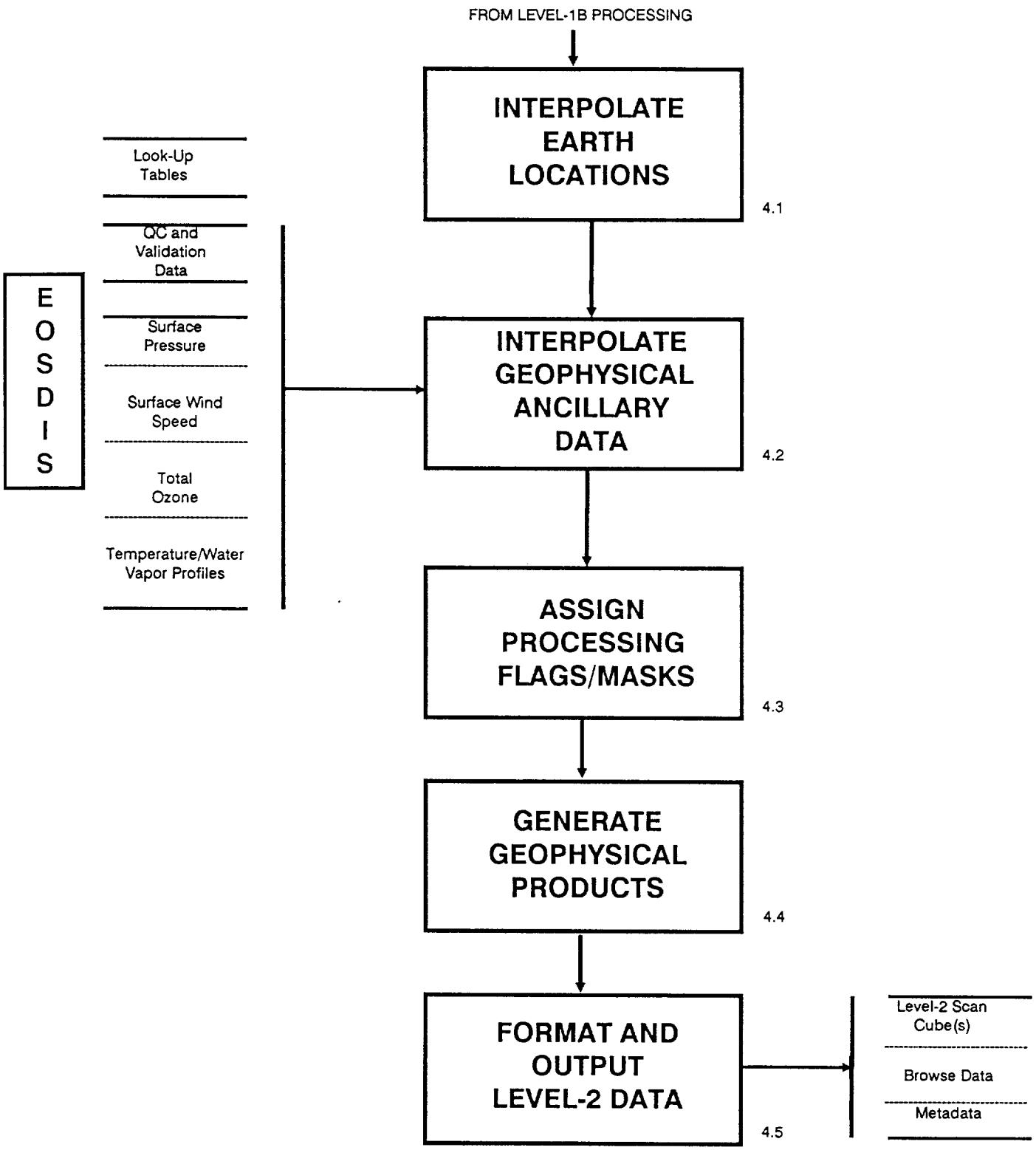
Revised 1/25/90

DATA FLOWS FOR ROUTINE LEVEL-1A MODIS DATA PROCESSING (2.0)



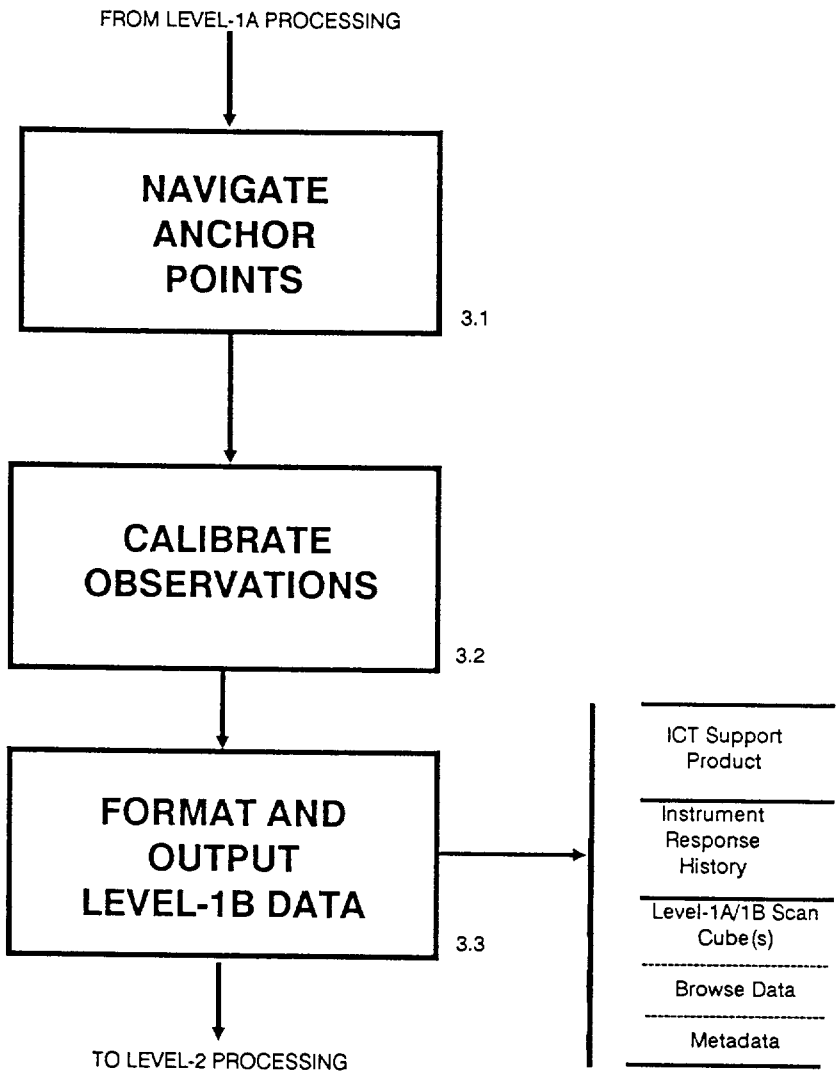
Revised 1/25/90

DATA FLOWS FOR ROUTINE LEVEL-2 MODIS DATA PROCESSING (4.0)



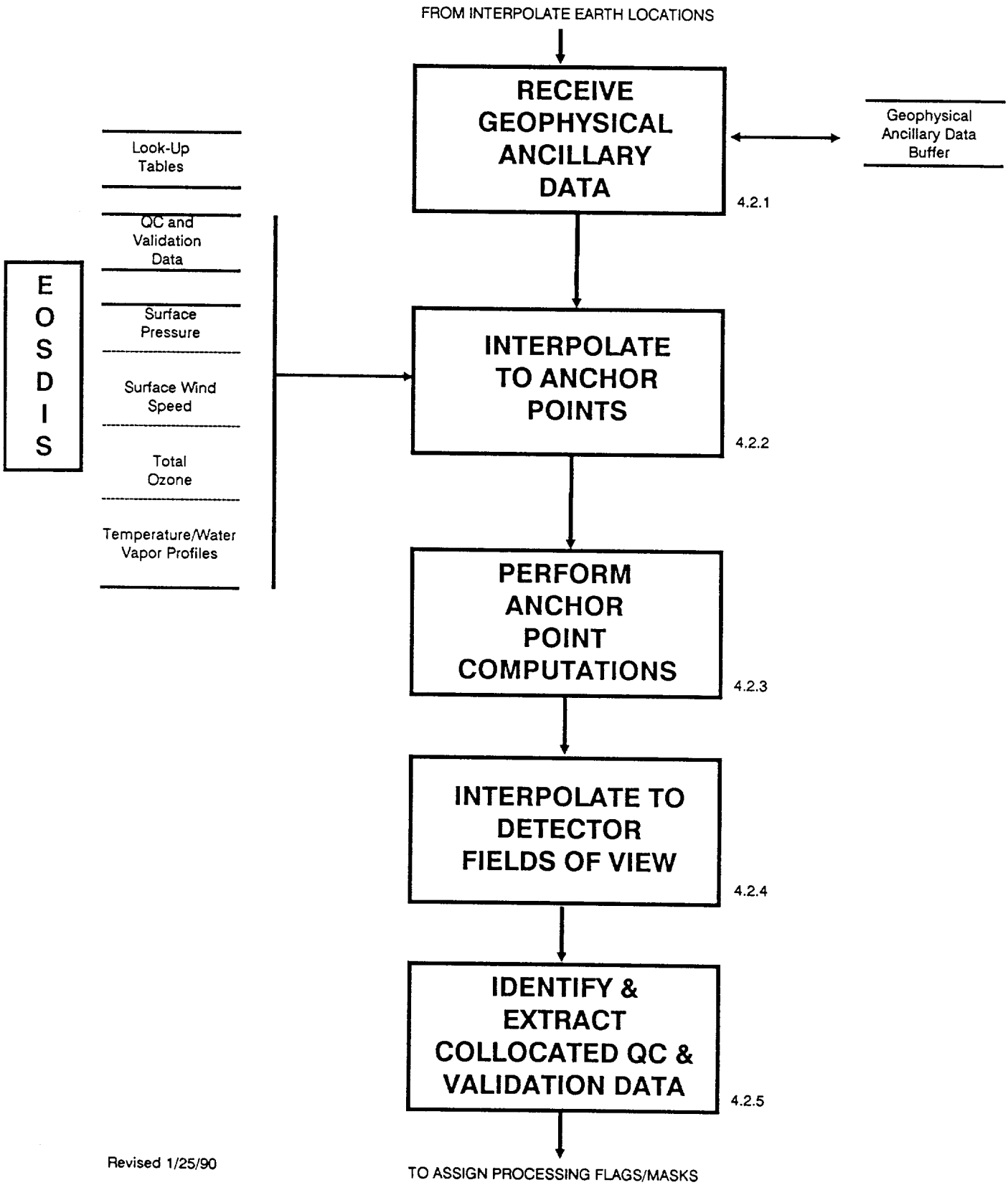
Revised 1/25/90

DATA FLOWS FOR ROUTINE LEVEL-1B MODIS DATA PROCESSING (3.0)



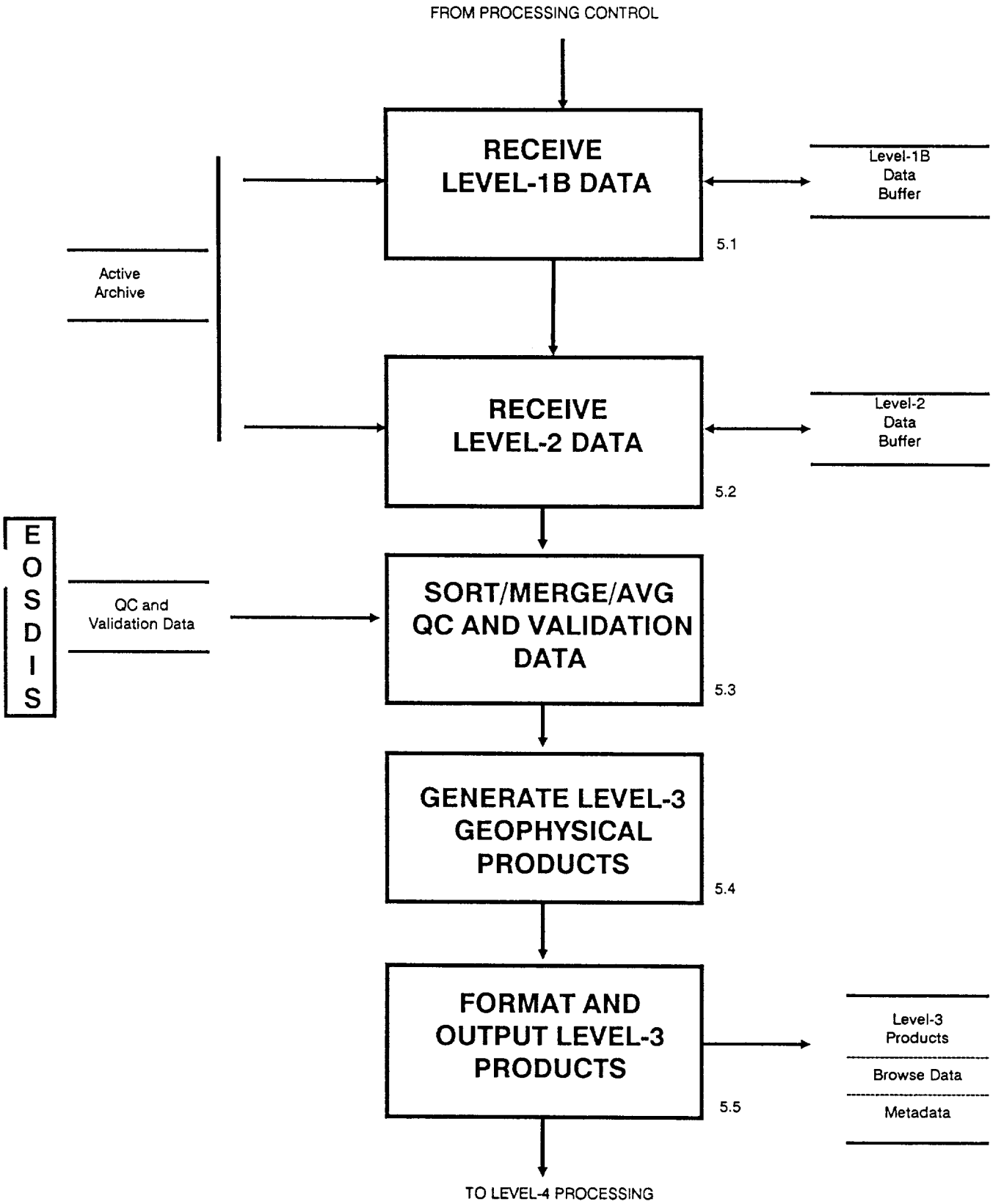
Revised 1/25/90

INTERPOLATE GEOPHYSICAL ANCILLARY DATA (4.2)



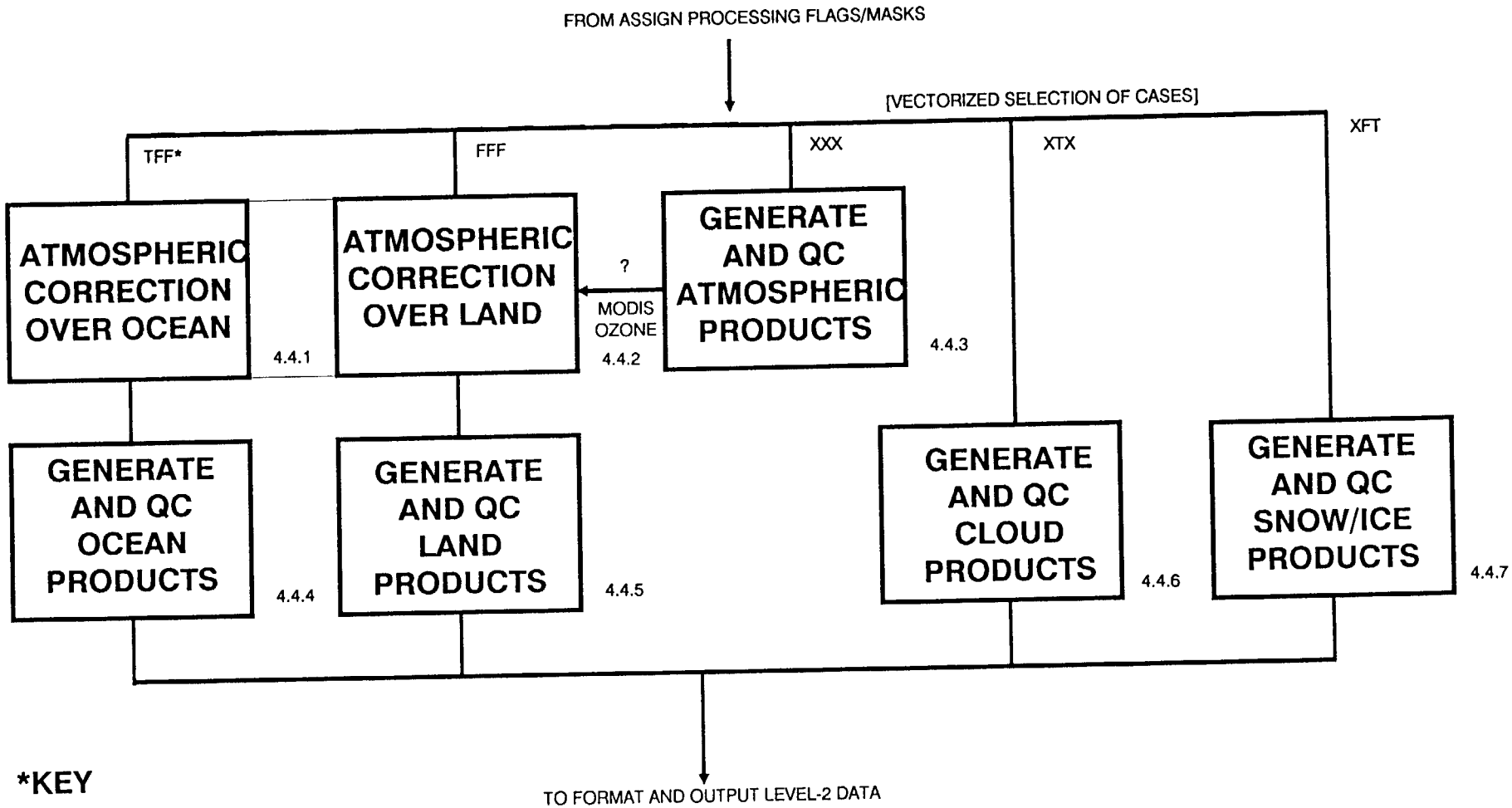
Revised 1/25/90

DATA FLOWS FOR ROUTINE LEVEL-3 MODIS DATA PROCESSING (5.0)



Revised 1/25/90

GENERATE GEOPHYSICAL PRODUCTS (4.4)



*KEY

FLAG 1: T = Ocean
F = Land
FLAG 2: T = Cloud
F = Clear
FLAG 3: T = Snow/Ice
F = Bare Surface

SIZING AND EVALUATION OF MODIS ANCHOR POINT EARTH LOCATION ALGORITHMS

1. EVALUATION OF ANCHOR POINT EARTH LOCATION ALGORITHMS

1.1 MODIS-N

The procedure we follow for evaluating anchor point Earth location algorithms is to first explicitly navigate every detector field of view for a scan. Then, linear and cubic spline interpolation strategies are applied across sparse arrays of "anchor points", at which the correct Earth locations exist. Using the interpolation algorithms, approximate Earth locations are obtained for each observation. The trade-off is for increased navigation error versus decreased computational expense. Errors are evaluated for every observation in a scan line that is four detector elements up from the bottom and three down from the top of the scan. This scan line will have the maximum error, as it is the farthest displaced from the anchor points.

Figure 1a. ±1.5° of latitude are scanned for a single scan at the equator for one scan line. The bi-linear interpolation method yields maximum errors which reach 125 m near the edge of the scan due to the Earth's curvature and the larger slant distance from the spacecraft to the target point.

Figure 1b. The error in latitude may be viewed in terms of fractional fields of view for each detector. This relative error increases to a maximum of about 0.13 (13%) of a field of view near the edge of a scan.

Figure 1c. ±10.3° of longitude are viewed in a single scan at the equator. Due to the Earth's curvature, the longitude errors due to interpolation are more serious than the latitude mislocations, reaching 900 m near the edge of each scan. Errors drop to near zero near the cross-track positions for which anchor points exist at the top and bottom scan lines.

Figure 1d. The size of the field of view increases by about a factor of four near scan angles of ±55°. However, the interpolation error increases more rapidly than the fields of view expand. As a result, relative errors of 0.23 (23%) of a field of view are incurred near the edges of each scan.

Figure 2a. Using the cubic spline method, the latitude mislocation errors are reduced to less than 4 m, even at the scan boundaries.

Figure 2b. The latitude errors are only 0.004 (0.4%) fields of view after normalization.

Figure 2c. Using the cubic spline method, the longitude mislocation errors are reduced to 28 m near the scan boundaries.

Figure 2d. Because of the factor of four increase in field of view size, the maximum longitudinal errors are only 0.007 (0.7%) fields of view after normalization.

The clear conclusion is that the cubic spline approach yields navigation errors that are quite acceptable for MODIS-N, while at the same time substantially reducing the computational cost associated with explicit Earth location.

1.2 MODIS-T for 20° Tilt

As with MODIS-N, the anchor point Earth location algorithms are evaluated by first explicitly navigating every detector field of view for a scan. Then, the cubic spline interpolation is applied across the sparse arrays of "anchor points", at which the correct Earth locations exist. Five cubic spline fits are employed, each across 1107 across-track positions. The specific scan lines chosen are 1, 8, 15, 22, and 30. Using the interpolation algorithms, approximate Earth locations are obtained for each observation. Errors are evaluated for every observation in scan line 26, which is four detector elements up from the spline in line 22 and four down from the top of the scan. This scan line will have the maximum error, as it is the farthest displaced from the anchor points, and (most importantly) will be the closest to the limb for forward tilts.

Figure 3a. +1.5° to 4.0°of latitude are scanned for a single scan at the equator for scan line 26 at a tilt of 20°. The cubic spline interpolation method yields maximum errors which reach 20 m near the edge of the scan due to the Earth's curvature and the larger slant distance from the spacecraft to the target point.

Figure 3b. When viewed in terms of fractional fields of view for each detector, the relative error increases to a maximum of about 0.015 (1.5%) of a field of view near the edge of a scan.

Figure 3c. ±7.5° of longitude are viewed in a single scan at the equator. This is a smaller swath width than MODIS-N due to the limit of ±45° of nadir angle across track. The longitude errors due to interpolation reach 28 m near the edge of each scan.

Figure 3d. The relative errors of 0.01 (1%) of a field of view are incurred near the edges of each scan.

The clear conclusion is that the cubic spline approach yields navigation errors that are quite acceptable for mild tilts of MODIS-T, while at the same time substantially reducing the computational cost associated with explicit Earth location.

1.3 MODIS-T for 45° Tilt

Figure 4a. For a 45° tilt (almost worst case), latitudes from 6.5° to 10°N are viewed. Using the cubic spline method, the latitude mislocation errors reach 250 to 350 m at the scan boundaries, and are approximately 100 m throughout most of the scan.

Figure 4b. The latitude errors are systematic, and range between 0.04 and 0.08 (4% to 8 %) fields of view after normalization.

Figure 4c. -13° to +10° of longitude are scanned by MODIS-T at a 45° tilt

angle. Using the cubic spline method, the longitude mislocation errors reach 420 m near the scan boundaries.

Figure 4d. Because of the factor of four increase in field of view size, the maximum longitudinal errors are 0.08 (8%) fields of view after normalization.

The conclusion is that the cubic spline approach yields navigation errors that are less that 0.1 (10%) of a field of view, while at the same time substantially reducing the computational cost associated with explicit Earth location. However, at high tilt angles, systematic errors in latitude and longitude occur. While these are perhaps the highest tilts angles that might realistically be employed for ocean color measurements, even larger tilt angles might be desired for bidirectional reflectance studies. These large tilts may then necessitate special interpolation strategies along the subsatellite track, such as spline fits, using the across-track interpolations as knots, for each across-track position. In the limit, a spline could be fit to every scan line.

2. SIZING OF ANCHOR POINT EARTH LOCATION ALGORITHMS

2.1 MODIS-N (One scan)

P = number of observations per scan line = 1582
D = number of detectors (scan lines) along track = 8
E = number of operations for Earth Location[1] = 450[2]
N = number of anchor points = 94 (per anchor point scan line)
R = performance requirement

2.1.1 Earth Locate Every Point

The explicit navigation to the Earth spheroid for each observation is by definition the most accurate method for obtaining the Earth locations, as no interpolation error is incurred. However, this method is also the most expensive computationally.

$$R = E * P * D = 5.70 \text{ MFLOP/SCAN}$$

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[1]Sized based on the Nimbus-7 Image Location Tape (ILT) source code, subroutine LOCATEL. Total sizing includes conversion from sensor tilt and scan angles to line of sight unit vector, navigation to Earth spheroid, and computation of target latitude and longitude. The CZCS navigation code was used to confirm the estimate. The latter indicated only about half the number of operations, but included small angle and other approximations.

[2]Simple operations, such as additions, subtractions, multiplications, divisions, if statements, and assignments are counted as single floating point operations; more complex functions, such as sin, cos, arccos, arctan, and square roots are counted as ten floating point operations. For this processing step, 200 operations of mixed complexity convert to 450 floating point operations.

2.1.2 Bi-Linear Interpolation

Bi-linear interpolation of Earth locations from a sparse array of explicitly navigated "anchor points" represents a computationally less expensive alternative. The MODIS-T scan is decomposed into a 94 x 2 array of anchor points (94 - 1 is an even factor of 1582 - 1). The 188 anchor points are first navigated, and then bi-linear interpolation is used to Earth locate the 17 x 8 fields of view within each set of four anchor points. Of course, this technique incurs error due to the Earth's local curvature between sets of anchor points, primarily along the scan.

Eight operations are required for each interpolation.

$$R = [2 \text{ lines} * E * N + P * D * 8 \text{ ops}] * 2\ (lat + lon) = 1800 * N + 202{,}496$$

For N = 94 Anchor points, R = **0.37 MFLOP/SCAN**

2.1.3 Cubic Spline Interpolation

In this approach, a cubic spline is fit along two scan lines, one at the top of the scan and the other at the bottom. Each of these spline fits uses the explicit Earth locations as data knots. The spline is then evaluated for every observation along the two scan lines. Finally, a linear interpolation along track between the two spline fits provides the Earth locations for every point in the scan. The spline allows the interpolation process to account for the Earth's curvature at large zenith angles, but is not required along track.

2.1.3.1 Set up

24 operations are required to set up the coefficients for each spline knot.

$$R_1 = [E * N + 11 + 24 * N] * 2 \text{ lines} * 2\ (lat + lon)$$
$$= 4 * 11 \text{ ops} + 4 * (E + 24 \text{ ops}) * N = 44 + 1896 * N$$

2.1.3.2 Interpolate along scan

10 operations are required to evaluate the spline at each interpolation point.

$$R_2 = 10 \text{ ops} * P * 2 \text{ lines} * 2\ (lat + lon) = 63{,}280$$

2.1.3.3 Linear interpolation along track

8 operations are required to evaluate a linear interpolation at each point.

$$R_3 = 8 \text{ ops} * (8 - 2) \text{ points} * P * 2\ (lat + lon) = 151{,}872$$

2.1.3.4 Total Equation

$$R = R_1 + R_2 + R_3 = 215{,}152 + 1896 * N$$

For N = 94 anchor points, R = **0.39 MFLOP/SCAN**

2.1.4 Other considerations

2.1.4.1 Longitude interpolation across dateline

2.1.4.2 Latitude and longitude determination near the poles

2.1.4.3 Tests for specific conditions/treatment of other problems

2.1.4.4 Interpolation to 214 and 428 m bands

Table 1. Comparison of strategies for MODIS-N Earth location. Interpolation schemes assumes 94 anchor points at top and bottom of scan matrix (MFLOP/SCAN).

	Explicit Earth Location	Bi-Linear Interpolation	Cubic Spline Interpolation
Navigate to 856 m pixel	5.70	0.37	0.39
Dateline Problem	0.00	0.03	0.03
Polar Problem	0.00	0.06	0.06
Tests/Other Problems	0.00	0.11	0.11
Subtotal	5.70	0.57	0.59
214/428 m band Navigation[3]	0.89	0.89	0.89
Total	6.59	1.46	1.48

1.58

2.2 MODIS-T (One scan)

P = number of observations per scan line = 1107
D = number of detectors (scan lines) along track = 30
E = number of operations for Earth Location = 450
N = number of anchor points = 80 (per anchor point scan line)
R = performance requirement

2.2.1 Earth Locate Every Point

As was the case with MODIS-N, the explicit navigation to the Earth spheroid for each observation is by definition the most accurate method for obtaining the Earth locations, but also the most expensive computationally.

[3]Because the interpolation to the 214 and 428 m bands is relatively computationally demanding, this step is subject to a more definitive statement on navigation requirements from the MODIS science team.

$$R = E * P * D = 14.9 \text{ MFLOP/SCAN}$$

2.2.2 Bi-Linear Interpolation

The MODIS-T scan is decomposed into an 80 x 5 array of anchor points (80 - 1 is an even factor of 1107 - 1). The 400 anchor points are first navigated, and then bi-linear interpolation is used to Earth locate the 14 x 8 fields of view within each set of four anchor points. This technique incurs error due to the Earth's local curvature between sets of anchor points, not only along the scan, but also along the track for high tilt angles.

Eight operations are required for each observation

$$R = [5 \text{ lines} * E * N + P * D * 8 \text{ ops}] * 2 \; (lat + lon) = 4500 * N + 531{,}360$$

For N = 80 anchor points per scan line, R = **0.89 MFLOP/SCAN**

2.2.3 Cubic Spline Interpolation

As with MODIS-N, a cubic spline is fit along the scan for a subset of scan lines. However, because the MODIS-T instrument has a larger set of detectors along track, more than two anchor point scan lines are used. In this example, five scan lines, one at the top of the scan, one at the bottom, and three within the scan to roughly partition the scan into quarters[4]. Each of these spline fits uses the explicit Earth locations as data knots. The spline is then evaluated for every observation along the two scan lines. Finally, a linear interpolation along track between the appropriate pairs of spline fits provides the Earth locations for every point in the scan. The spline allows the interpolation process to account for the Earth's curvature at large zenith angles, as does the segmenting along track, albeit to a lesser extent.

2.2.3.1 Set up

24 operations are required to set up the coefficients for each spline knot.

$$R_1 = [E * N + 11 \text{ ops} + 24 \text{ ops} * N] * 5 \text{ lines} * 2 \; (lat + lon)$$
$$= 110 + 10 * (E + 24) * N = 110 + 4740 * N$$

2.2.3.2 Interpolate along scan

10 operations are required to evaluate the spline at each interpolation point.

$$R_2 = 10 \text{ ops} * P * 5 \text{ lines} * 2 \; (lat + lon) = 110{,}700$$

2.2.3.3 Linear interpolation along track

---

[4]The design of the MODIS-T instrument may include from 30 to 32 detectors along track, each with a nadir footprint of from 1.1 to 1.0 km. There may be from 1107 to 1007 samples taken along the scan.

8 operations are required to evaluate a linear interpolation at each point.

$$R_3 = 8 \text{ ops} * (30 - 5) \text{ points} * P * 2\ (lat + lon) = 442{,}800$$

2.2.3.4 Total Equation

$$R = R_1 + R_2 + R_3 = 553{,}610 + 4740 * N$$

For N = 80 anchor points, **R = 0.93 MFLOP/SCAN**

2.2.4 <u>Other considerations</u>

2.2.4.1 Longitude interpolation across dateline

2.2.4.2 Latitude and longitude determination near the poles

2.2.4.3 Tests for specific conditions/treatment of other problems

2.2.4.4 Possibly refined navigation for large tilt angles (>>20°)

(Fit bi-cubic splines?)

Table 2. Comparison of strategies for MODIS-T Earth location. Interpolation schemes assumes 80 anchor points at five scan lines of scan matrix (MFLOP/SCAN).

	Explicit Earth Location	Cubic Spline Interpolation
Navigate to 1,100 m pixel	14.9	0.93
Dateline Problem	0.00	0.03
Polar Problem	0.00	0.04
Tests/Other Problems	0.00	0.11
Subtotal	14.9	1.11
Large tilt angle Navigation[5]	0.00	0.36
Total	14.9	1.47

[5]At large tilt angles, the Earth's curvature becomes important and a piecewise linear interpolation may not be sufficiently accurate. Under these conditions, a bi-linear cubic spline fit will yield substantial increases in accuracy.

3. FIELD OF VIEW SIZE AS A FUNCTION OF SCAN AND TILT ANGLES

3.1 MODIS-N

Figure 5a. The fields of view for a complete 856 m (at nadir) MODIS-N scan out to ±55° of nadir angle. The along-scan (essentially longitude at the equator) size increases to over 4 km at the edge of the scan, while the along-track (essentially latitude at the equator) size expands to almost 1 km. The larger longitudinal effect is due to the effects of the Earth's curvature on top of the increased slant path.

3.2 MODIS-T

Figure 5b. The fields of view for a complete 1 km (at nadir) MODIS-T scan, for 20° tilt, out to ±45° of nadir angle[6]. The along-scan (essentially longitude at the equator) size increases to over 2.5 km at the edge of the scan, while the along-track (essentially latitude at the equator) size expands to 1.2 to 1.4 km. The larger longitudinal effect at the edges of the scan is due to the effects of the Earth's curvature on top of the increased slant path. The latitudinal stretching is greater at the middle of the scan because of the 20° tilt angle.

Figure 5c. The fields of view for a complete 1 km (at nadir) MODIS-T scan, for a more extreme 45° tilt, out to ±45° of nadir angle. The along-scan (essentially longitude at the equator) size varies from 1.5 km at the middle of the scan to 5.5 km at the edge of the scan, while the along-track (essentially latitude at the equator) size varies from 2.5 to over 4 km. The latitudinal stretching is greater than the longitudinal effect at the middle of the scan because of the 45° tilt angle. At the edges of the scan, the effective nadir angle reaches 60° (and the effective azimuth to spacecraft motion 75°). Therefore, the longitudinal effect dominates, though by less than for MODIS-N or MODIS-T with a 20° tilt.

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[6]In the final design, the nadir field of view for MODIS-T may be 1.1 km.

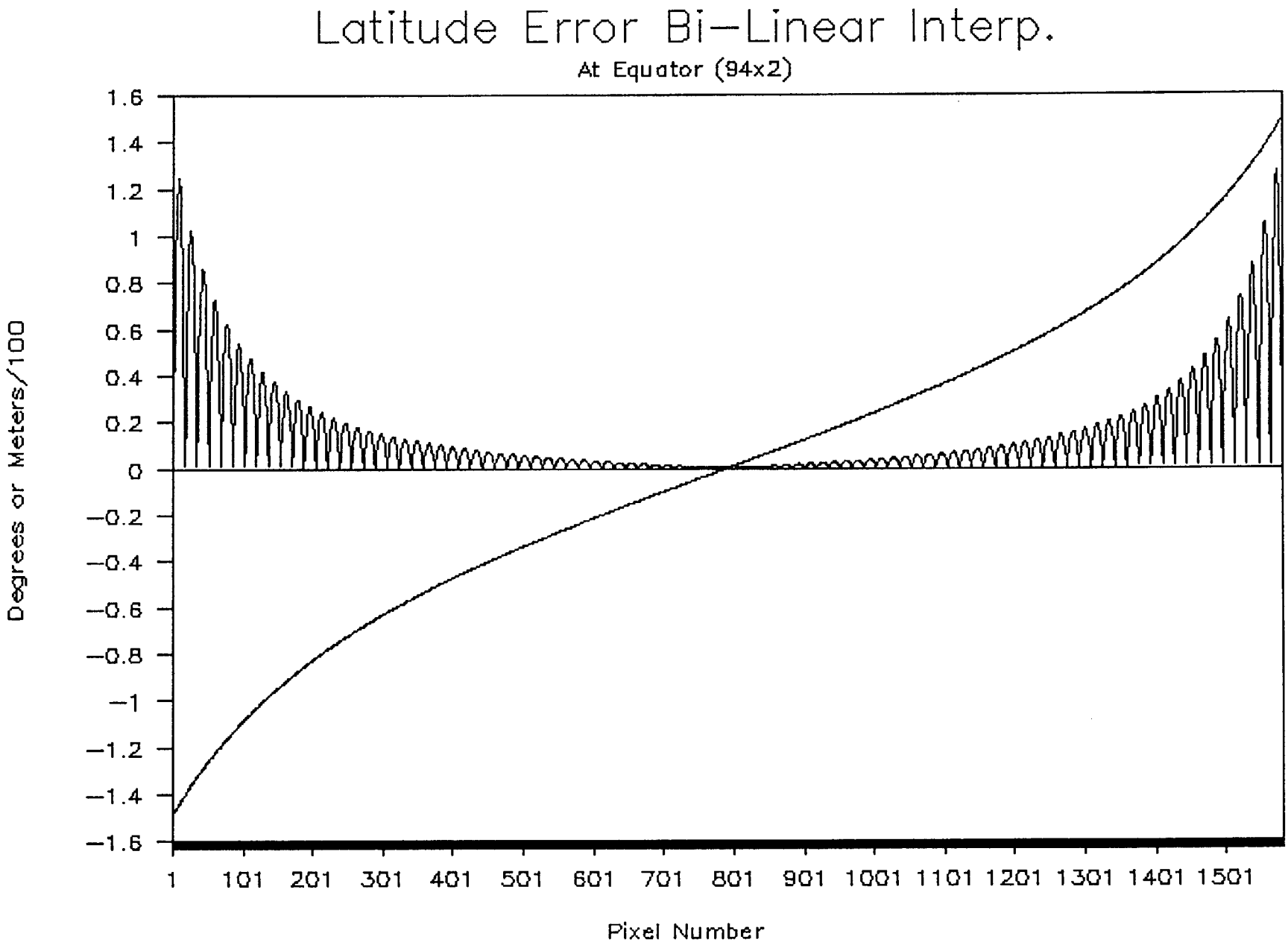
Latitude Error Bi-Linear Interp.
At Equator (94x2)
Degrees or Meters/100
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2
-1.4
-1.6
1
101
201
301
401
501
601
701
801
901
1001
1101
1201
1301
1401
1501
Pixel Number

Figure 1a.

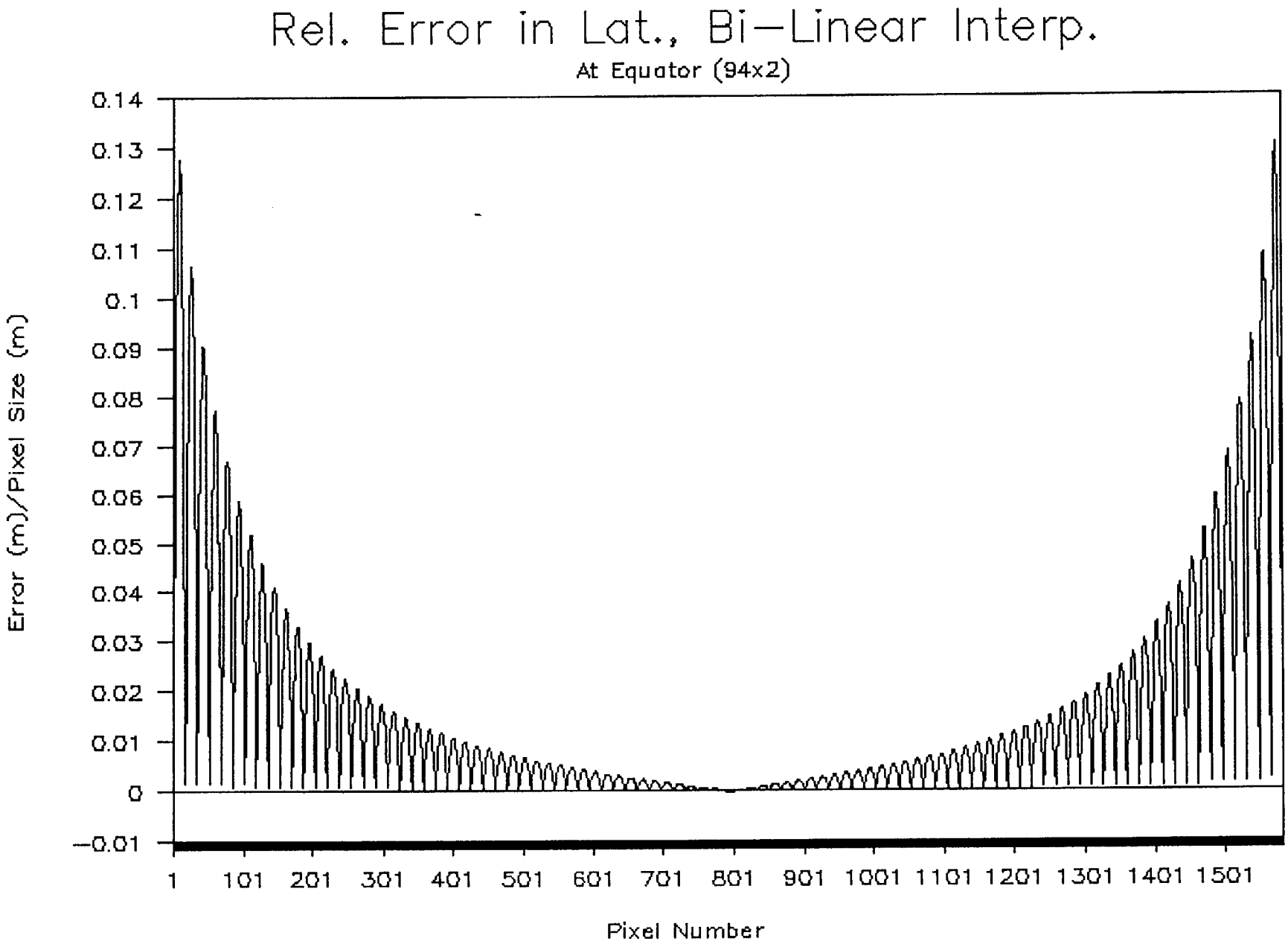
Rel. Error in Lat., Bi-Linear Interp.
At Equator (94x2)
Error (m)/Pixel Size (m)
0.14
0.13
0.12
0.11
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
-0.01
1
101
201
301
401
501
601
701
801
901
1001
1101
1201
1301
1401
1501
Pixel Number

Figure 1b.

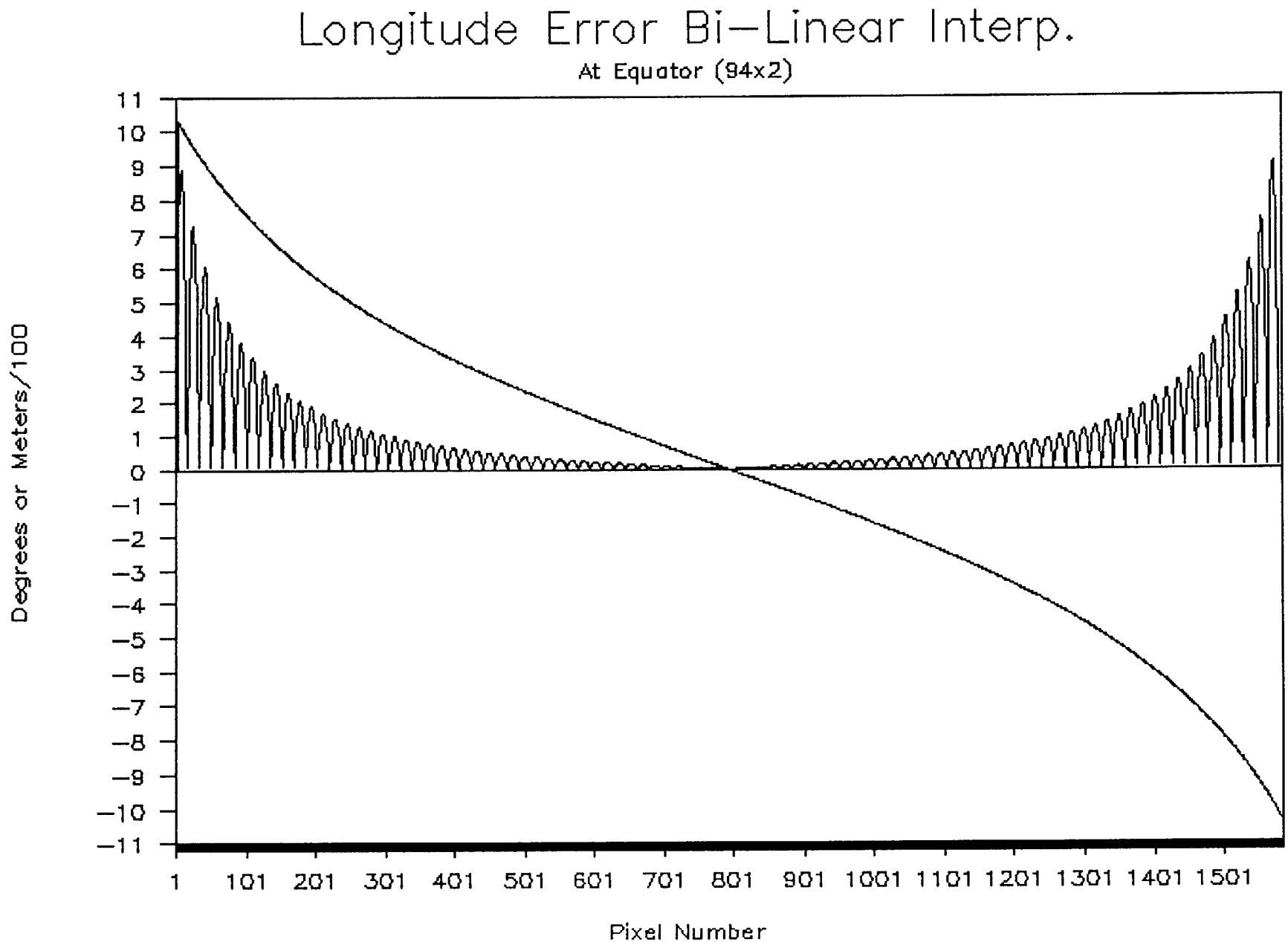
Longitude Error Bi—Linear Interp.
At Equator (94x2)
Degrees or Meters/100
11
10
9
8
7
6
5
4
3
2
1
0
−1
−2
−3
−4
−5
−6
−7
−8
−9
−10
−11
1
101
201
301
401
501
601
701
801
901
1001
1101
1201
1301
1401
1501
Pixel Number

Figure 1c.

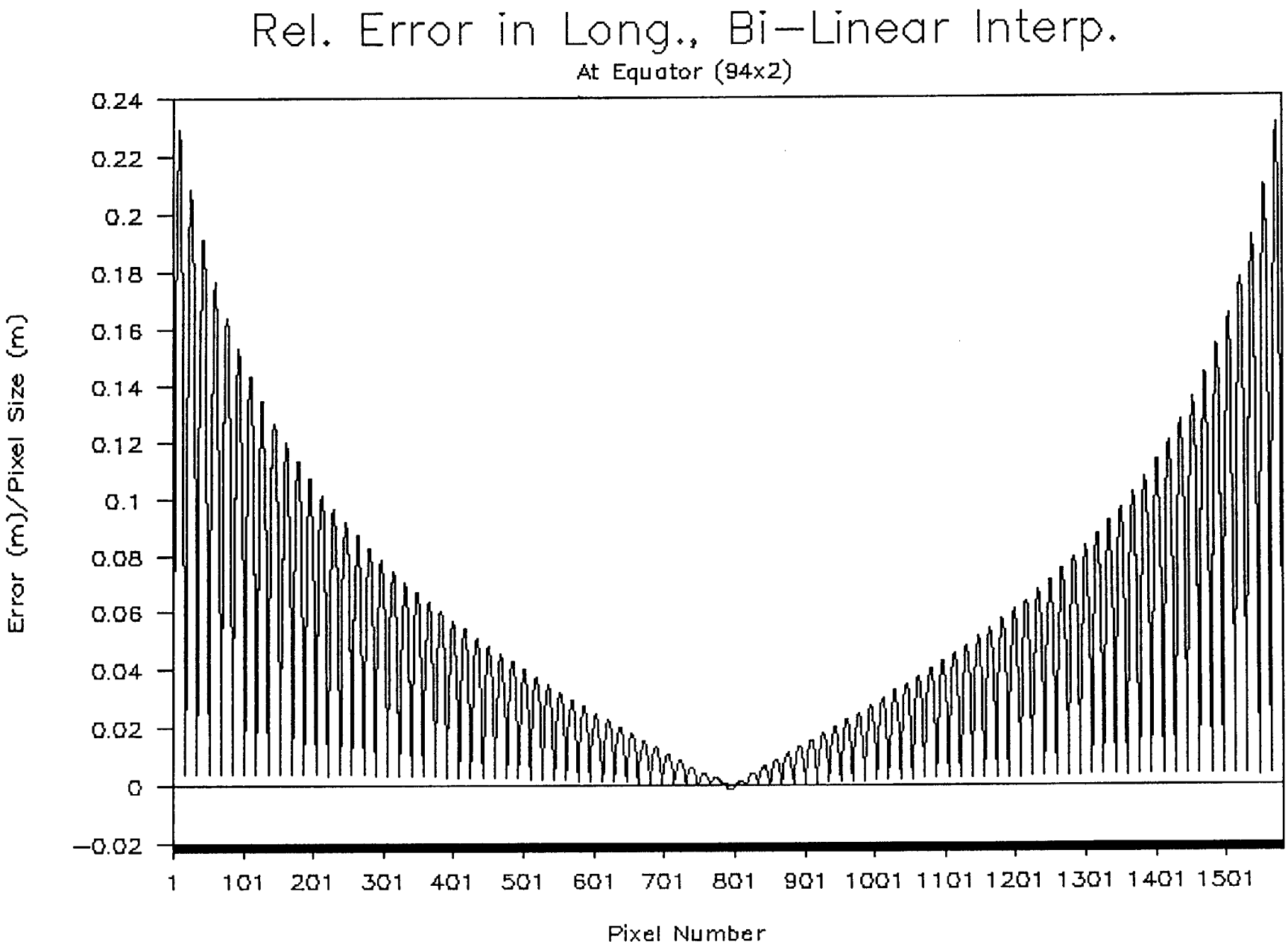
Rel. Error in Long., Bi-Linear Interp.
At Equator (94x2)
Error (m)/Pixel Size (m)
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
-0.02
1
101
201
301
401
501
601
701
801
901
1001
1101
1201
1301
1401
1501
Pixel Number

Figure 1d.

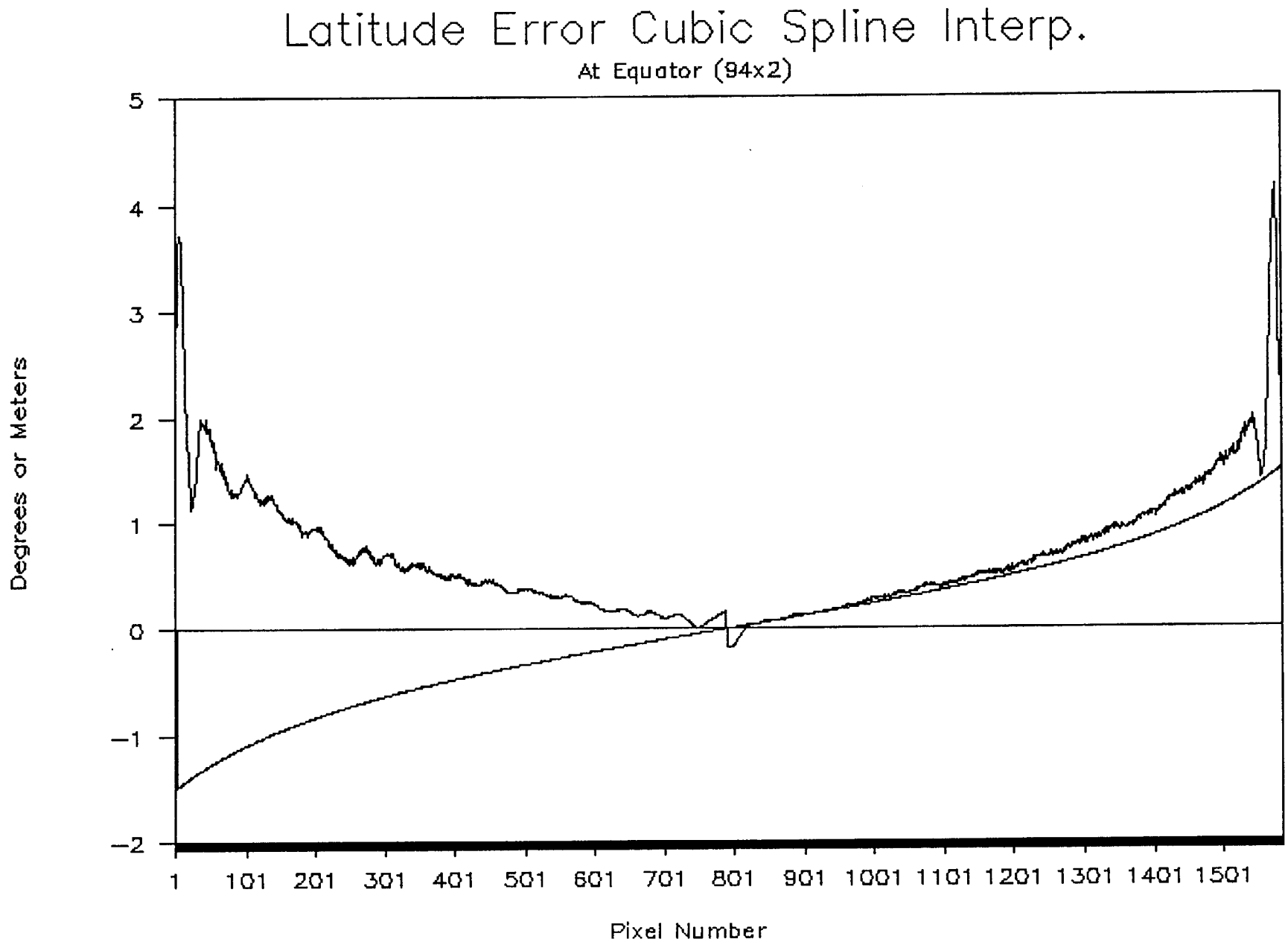
Latitude Error Cubic Spline Interp.
At Equator (94x2)
Degrees or Meters
5
4
3
2
1
0
−1
−2
1
101
201
301
401
501
601
701
801
901
1001
1101
1201
1301
1401
1501
Pixel Number

Figure 2a.

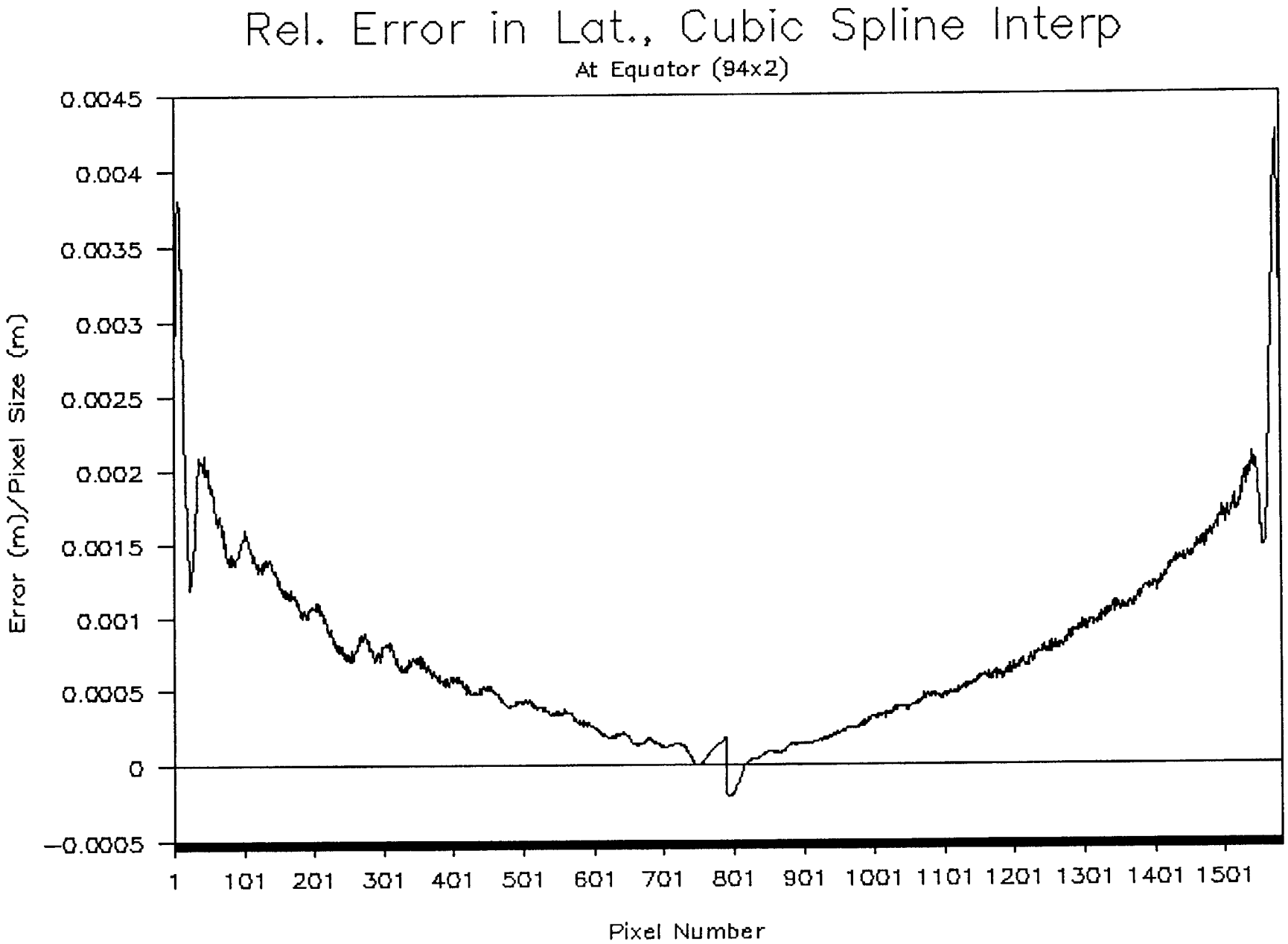
Rel. Error in Lat., Cubic Spline Interp
At Equator (94x2)
Error (m)/Pixel Size (m)
0.0045
0.004
0.0035
0.003
0.0025
0.002
0.0015
0.001
0.0005
0
-0.0005
1
101
201
301
401
501
601
701
801
901
1001
1101
1201
1301
1401
1501
Pixel Number

Figure 2b.

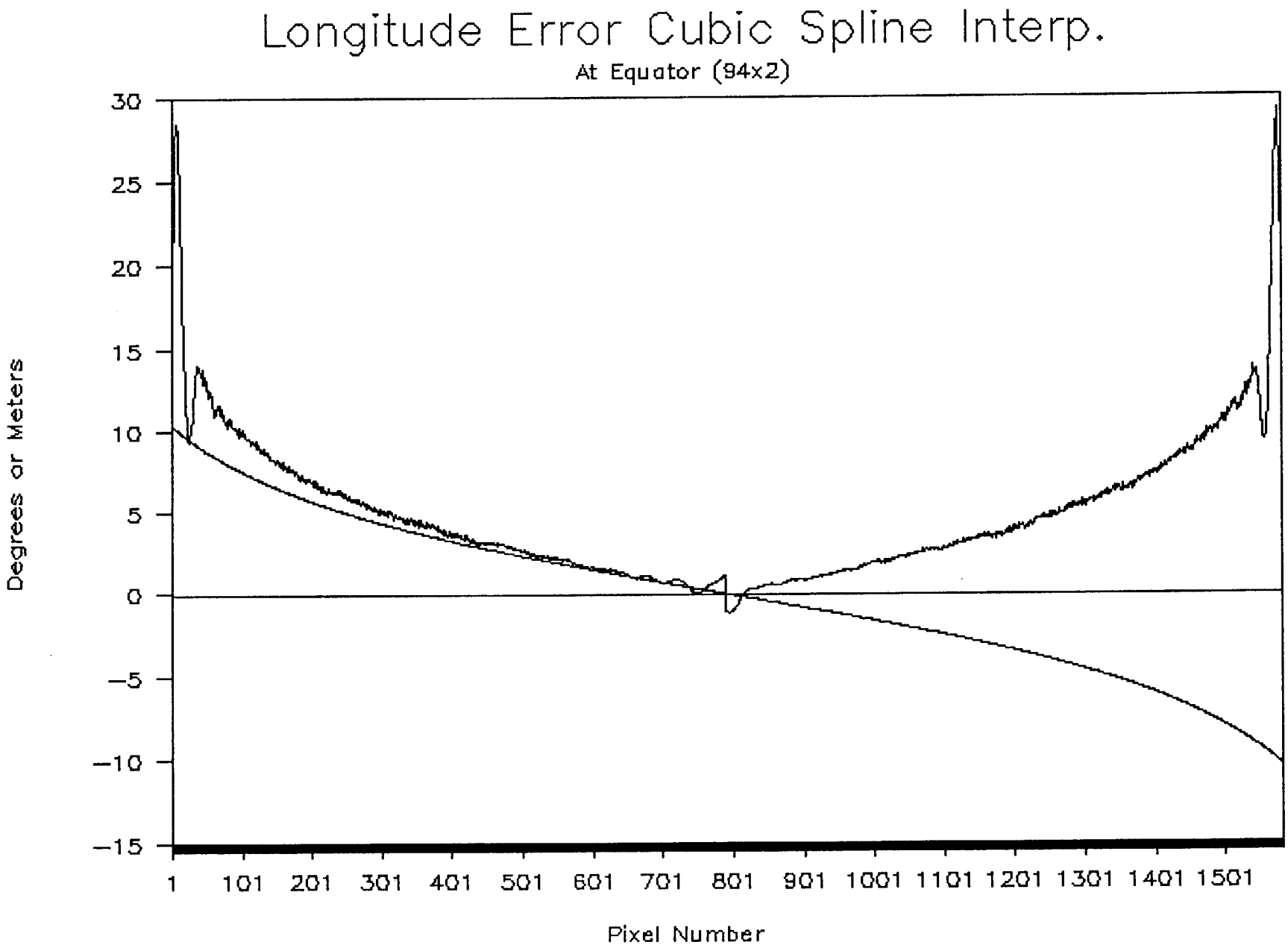
Longitude Error Cubic Spline Interp.
At Equator (94x2)
Degrees or Meters
30
25
20
15
10
5
0
−5
−10
−15
1
101
201
301
401
501
601
701
801
901
1001
1101
1201
1301
1401
1501
Pixel Number

Figure 2c.

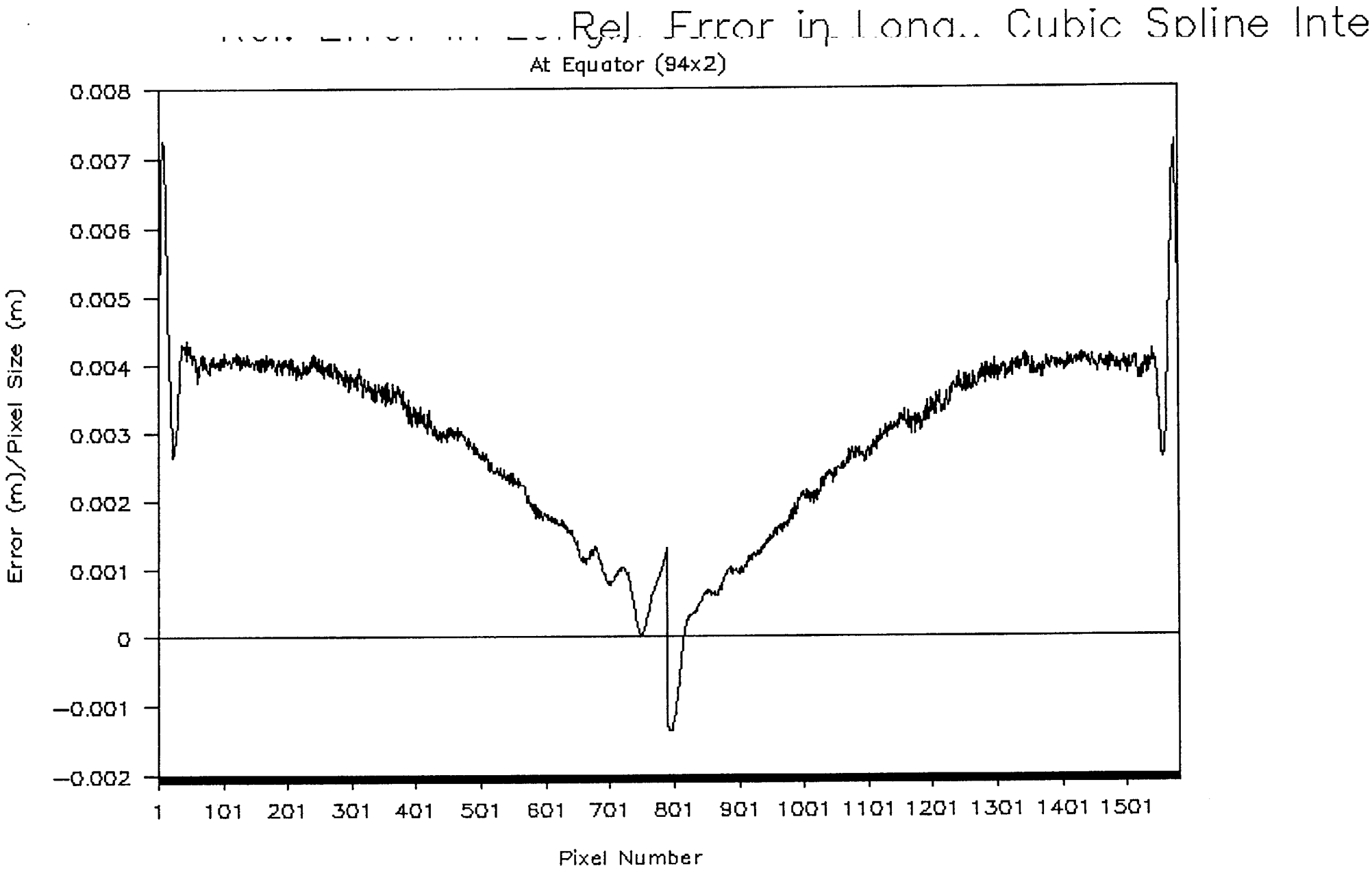
Rel. Error in Long. Cubic Spline Inte
At Equator (94x2)
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
−0.001
−0.002
Error (m)/Pixel Size (m)
1
101
201
301
401
501
601
701
801
901
1001
1101
1201
1301
1401
1501
Pixel Number

Figure 2d.

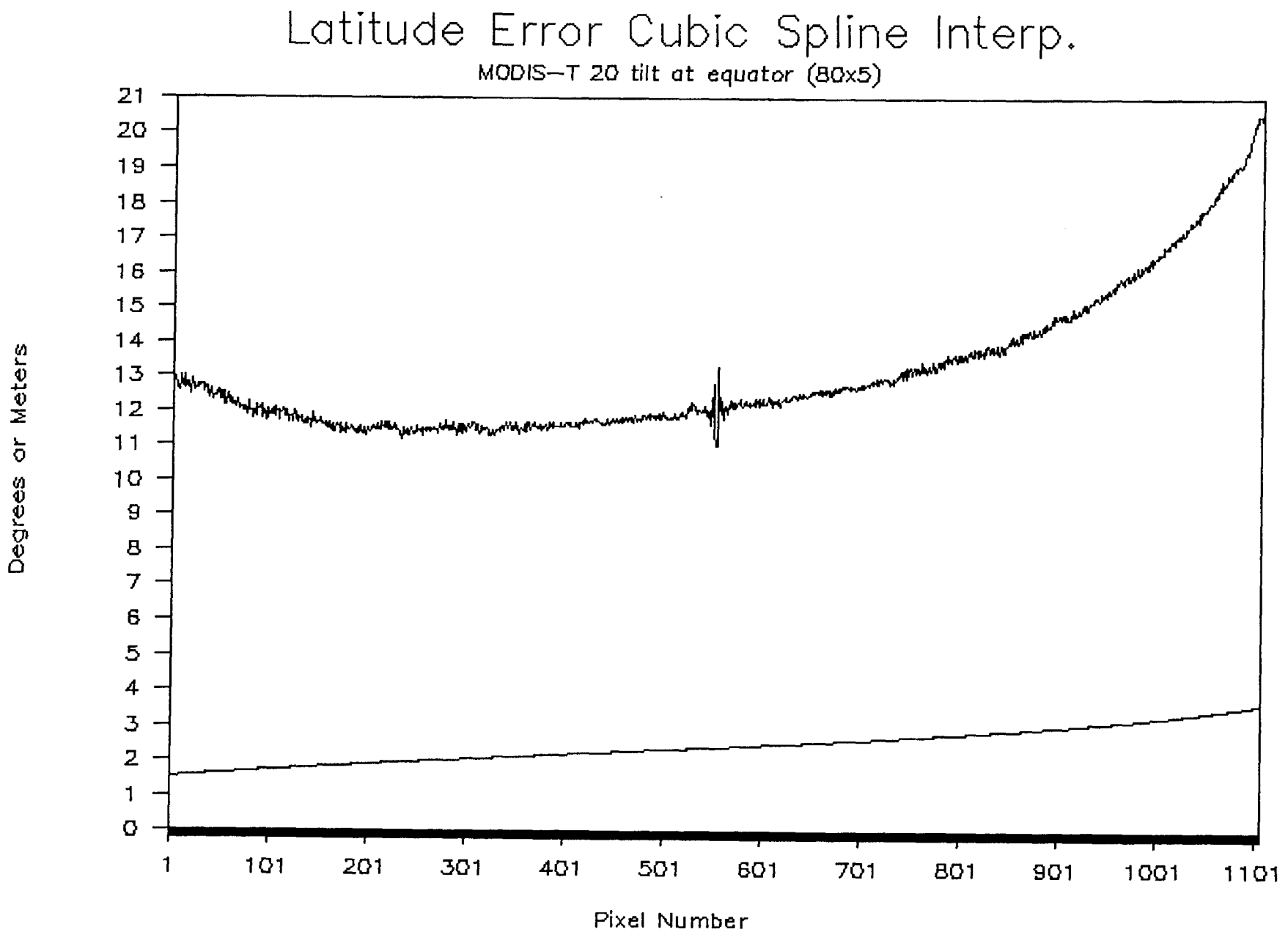
Latitude Error Cubic Spline Interp.
MODIS-T 20 tilt at equator (80x5)
Degrees or Meters
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
1
101
201
301
401
501
601
701
801
901
1001
1101
Pixel Number

Figure 3a.

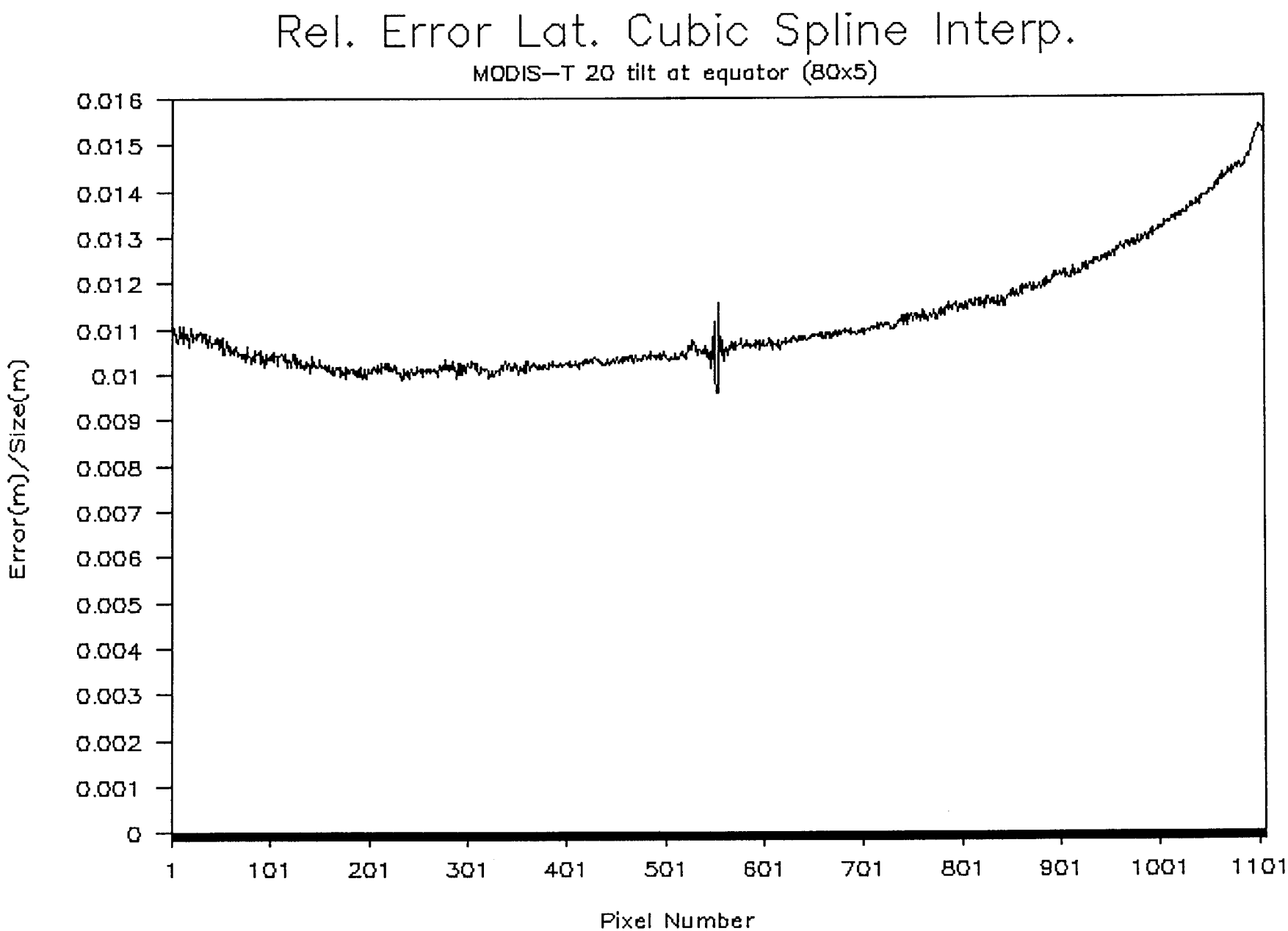
Rel. Error Lat. Cubic Spline Interp.
MODIS—T 20 tilt at equator (80x5)
Error(m)/Size(m)
0.016
0.015
0.014
0.013
0.012
0.011
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
1
101
201
301
401
501
601
701
801
901
1001
1101
Pixel Number

Figure 3b.

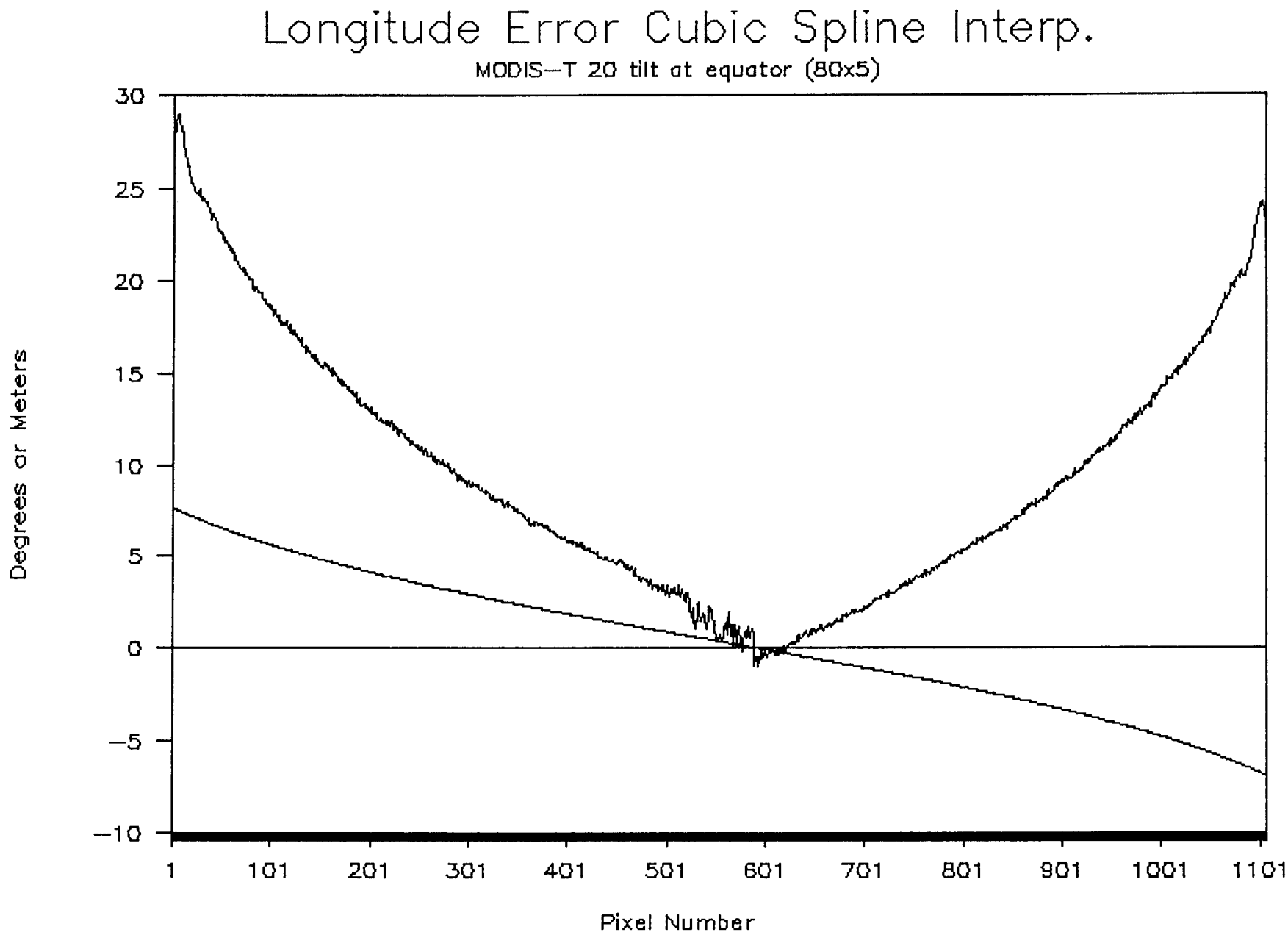
Longitude Error Cubic Spline Interp.
MODIS—T 20 tilt at equator (80x5)
Degrees or Meters
30
25
20
15
10
5
0
−5
−10
1
101
201
301
401
501
601
701
801
901
1001
1101
Pixel Number

Figure 3c.

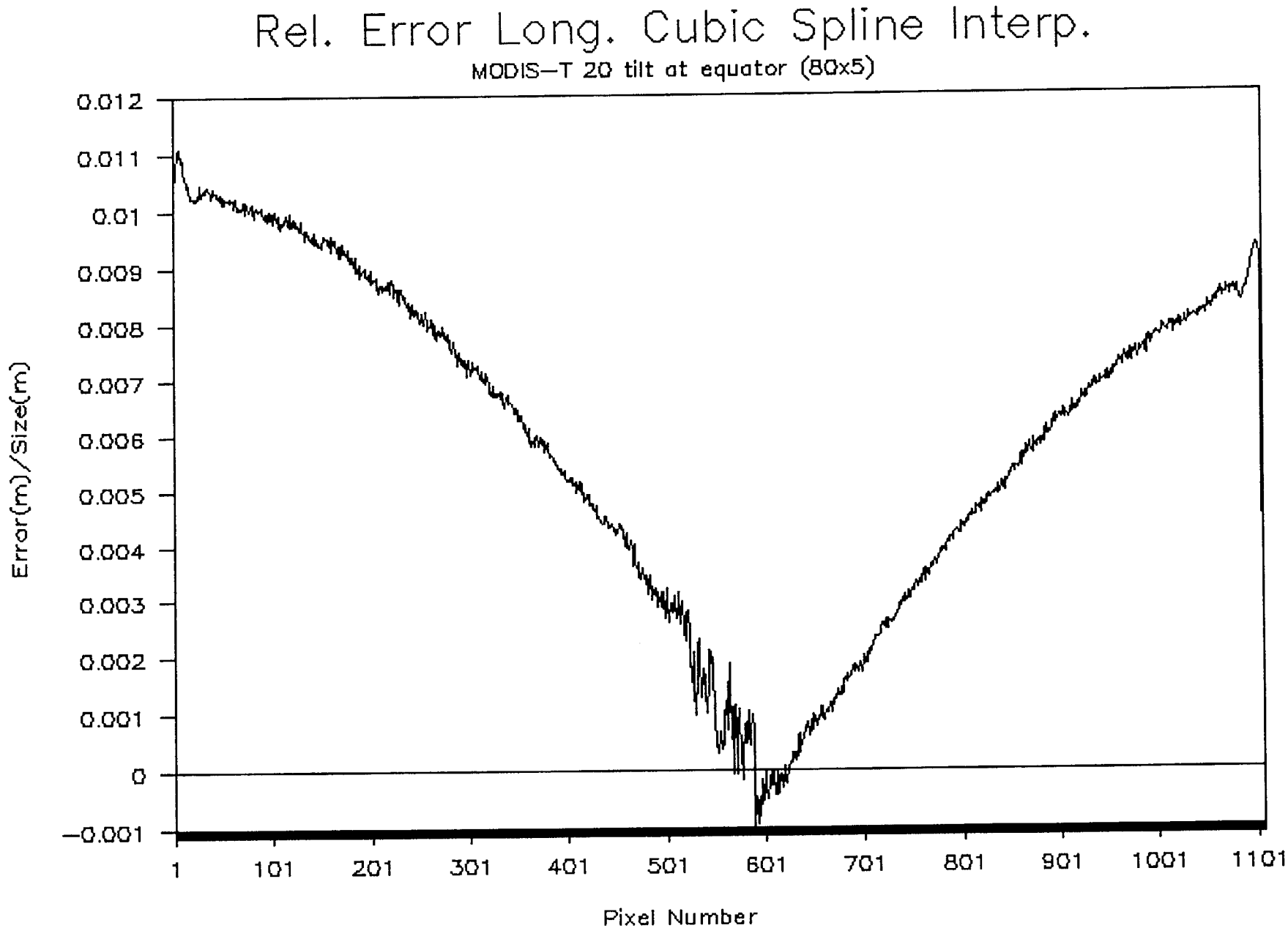
Rel. Error Long. Cubic Spline Interp.
MODIS-T 20 tilt at equator (80x5)
Error(m)/Size(m)
0.012
0.011
0.01
0.009
0.008
0.007
0.006
0.005
0.004
0.003
0.002
0.001
0
-0.001
1
101
201
301
401
501
601
701
801
901
1001
1101
Pixel Number

Figure 3d.

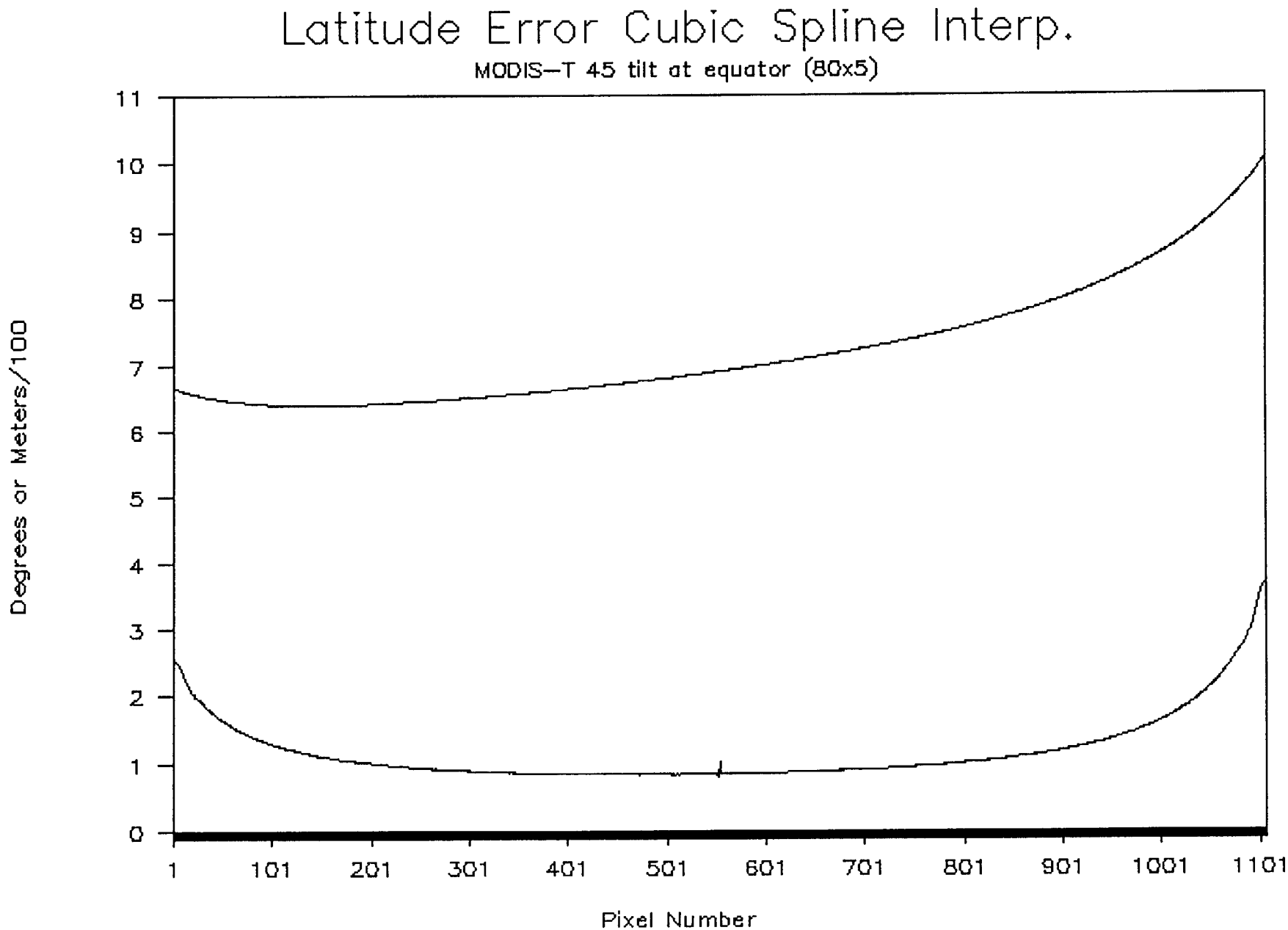
Latitude Error Cubic Spline Interp.
MODIS-T 45 tilt at equator (80x5)
Degrees or Meters/100
0
1
2
3
4
5
6
7
8
9
10
11
1
101
201
301
401
501
601
701
801
901
1001
1101
Pixel Number

Figure 4a.

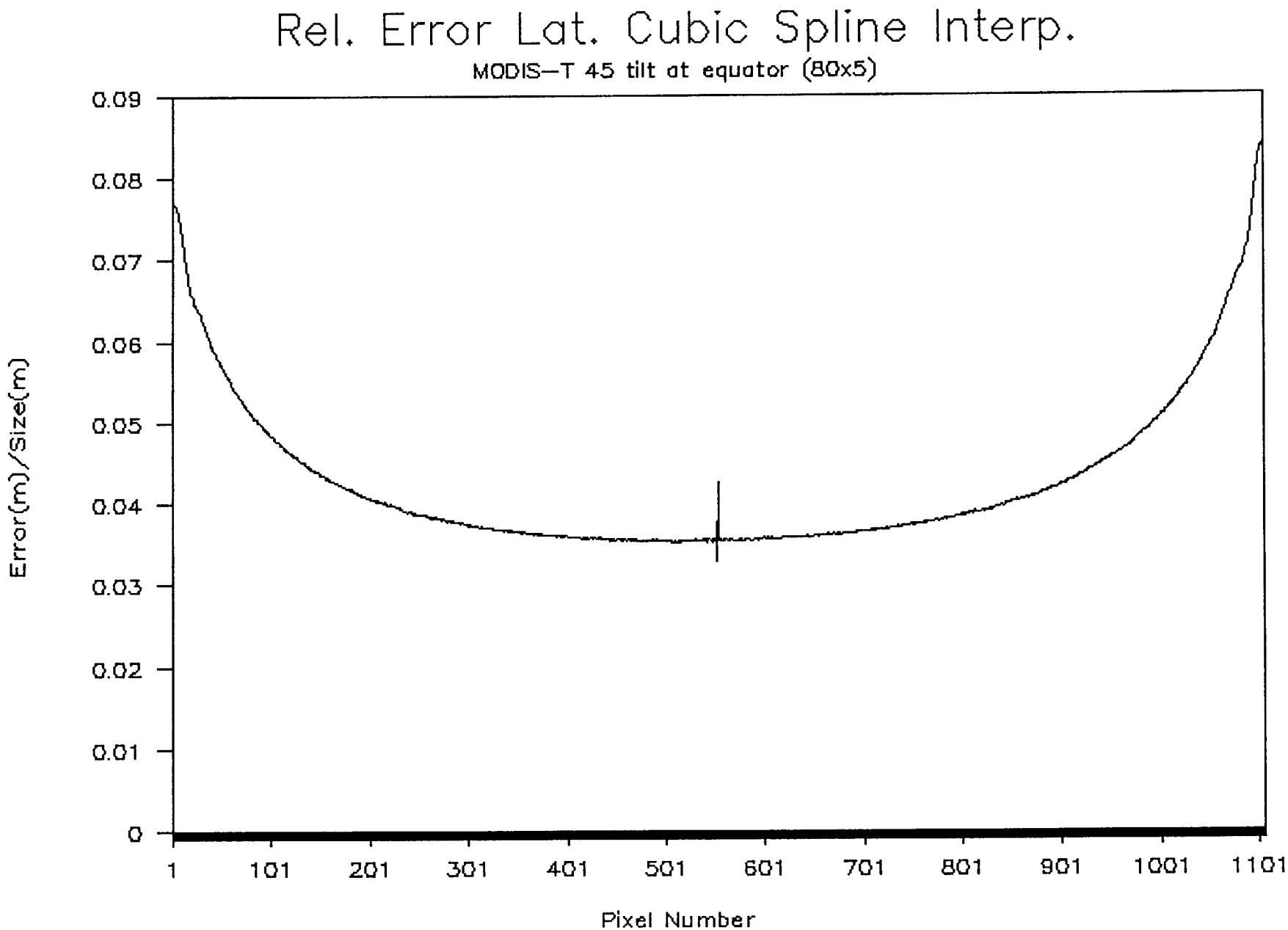
Rel. Error Lat. Cubic Spline Interp.
MODIS—T 45 tilt at equator (80x5)
Error(m)/Size(m)
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1
101
201
301
401
501
601
701
801
901
1001
1101
Pixel Number

Figure 4b.

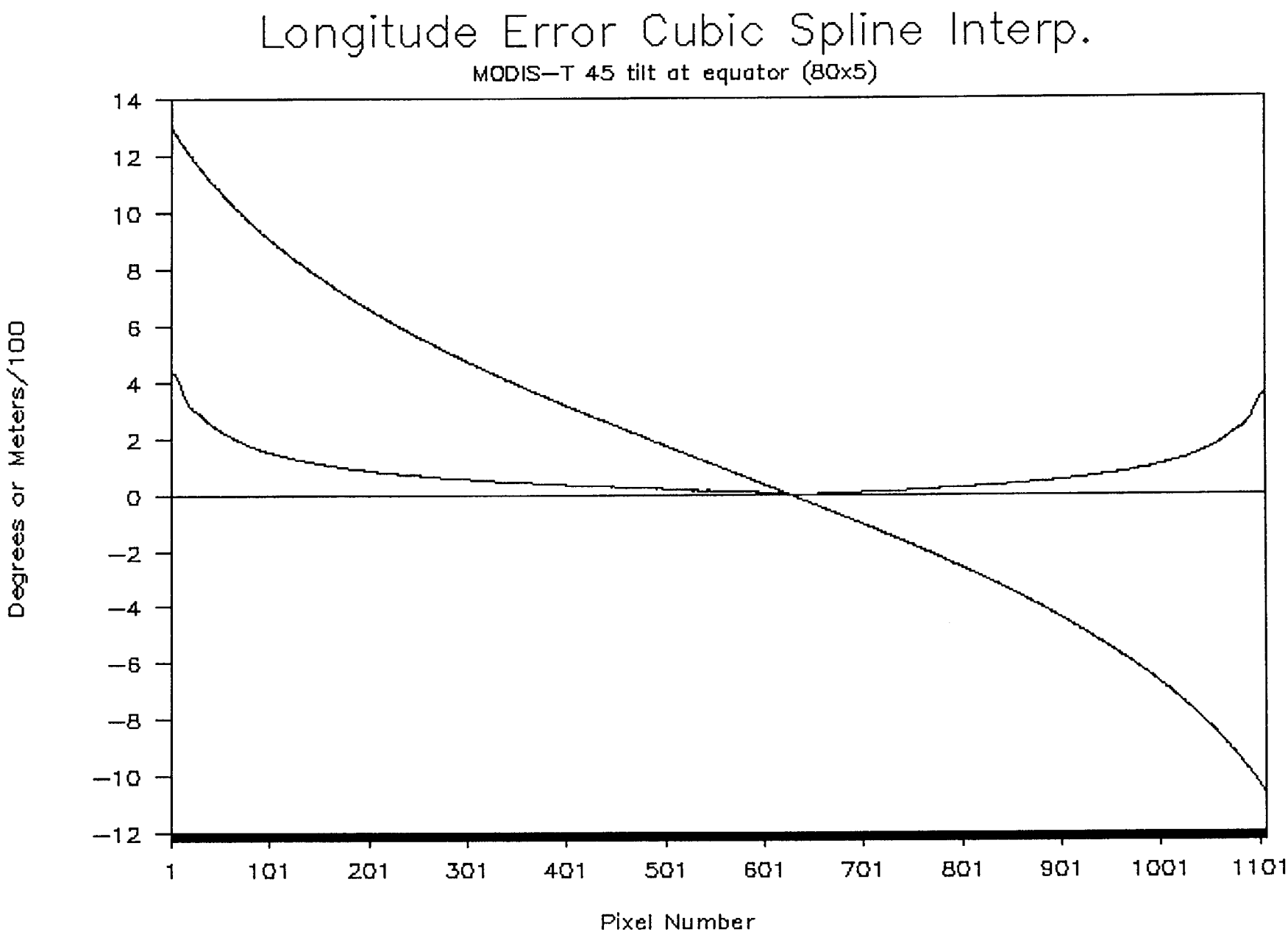
Longitude Error Cubic Spline Interp.
MODIS—T 45 tilt at equator (80x5)
Degrees or Meters/100
14
12
10
8
6
4
2
0
−2
−4
−6
−8
−10
−12
1
101
201
301
401
501
601
701
801
901
1001
1101
Pixel Number

Figure 4c.

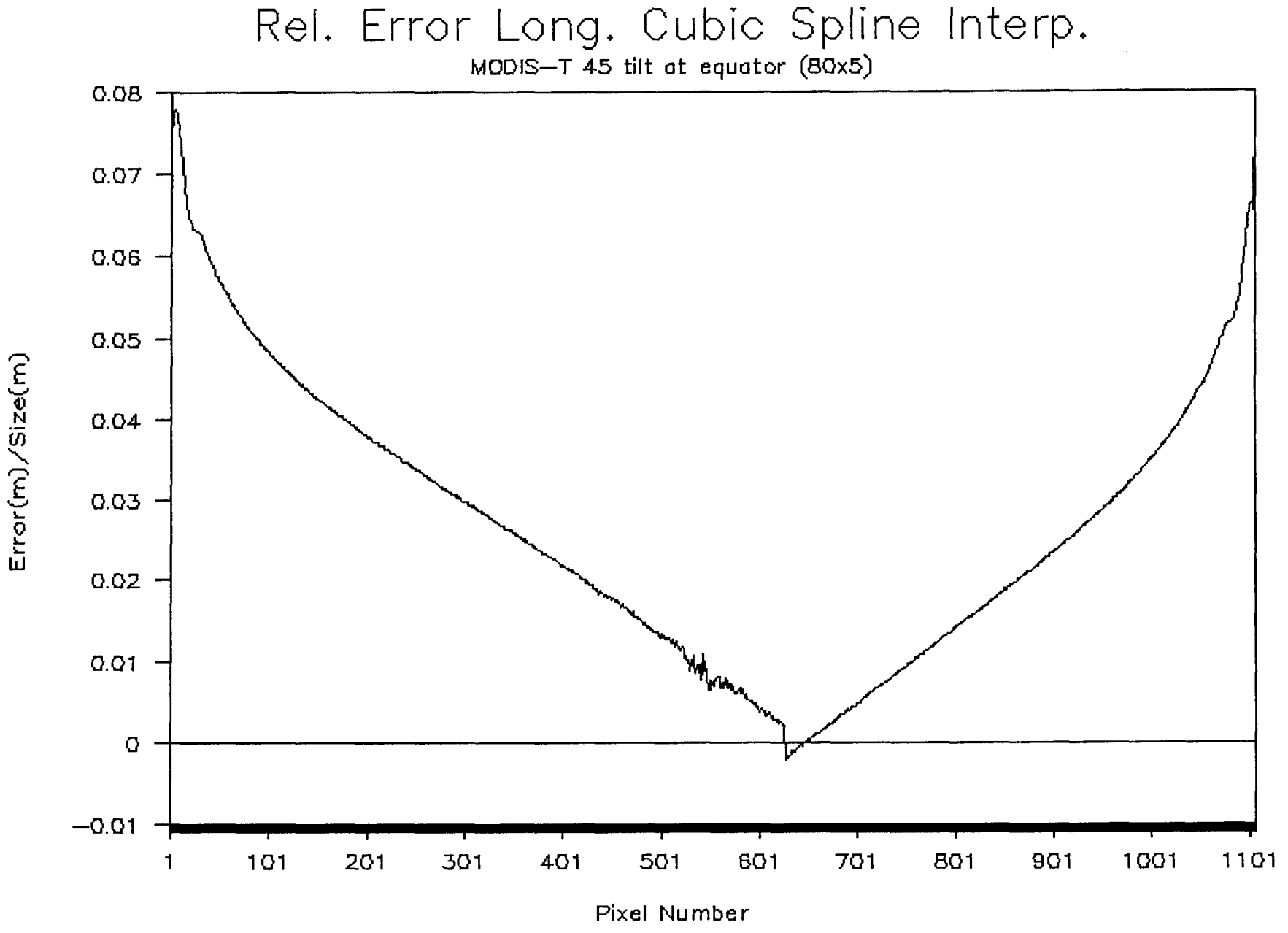
Rel. Error Long. Cubic Spline Interp.
MODIS—T 45 tilt at equator (80x5)
Error(m)/Size(m)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
−0.01
1
101
201
301
401
501
601
701
801
901
1001
1101
Pixel Number

Figure 4d.

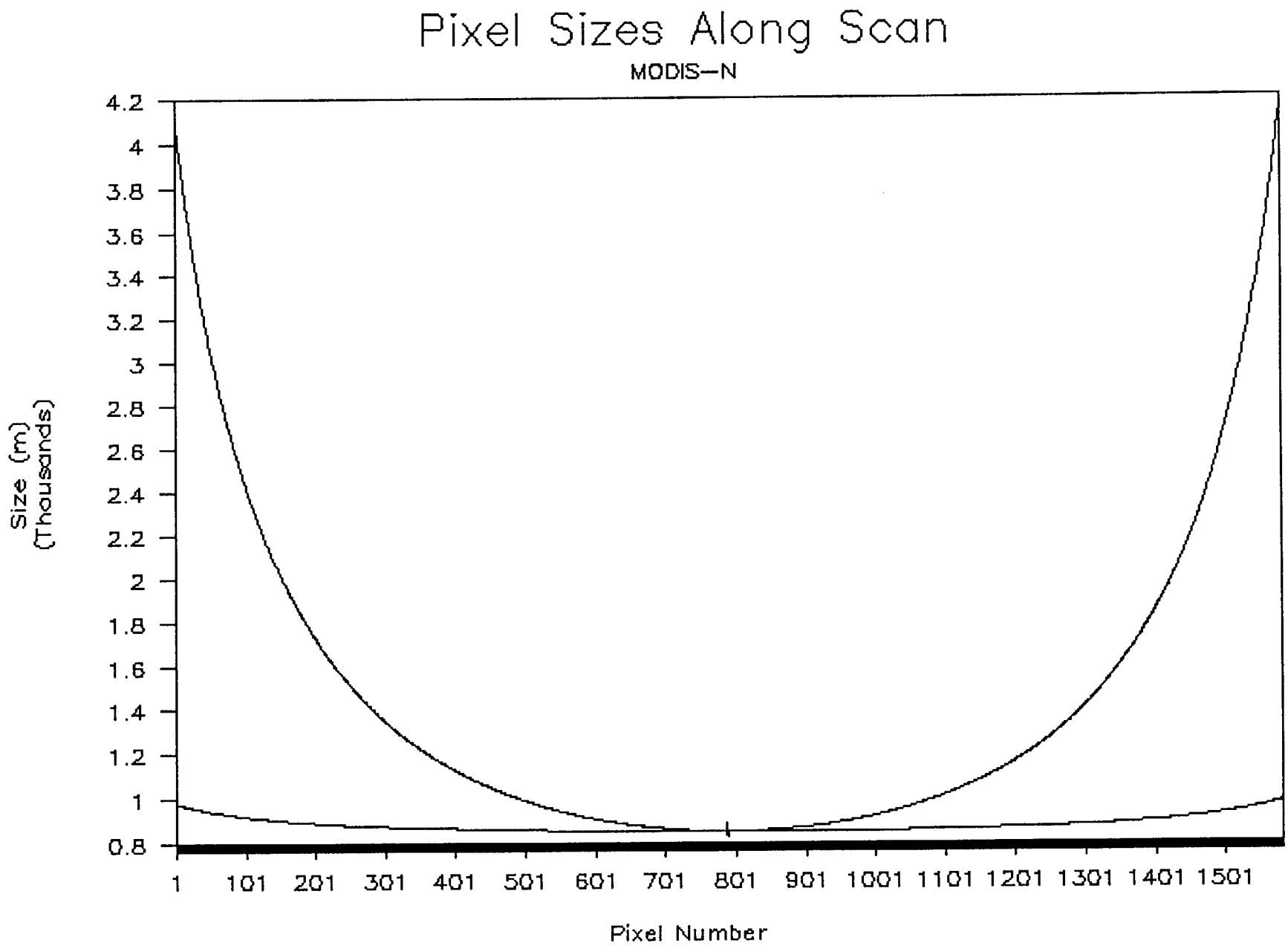
Pixel Sizes Along Scan
MODIS-N
Size (m)
(Thousands)
4.2
4
3.8
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
1
101
201
301
401
501
601
701
801
901
1001
1101
1201
1301
1401
1501
Pixel Number

Figure 5a.

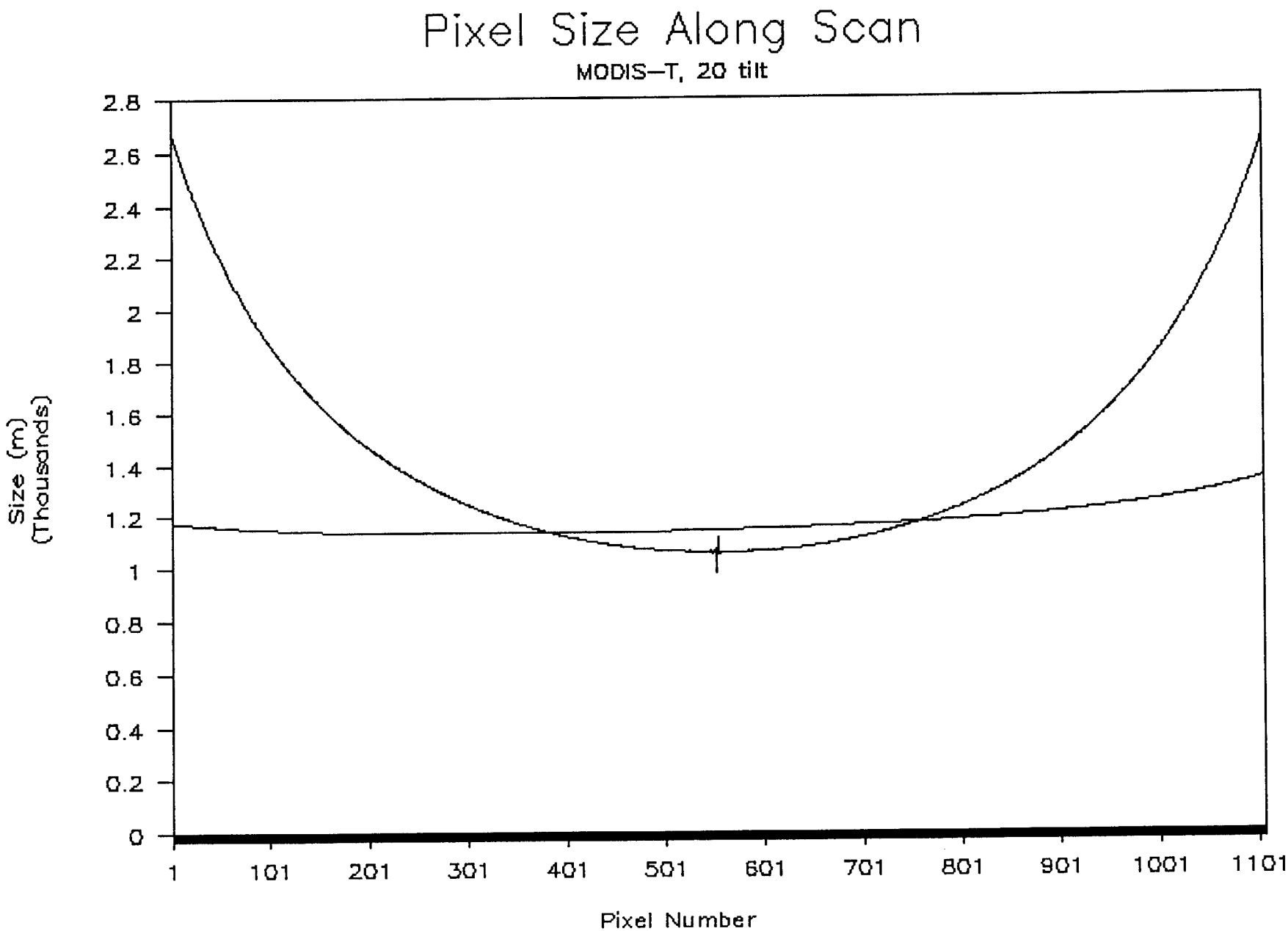
Pixel Size Along Scan
MODIS–T, 20 tilt
Size (m)
(Thousands)
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
101
201
301
401
501
601
701
801
901
1001
1101
Pixel Number

Figure 5b.

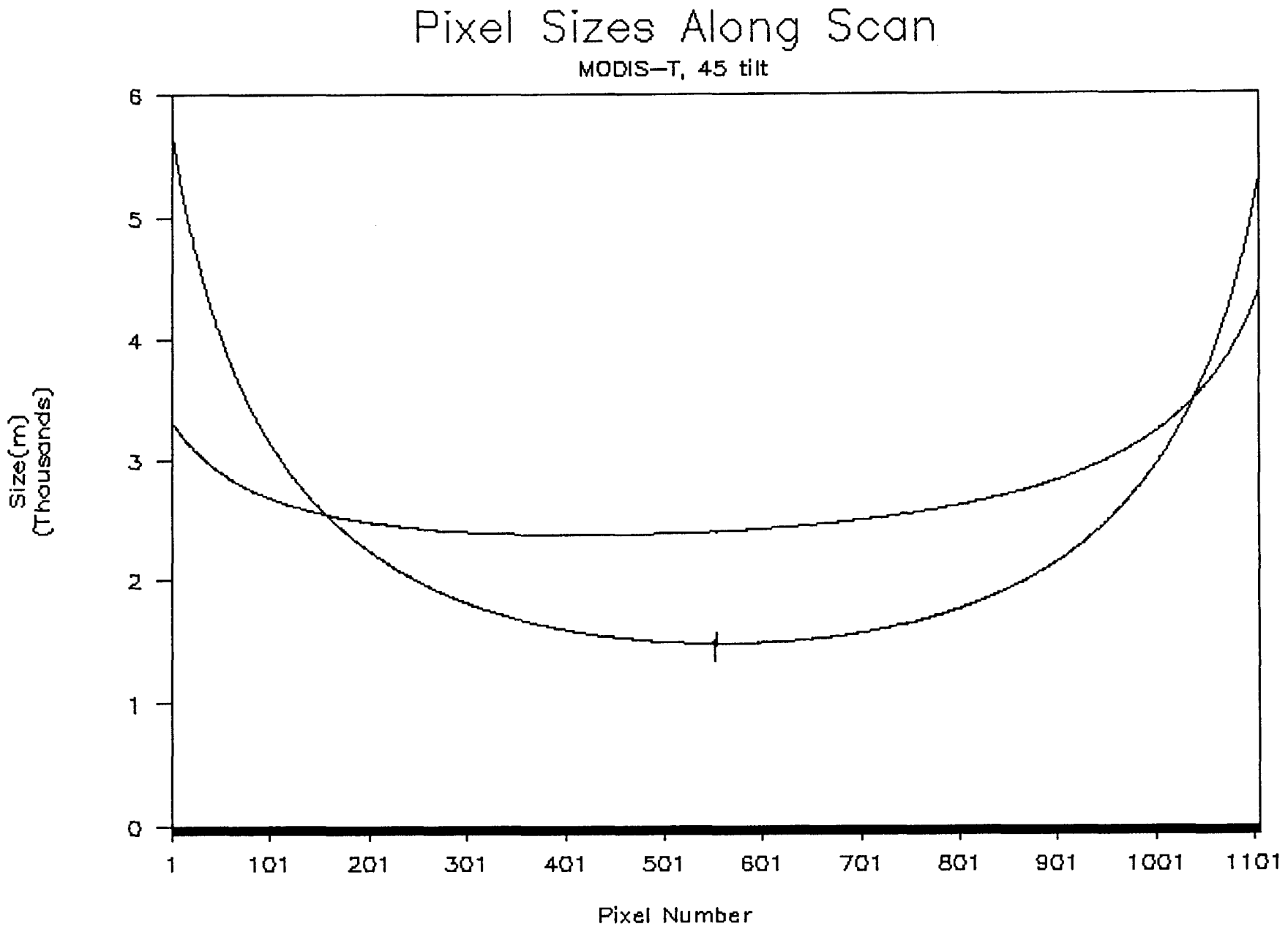
Pixel Sizes Along Scan
MODIS–T, 45 tilt
Size(m)
(Thousands)
0
1
2
3
4
5
6
1
101
201
301
401
501
601
701
801
901
1001
1101
Pixel Number

Figure 5c.