MODIS DATA STUDY
TEAM PRESENTATION

June 16, 1989

AGENDA

1. Effects of Atmospheric Refraction on Earth Location Determinations
2. Evaluation of Presently Available Digital Elevation Models.
3. MODIS Input Data Attributes Document Outline.
4. Error Checking by CDOS; GPS/FDF Role.
5. GPS for Position and Attitude Determination.
6. Ocean Color: Availablitly of the Global Data Set.

EFFECTS OF ATMOSPHERIC REFRACTION ON EARTH LOCATION DETERMINATIONS FOR MODIS

One requirement on the MODIS experiment is that pointing accuracy will be determined to an accuracy of a tenth of a pixel. For the 840 meter channels, this requirement means that any pixel must be located on the Earth to within 0.084 kilometers.

If MODIS were viewing the Earth's surface through a vacuum, pointing accuracy would be only a function of geometry requiring knowledge of time, the NPOP-1 state vector, and digital elevation models. However, since the Earth has an atmosphere and the index of refraction of the atmosphere is not one, but ranges from 1.0002982 to 1.0002726 in the 0.4 to 14.2 micron wavelength range, the light rays in the atmosphere will be bent, causing further uncertainty in the pointing. The atmosphere acts like a lens, with pixels appearing further from the center of the field of view than they actually are. The path rays can be bent as much as 0.025 degrees for a slant path of 55 degrees. Although this seems small, in fact, a portion of the Earth viewed at this angle will appear to be about 4 kilometers further from nadir than it would be if no atmosphere existed.

The atmospheric refraction effect has been calculated many times since Bemporad first did it in 1904. The purpose of these calculations have generally been to calculate the air mass through which one transverses in viewing the sun. The mathematics of that problem is very similar to the present problem, except that the satellite is 705 kilometers above the Earth whereas the sun is much further away. The radius of the Earth is 6371 kilometers so the satellite is 7076 kilometers from the center of the Earth. The angle of view between the nadir and the pointing of the satellite (scan angle) varies from 0 to 55 degrees. The effective scan angle with an atmosphere is from 0 to about 54.975 degrees. The location of any point observed on the Earth is 6371 kilometers from its center. The length of two sides of a triangle and one angle are known, both for the case of no atmosphere and for the case with an atmosphere. Using the law of sines and solving the geometry allows the difference in Earth location to be calculated for the two cases. The refraction perturbation in arc seconds is tabulated in Allen's Astrophysical Quantities (p. 125 of the 1973 edition). These perturbations are based upon earlier calculations such as those by Nefedeva (1968) and Landolt-Bornstein (1965). The perturbations in Allen's table are to the nearest arc second which is satisfactory for these preliminary calculations, but for MODIS operations, they will need to be repeated with better accuracy.

The lensing distortion by the atmosphere is dependent on atmospheric pressure and temperature so latitudinal and seasonal variations will occur. A simple correction formula based upon surface pressure and temperature is also given by Allen. For a normal sea level pressure of 1013.25 mb (760 mm Hg), variations in surface temperature from -10 to +30°C cause changes in apparent position of as much as about 0.7 km. at a 55 degree viewing angle

as shown in the accompanying figure. Thus the refraction correction will be dependent on latitude and on season. The changes are always such as to move the apparent location further from nadir.

Considering first the temperature dependency of the refraction correction, the figure shows the refraction correction in kilometers for scan angles between 0 and 55 degrees for 5 different atmospheres with surface temperatures between -10 and +30°C. Between about 0 and 20 degrees the curves in the figure go opposite to the curvature from 20 to 55 degrees. The curvature beyond 20 degrees is caused by the curvature of the Earth. As MODIS scans closer to 55 degrees the surface of the Earth bends away from the view so uncertainties in pointing become increasingly severe. At 64.2 degrees the tangent to the Earth would be viewed and the pointing errors would approach infinity. In the 0 to 20 degree scans, the pointing errors as a function of scan angle are changing much like it would for a flat Earth. The boxes for the atmosphere with -10°C (upper curve) have a vertical length of about 0.1 km., which is close to the required pointing accuracy. Beyond a scan angle of about 30 degrees, a 10°C change in surface temperature causes an apparent change in location of more than 0.1 km. Based upon Trewartha (1968) and the Handbook of Applied Meteorology (1985), between 1% and 5% of the Earth on any one day will deviate from its climatological mean by more than 10°C. Continental interiors in winter have the greatest variability in temperature. To maintain the desired pointing accuracy, a climatological model is sufficient for calculating the refraction correction at least 95% of the time. If a climatological model is used for surface temperature, it must be a function of both longitude and latitude since, at any specified latitude, the longitudinal variations in mean surface temperature exceed 10°C (e.g, Yearbook of Agriculture, 1941, p. 704).

Considering secondly the pressure dependency of the refraction correction, similar figures to one shown could be drawn for atmospheres with different surface pressures, but they would appear nearly the same. A 13 mb (10 mm Hg) change in surface pressure causes a change in apparent location of about 0.02 km. at a 30 degree scan angle, but can be as much as 0.06 km. at 55 degrees. On a monthly basis, only 1% of the locations on the Earth will have systematic departures of 13 mb or more (U. S. Standard Atmosphere, 1976). On a daily basis we estimate that about 5% of the Earth will have 13 mb or more departures from their climatological means. Normal meteorological variations in surface pressure at sea level will probably not cause refraction corrections of more than 0.08 km., except in rare cases, and thus can be neglected. Systematic variations in surface pressure caused by topography are another issue. Systematic differences of more than about 17 mb from the mean sea level pressure will cause a 0.08 km. apparent location change at a 55 degree scan angle. For a surface pressure change of about 60 mb and a 30 degree scan angle, an 0.08 km. apparent location change will also occur. These calculations imply that many locations above 600 meters in elevation will require use of their actual surface pressure rather than the sea level equivalent surface pressure. This conclusion,

in turn, implies that a simple digital elevation model is probably required as part of the refraction correction. A low spatial and low vertical resolution digital elevation model will probably be sufficient, but more work is required to define the nature of the model needed. Alternatively, a low resolution map of actual climatological mean surface pressure is probably adequate, and could be derived from a digital elevation model and maps of sea surface pressure.

Finally we consider the dependence of the refraction correction on wavelength. The plot is for an effective wavelength of 0.6 microns (i.e, the index of refraction equals 1.000292). Since the index of refraction varies with wavelength, the determination of correct Earth locations will also be wavelength dependent. As a rule of the thumb, dividing the distance corrections in the figure by 10 will give a good approximation of the difference in distance corrections between 0.4 microns and 14.2 microns. If one is concerned with deriving the color of the surface, some mixing will occur due to different degrees of refraction at different wavelengths. The effect is small and if the true color is varying slowly over the surface of the Earth as is most often the case, a single refraction correction for all wavelengths is probably sufficient.

In summary, the refraction correction can be calculated to the required accuracy for 95% of the MODIS pixels provided a 2 dimensional climatological model of surface temperature and pressure is available. The spatial resolution, temporal coverage (e.g, seasonal or monthly), temperature resolution, and pressure resolution for these climatological maps can be determined by further study.

References:

Allen, C.W., 1973. Astrophysical Quantities, The Althone Press, London, 310 pp.

Houghton, D.D.(ed.), 1985. Handbook of Applied Meteorology, John Wiley and Sons, Inc., N.Y., p. 118.

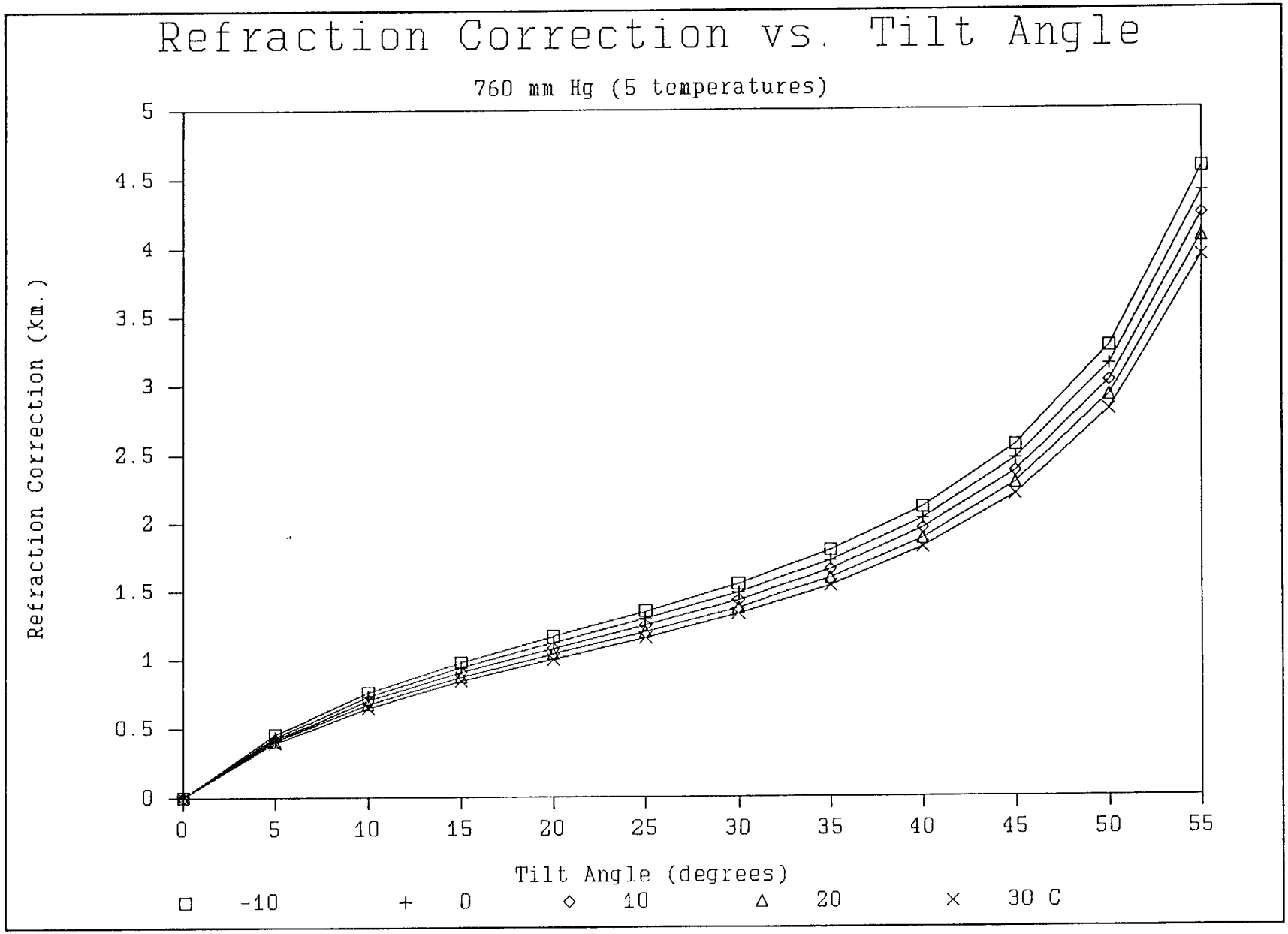
Landolt-Bornstein Tables, 1965. Vol. VI, No. 1, pp. 49, 52.

Nefedeva, A.I., 1968. Kazan. Iz., 36, p. 1.

Trewartha, G.T., 1968. An Introduction to Climate, McGraw-Hill Co., N.Y., p. 59.

USDA, 1941. Climate and Man, Yearbook of Agriculture, Washington, D.C., p. 704.

U. S. Standard Atmosphere, 1976. Washington, D.C., NOAA-S/T 76-1562, p. 25.


Refraction Correction vs. Tilt Angle
760 mm Hg (5 temperatures)
Refraction Correction (km.)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
0
5
10
15
20
25
30
35
40
45
50
55
Tilt Angle (degrees)
-10
0
10
20
30 C

EVALUATION OF PRESENTLY AVAILABLE DIGITAL ELEVATION MODELS

The following five plots were produced from the National Geophysical Data Center (NGDC) 5-minute Global Topography Database.

Figure 1 illustrates the topography of the entire Earth with a 500 meter vertical resolution. The data are subsampled every 30th point in latitude and longitude, providing an effective resolution of 2.5°.

Figure 2 presents the East Central United States, with a base contour of 10 meters and elevation increments of 100 meters. The relatively flat coastal plan and tidewater areas, the Piedmont Plateau, the rugged Appalachian Mountains, and the again relative flat Allegheny Plateau and Ohio Valley are clearly shown.

Figure 3 shows a portion of the central ice-cap of Greenland. Again, the contour interval is 100 meters. The surface begins to slope down to the coast to the southwest. This area is exceedingly flat and featureless. The step-like appearance of the contours suggests that full 5-minute resolution is not achieved here, with some repetion of adjacent elevations.

Figure 4 presents an area of central USSR with a contour interval of 100 meters. The valley of the Nizhnyaya Tunguska River extends from northwest to southeast across the plot, with a very flat plateau to the south and hilly terrain to the north.

Figure 5 depicts a portion of the Tibeton High Plateau with a contour interval of 500 meters. Peaks above 6,000 meters are seen, with up to 2,000 meters of relief.

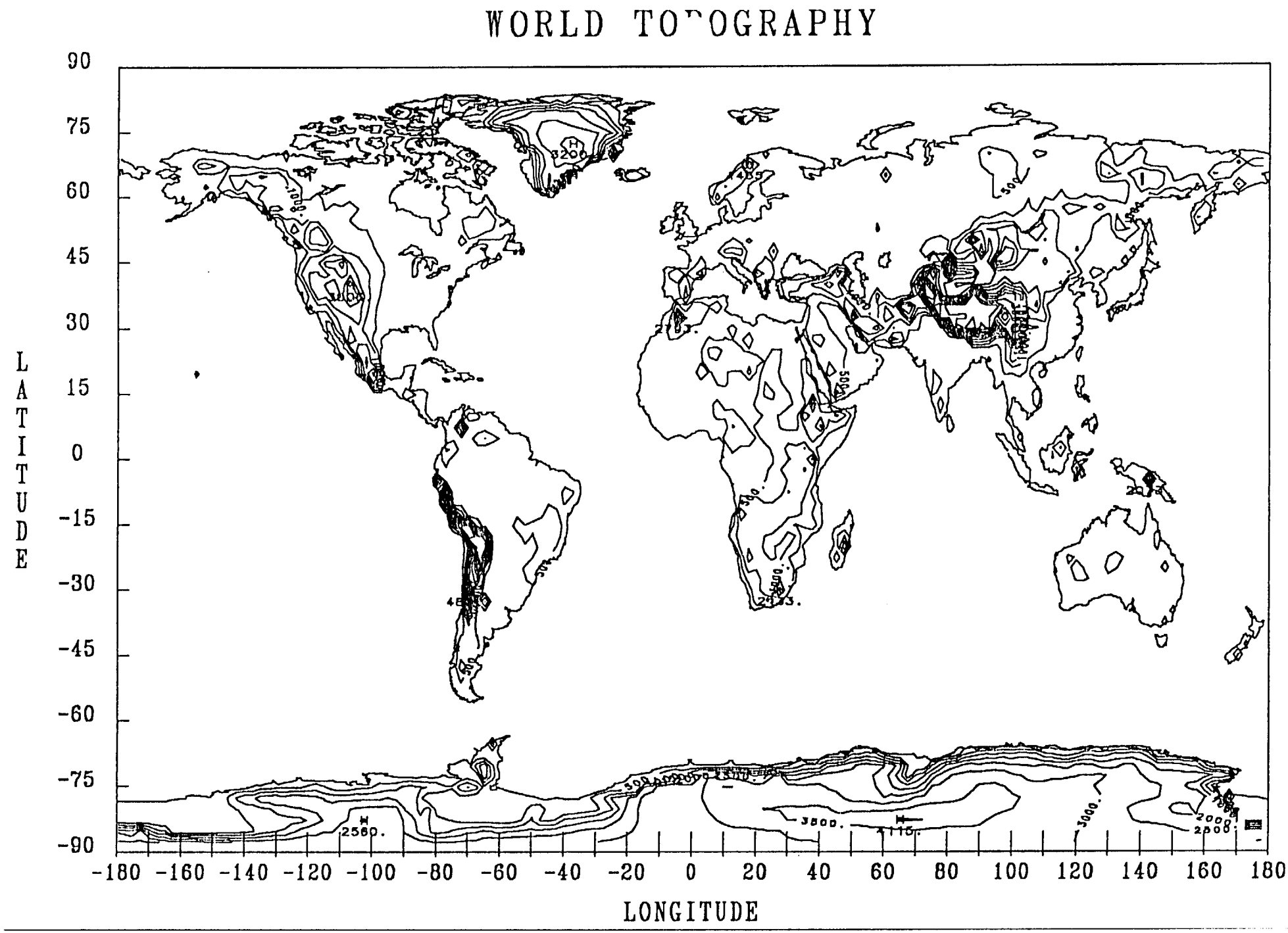

WORLD TOPOGRAPHY
LATITUDE
90
75
60
45
30
15
0
-15
-30
-45
-60
-75
-90
-180 -160 -140 -120 -100 -80 -60 -40 -20 0 20 40 60 80 100 120 140 160 180
LONGITUDE

Figure 1

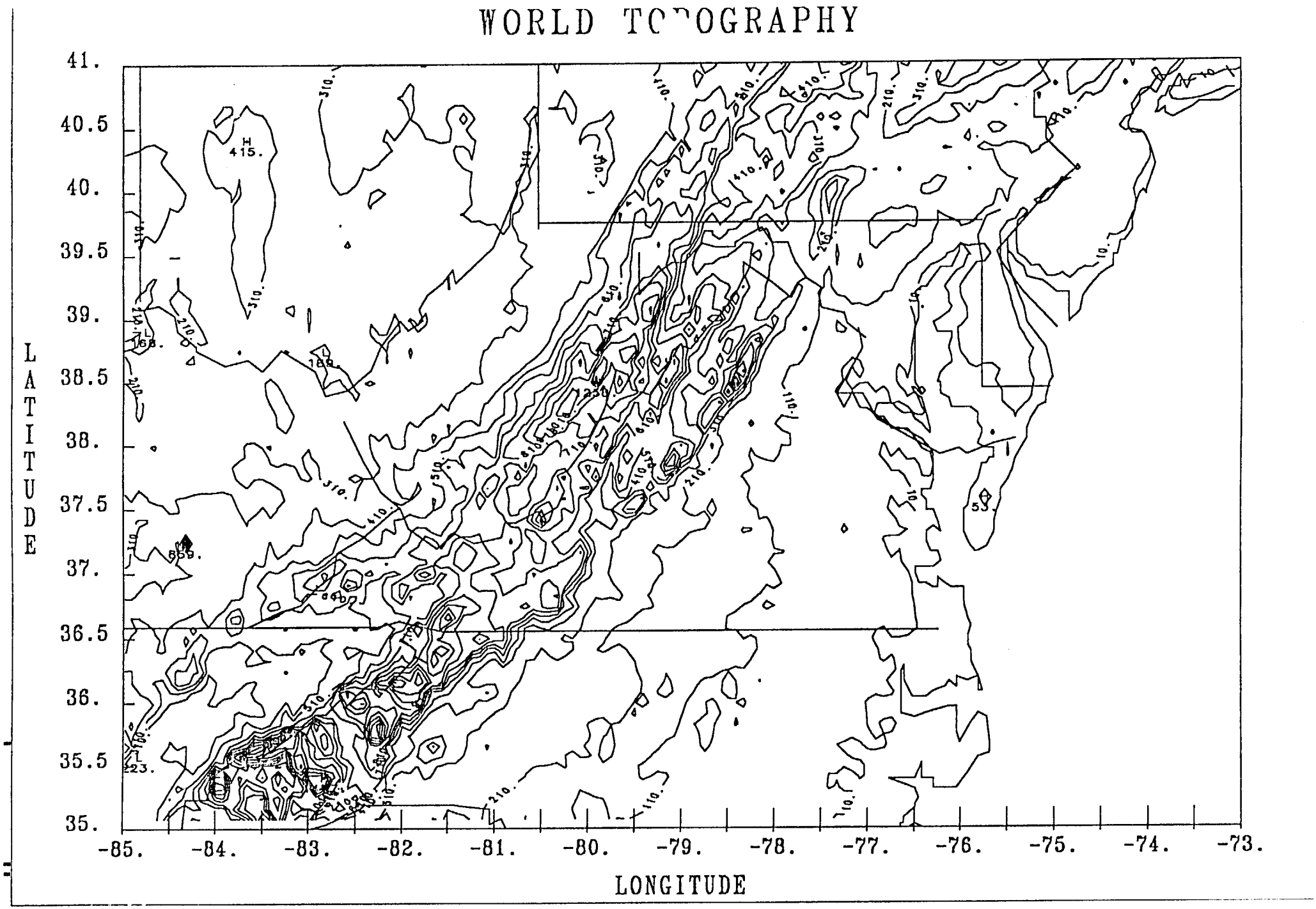

WORLD TOPOGRAPHY
LATITUDE
LONGITUDE
41.
40.5
40.
39.5
39.
38.5
38.
37.5
37.
36.5
36.
35.5
35.
-85.
-84.
-83.
-82.
-81.
-80.
-79.
-78.
-77.
-76.
-75.
-74.
-73.

Figure 2

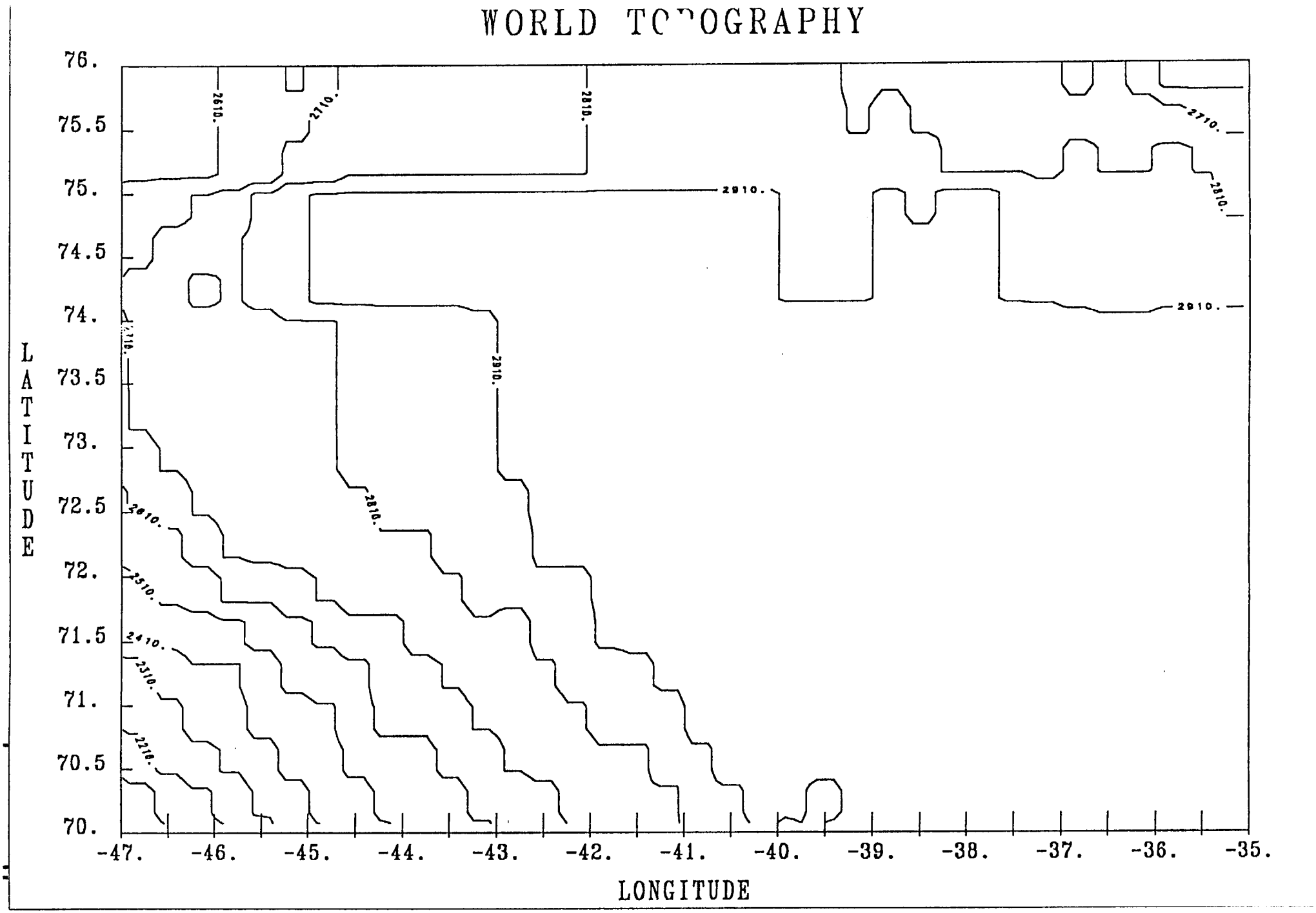

WORLD TOPOGRAPHY
LATITUDE
LONGITUDE
76.
75.5
75.
74.5
74.
73.5
73.
72.5
72.
71.5
71.
70.5
70.
-47.
-46.
-45.
-44.
-43.
-42.
-41.
-40.
-39.
-38.
-37.
-36.
-35.
2610.
2710.
2810.
2910.
2510.
2410.
2310.
2210.

Figure 3

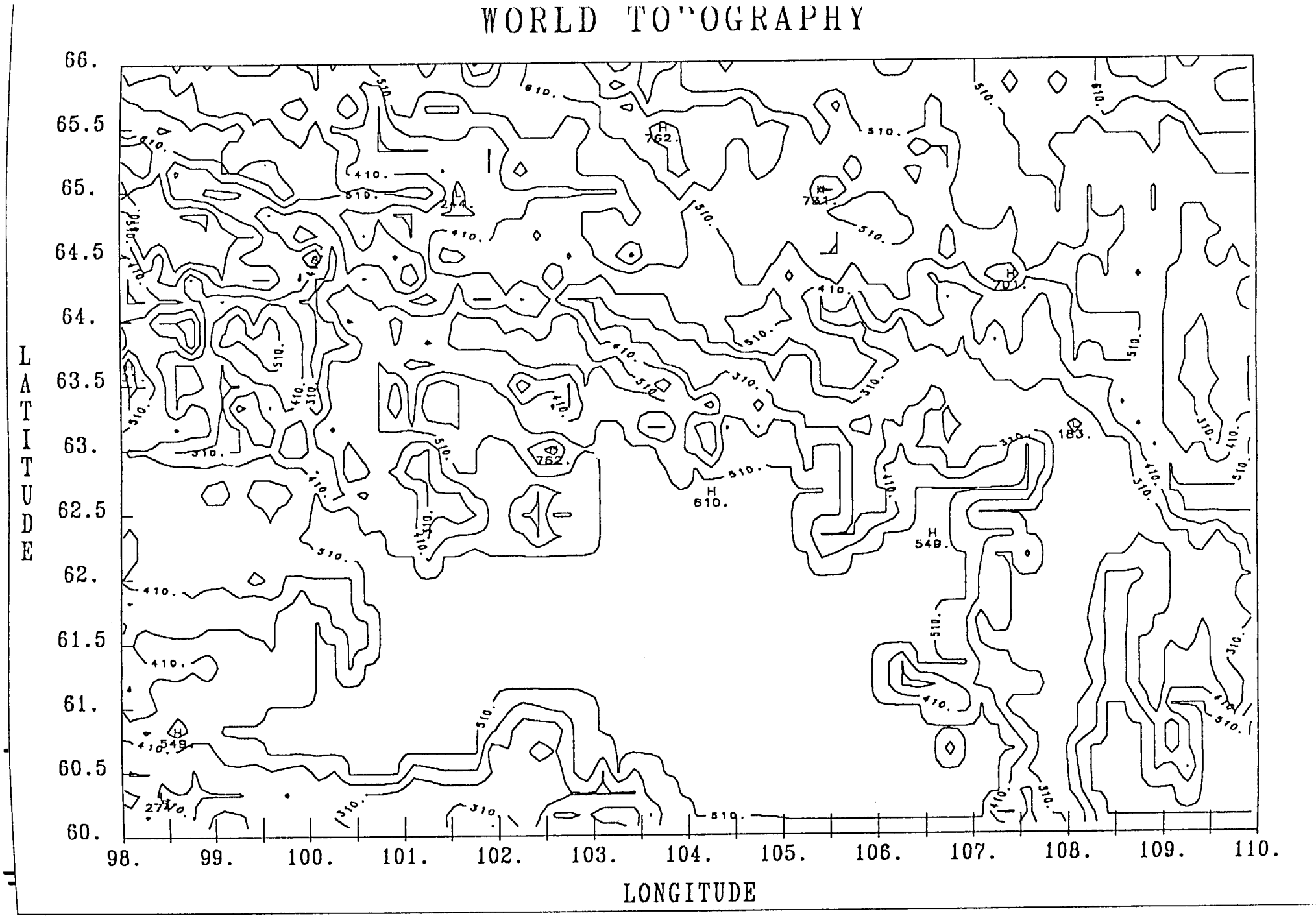

WORLD TOPOGRAPHY
LATITUDE
LONGITUDE
66.
65.5
65.
64.5
64.
63.5
63.
62.5
62.
61.5
61.
60.5
60.
98.
99.
100.
101.
102.
103.
104.
105.
106.
107.
108.
109.
110.

Figure 4

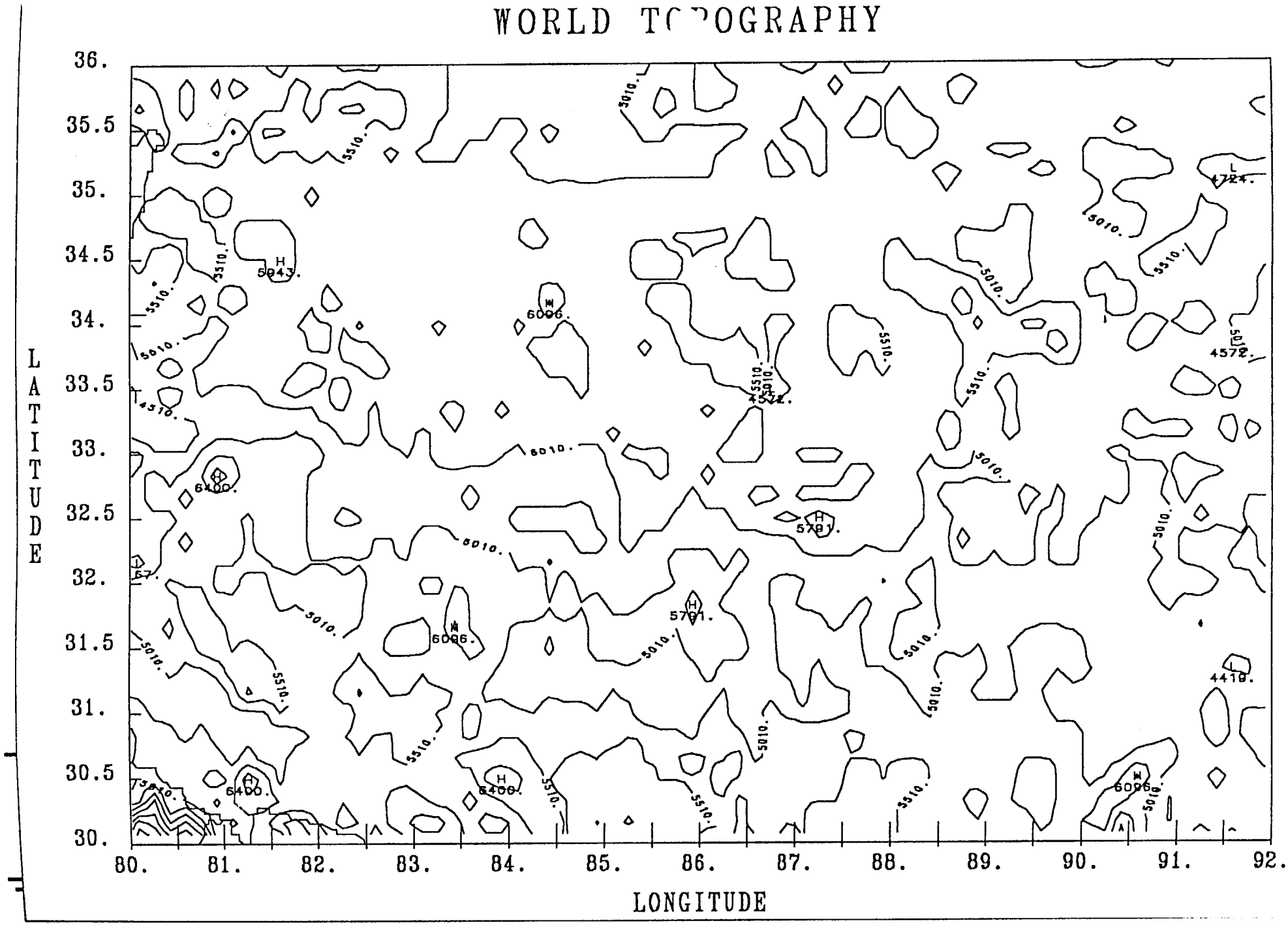

WORLD TOPOGRAPHY
LATITUDE
LONGITUDE
36.
35.5
35.
34.5
34.
33.5
33.
32.5
32.
31.5
31.
30.5
30.
80.
81.
82.
83.
84.
85.
86.
87.
88.
89.
90.
91.
92.
5010.
5510.
4510.
H
5943.
6096.
6400.
5791.
4572.
4724.
4419.

Figure 5

MODIS INPUT DATA ATTRIBUTES DOCUMENT OUTLINE

Purpose: To identify, quantify, and develop the set of attributes for all ancillary and auxiliary input data required to generate the proposed MODIS data products.

1. INTRODUCTION

2. MODIS DATA[1]

    2.1 Science
    2.2 Engineering
    2.3 Calibration

3. PLATFORM ANCILLARY DATA

4. NON-MODIS EOS SCIENCE DATA

    4.1 Algorithm Development

        4.1.1 NPOP-1
        4.1.2 Other Eos Platforms

    4.2 Routine Production

        4.2.1 NPOP-1
        4.2.2 Other Eos Platforms

    4.3 Validation

        4.3.1 NPOP-1
        4.3.2 Other Eos Platforms

5. NON-EOS DATA

    5.1 Algorithm Development

    5.2 Routine Production

    5.3 Validation

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[1]As with an earlier deliverable on data requirements, all data items will include a discussion of the following five key categories:
- o Description
- o Path
- o Requirements
- o Attributes
- o Impacts.

ERROR CHECKING BY CDOS

Error checking will be performed by both the DIF and DHC elements of the CDOS. This error checking appears to be a checking of an optional error detection code appended to the packet. It is used to verify that the overall integrity of the packet has been maintained during transmission. The DHC maintains an accounting of the error checks made for completeness of data. Error checking will be performed at the DIF for data downlinked through the TDRS and by the DHC for data passed through the Virtual Channel Gateway (VCGW). The DHC will not discriminate between the packet types for this error checking. Data will be retransmitted from temporary data stores (2-day stores) at the DIF and the DHC Another type of error checking is also performed by the DHC. This type is the quality checking of the ancillary data packets. This checking is performed by comparing a copy of the ancillary data or a derived product produced by the DHC to an FDF-generated reference profile. This quality check is a limit check against a specified sigma reference value. If ancillary data passes this quality check, nothing else is done; if ancillary data is out of tolerance, then the FDF may use CDOS-supplied information, such as raw attitude or orbit telemetry data, to refine/repair the ancillary data, repacketize it, and send it back to the DHC L0 processor as auxiliary data for inclusion into the ancillary data store.

GPS / FDF ROLE

GPS will provide for the autonomous position and velocity determination of platforms. This data will be made available to users as part of the ancillary data packet which is quality checked by the DHC/FDF. The role of the FDF in this process is to provide the reference profiles against which the ancillary data is checked and to refine and/or repair position and velocity data (and all other ancillary data) if necessary. The FDF will not routinely perform orbit determination unless specified for this process, such as to provide an independent source for orbit predictions. To repair and/or refine the position and velocity data, the FDF will obtain utility packets containing onboard-derived measurements made by the GPS or via scheduled TDRS tracking. The measurements will be made available by CDOS interfaces with the FDF.

GPS for
Position and Attitude Determination

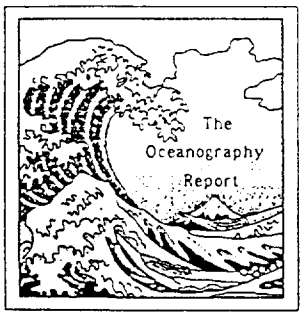
(Obtained from Mr. Ron Beard at NRL)

The second operational GPS satellite was successfully launched last week. Other previously launched satellites were test beds. The full constellation is expected be in place in 1992 or 1993. There will be six satellites in each of three orbital planes, with three to six on-orbit spares.

The general service will provide a position accuracy of 100 meters in three dimensions. The precise service, which will not be available at all times, will determine position to 10 meters. These are figures for a single observation. Continuous observations may produce more accurate positions.

Mr. Beard is currently leading a research effort to develop a GPS receiver for attitude determination. He expects to be able to determine attitude to an accuracy of at least 1 milliradian and 0.1 milliradians may been achieved. A tilt angle of 0.1 milliradians corresponds to a position shift of 70 m at an altitude of 705 km.

The Oceanography Report



The Oceanography Report: *The focal point for physical, chemical, geological, and biological oceanographers.*

Editor. Robin D. Muench, SAIC, 13400B Northrup Way, Suite 36, Bellevue, WA 98005; GTE Mail: R.MUENCH/OCEAN.

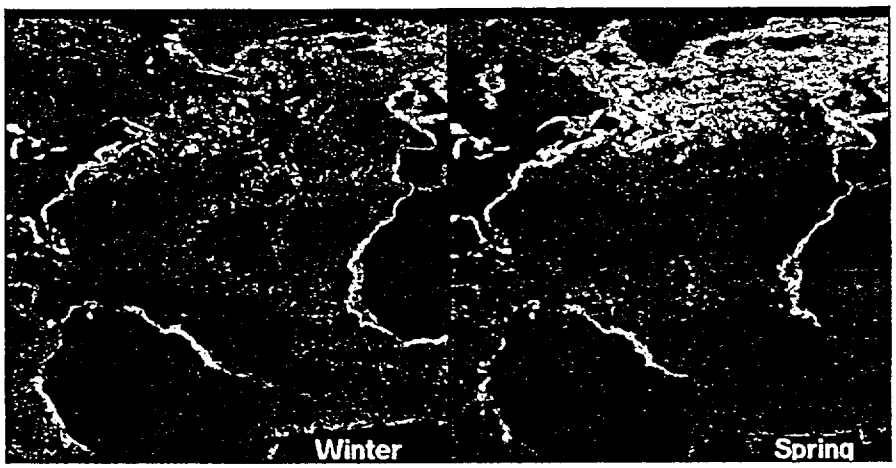


Plate 1. The development and intensity of the North Atlantic "Spring Bloom" are shown in these two seasonal composites of CZCS data acquired during the winter (January-March) and spring (April-June) of 1979 and 1980 (see Plate 2a for color scale). From the temperate regions to the poles the nutrient supply of the upper ocean is replenished through the deep vertical mixing driven by surface cooling and the intense winter storms. As the seasons progress from winter to spring, the amount of sunlight available for phytoplankton growth increases and the waters begin to stabilize. This period of rapid growth and accumulation of phytoplankton biomass in the upper waters is referred to as the "Spring Bloom."

Continuously high phytoplankton biomass in the coastal zones and major fisheries grounds is also seen. Despite the immense volume of data collected, large regions of the central Atlantic are still blank since the CZCS could operate only intermittently. A major focus for oceanographers in the next decade, as part of the Joint Global Ocean Flux Study (JGOFS) and the International Geosphere-Biosphere Program (IGBP), for example, is to understand the dynamics responsible for this global phenomenon and to place it in perspective with the atmospheric CO_2 increase and projected effects on climate.

Ocean Color

Availability of the Global Data Set

Overview

The National Aeronautics and Space Administration/Goddard Space Flight Center's Nimbus Project Office, in collaboration with the NASA/GSFC Space Data and Computing Division, the NASA/GSFC Laboratory for Oceans and the University of Miami/Rosenstiel School of Marine and Atmospheric Science, have undertaken to process all data acquired by the Coastal Zone Color Scanner (CZCS) to Earth-gridded geophysical values and to provide ready access to data products [*Esaias et al.*, 1986].

An end-to-end data system utilizing recent advances in data base management and both digital and analog optical disc storage technologies has been developed to handle the processing, analysis, quality control, archiving and distribution of this data set. A more complete description of this system, which has been fully operational for the past 2 years, is in preparation. The entire Level-1 data set (see Tables 1, 2) has been copied from magnetic tape to digital optical disc, and all data from the first 32 months (50% of the total scenes acquired, and covering the period November 1978 through June 1981) have been processed to Levels 2 and 3 and are now available for distribution. The remainder of the data set should be completed and released by fall 1989.

The central archive and distribution facility responsible for providing access to the entire CZCS data set is the National Space Science and Data Center (NSSDC) at NASA/GSFC. In addition, a number of academic and research institutions (see Table 3) have been established by NASA to serve as regional browse, distribution and analysis centers for Levels 1a, 2 and 3. These centers will soon have resident copies of all Level 1a and higher data, and the necessary hardware and software required for browsing, copying and reformatting the images. One of the most innovative aspects of this project has been the development of an analog optical disc browse and data order capability, which is expected to become widely distributed within the research and educational communities.

Background

Understanding the distribution of phytoplankton, the microscopic plants that grow in the upper, sunlit regions of the oceans, and which form the base of the marine food web, is critical for many branches of marine ecology and fisheries science. There is great uncertainty regarding the magnitude of oceanic production [*Ryther*, 1969; *Koblentz-Mishke et al.*, 1970; *Platt and Subba Rao*, 1975; *DeVooys*, 1979; *Berger et al.*, 1987], and the historical data sets do not permit reliable estimates of the large-scale temporal and spatial variability.

While the magnitude of carbon fixation in the ocean by photosynthesis is comparable to that occurring on land, the turnover rates and reservoir sizes are vastly different between the two regimes [*McCarthy et al.*, 1987; *GOFS*, 1984]. The rapid uptake of carbon dioxide by the photosynthetic phytoplankton and the subsequent sinking of a portion of the particulate organic carbon to the deep ocean is an important mechanism affecting the partitioning of carbon within global reservoirs.

To more fully describe the role of the ocean in the global carbon cycle, a better understanding of the temporal and spatial distributions of phytoplankton biomass and primary production, and a better understanding of the processes regulating the growth of phytoplankton and of the processes influencing the ultimate fate of this organically fixed carbon is required. Traditional shipboard sampling techniques are inadequate to meet these needs on a global scale. However, satellite observations of ocean color can address one of these needs by providing reliable estimates of marine phytoplankton biomass on synoptic scales which are useful in studies of phytoplankton processes.

Satellite Ocean Color

Variability in optical properties of the open ocean is determined primarily by variability in abundance of phytoplankton and their associated pigments. As the concentration of phytoplankton pigments increases, ocean color shifts from blue to green. Taking advantage of this change, NASA developed the Coastal Zone Color Scanner, which was launched on the Nimbus-7 satellite in October 1978 [*Hovis et al.*, 1980]. During its 7½-year lifetime, the CZCS acquired nearly 66,000 images, each covering up to 2 million square kilometers of ocean surface. This data set has now been processed with a consistent set of procedures and represents the most comprehensive source of ocean color measurements to date. It provides the first view of the distribution and abundance of phytoplankton over the global oceans based on observations approaching synoptic sampling and demonstrates the ability to monitor how these patterns change both in time and space (see cover and Plates 1–3).

Since the sensor was launched, processing, analysis and application of CZCS data has progressed from scene by scene studies to regional time series as a result of advances in algorithm and software development and computer technology. For ocean-basin- and global-scales the analysis has just begun. Preliminary work on basin-scale [e.g., *Esaias et al.*, 1986; *Platt and Sathyendranath*, 1988] and global-scale CZCS data underway at GSFC and the University of Miami, to be reported separately, demonstrate that large-scale composites contain useful and oceanographically valid information. This new perspective has broadened the scope of the questions that can now be realistically addressed.

Data Processing

The major components of the CZCS data processing system are outlined in Figure 1, and a much more comprehensive description of the procedures and algorithms used is being prepared and will be reported later. The first step in the processing involves transferring the full resolution Level-1 data from magnetic tape to digital optical disc. This conversion activity has reduced the volume of media required to store the data significantly (30,000 magnetic tapes in a warehouse have been reduced to three bookcases of optical discs adjacent to a computer workstation).

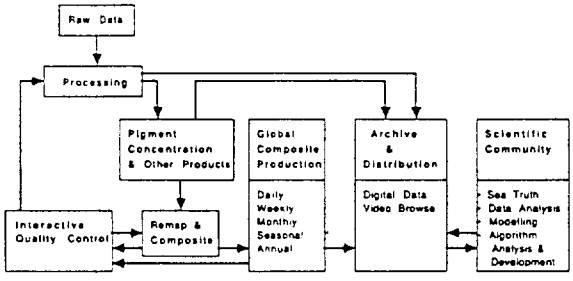


Figure 1. Coastal Zone Color Scanner data processing system overview.

Table 1. Definitions of Coastal Zone Color Scanner Data Products

	Definition
Level 1	Standard NASA CRTT format data containing calibrated radiances for all six CZCS channels, and Earth location information for a single CZCS scene (maximum 2 min of data) at full resolution (about 1 km) in swath projection.
Level 1a	Subsampled Level-1 data (every 4th pixel, every 4th line) in DSP (University of Miami) format for bands 1-5 (about 4 km).
Level 2	Derived geophysical parameters for a single CZCS scene in DSP format at about 4-km resolution and swath projection. The six derived products are Phytoplankton Pigment Concentrations, Diffuse Attenuation Coefficient, Normalized Water-Leaving Radiance (nlw440), Normalized Water-Leaving Radiance (nlw520), Normalized Water-Leaving Radiance (nlw550), and Aerosol Radiance at 670 (la670).
Level 3	Composited Earth-gridded (binned) data of the above-listed Level-2 parameters including compositing statistics binned to a fixed, linear latitude-longitude array of dimension 1024 × 2048 (about 18.5-km resolution at the equator). These files are stored in "compressed" form at daily, weekly (5-day, and monthly time intervals. Fields consist of those for Level 2 above, the standard deviations of the above, and numbers of valid level-2 pixels (n) and days (N), for a total of 14 fields. The daily products form the basic building blocks for all subsequent time/space averaging. Image file representations of these products can be produced but are not done so routinely nor are they proposed as archive products. Note that there are no routine film or hardcopy products.

APPLIED ENVIRONMETRICS OCEANOGRAPHIC TABLES

Dr. Tom Beer, author of the successful textbook, *Environmental Oceanography*, has produced a work, in a radical new format, that is designed to be the standard reference for commonly used oceanographic data. **The Applied Environmetrics Oceanographic Tables** comprise documentation plus a 5.25 inch MSDOS disk (requiring DOS2.10 or later plus at least 256K of RAM to run). The tables cover:

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- physical properties
- geodesy
- sunrise-sunset times
- waves
- dissolved gases
- ocean dynamics
- statistical tables
- tidal tables
- transport properties
- Beaufort scale
- blackbody radiation

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AUSTRALIA

Table 2. Volume of Coastal Zone Color Scanner Data Products

Data Type	Spatial Resolution, km	Total Scenes	Presently Available	Individual File Size, mbyte	Total Volume, gbyte
Level 1	1	67,789	67,789	12	813
Level 1a	4	66,000	66,000	0.7	48
Level 2	4	60,000	31,000	0.7	44
Level 3					
DAILYPST	20	2,800	960	4	11
DAILYCOMP*	20	2,800		28	78
WEEKLYPST	20	560	192	12	7
WEEKLYCOMP*	20	560		28	16
MONTHLYPST	20	93	32	26	2
MONTHLYCOMP*	20	93		28	3

*These image file products are not routinely produced nor archived. Only compressed files (PST) are archived.

Table 3. NASA-Sponsored Archive Sites

Institution	Principal Investigator (Contact)
Central Archive (Levels 1, 1a, 2, 3)	
NASA/GSFC Space Data and Computing Division	Gene Feldman Norman Kuring Carolyn Ng
Distributed Archives (Levels 1a, 2, 3)	
NASA/GSFC Laboratory for Oceans	Wayne Esaias Chuck McClain Jane Elrod Nancy Maynard
University of Rhode Island	Peter Cornillon Jim Yoder
Bigelow Laboratory for Ocean Sciences	Janet Campbell
University of Miami	Robert Evans Otis Brown Guillermo Podesta
University of South Florida	John Walsh Ken Carder Frank Muller-Karger
University of California at Santa Barbara	Ray Smith
Jet Propulsion Laboratory	Curtiss Davis Don Collins
Oregon State University	Mark Abbott
University of Washington	Mary Jane Perry David English

thereby making the data more accessible to scientists and reprocessing efforts. The images are then subsampled from 1-km resolution to 4-km resolution (Level 1a, see Table 1), thereby reducing the volume of data by a factor of 16. Level-1 (full resolution) data are still available from the NASA/GSFC archive for those investigations that require it.

The generation of derived geophysical parameters from the Level-1a data incorporates our latest understanding of sensor degradation and calibration developed by the coauthors at the University of Miami. In addition, the processing procedures make use of satellite-derived ozone concentrations from the Total Ozone Mapping Spectrometer (TOMS) on Nimbus-7 [*Krueger et al.*, 1980] to correct for Chappieu band absorbance errors of the type reported by *Andre and Morel* [1989], as well as masks to eliminate data severely impacted by cloud ringing (sensor recovery from saturation downscan from bright targets) and sunglint.

The six derived geophysical products (Level 2, see Table 1) are computed, archived and then binned to a fixed, linear latitude-longitude array of dimension 1024 lines by 2048 pixels (about 20-km resolution at the equator). All the images acquired on a given day are binned (averaged) to produce composite files for 14 parameters at daily intervals (see Table 1). Each individual 2-min scene that is contained within the daily composite is then evaluated during the quality control phase. The prime criterion in this screening has been to produce reliably processed pigment fields, which at times sacrifices water-leaving radiance and aerosol radiance data. About 8.6% of all the scenes screened to date were flagged as containing such unreliable data, along with the reason for that determination, and are not included in the subsequent global composites. They are, however, still available from the archive as Levels 1, 1a and 2.

For the scenes that pass the quality control step, composites of derived geophysical parameters at daily, weekly (5-day), monthly, seasonal and annual time scales are produced, including all the relevant compositing statistics. All the archive products are stored on optical disc, making subsequent retrieval, analysis and distribution more convenient. The processing and quality control procedures are linked through data base control, producing a comprehensive and consistent data base for all CZCS holdings. Many duplicates and errors have thereby been eliminated. The data base entries also provide the framework for the browse, archiving and search operations.

It is appropriate at this point to briefly discuss two sets of caveats associated with this data set. The first relates to the algorithms that were used to process the data and the second to a potential bias associated with sampling and compositing. The atmosphere contributes 80–90% of the total radiance received by the CZCS, and this must be corrected for before an accurate estimate of the water-leaving radiance (that portion of the signal used to compute phytoplankton-pigment concentration) can be made.

For the production of the global data set we have assumed a standard atmospheric aerosol type characterized by Angstrom exponents equal to zero. This aerosol correction is valid for most open ocean regions but undoubtedly has introduced errors in regions impacted by continental air masses (e.g., off Northwest Africa and eastern North Ameri-

TOR (*cont. on p. 640*)

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EOS

Transactions, American Geophysical Union
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Cover. Global phytoplankton distribution. This image is a composite of all Coastal Zone Color Scanner (CZCS) data collected during the first 32 months of the sensor's operation from November 1978 through June 1981. Producing it required processing 31,352 individual CZCS scenes (nearly 400 gigabytes of data and almost ½ of all data collected by the instrument through its 7½-year lifetime). Note that were areas of the Pacific Ocean that had not been sampled even once. The color code is identical to that used for the North Atlantic series (Plate 1 of accompanying article). Overall, the correspondence between pigment distribution and major physical processes in the ocean is readily apparent.

Some of the most notable features in the global ocean color image are the clear delineation of the equator through increased plant pigment abundance, and the differences between the equatorial Atlantic, Indian and Pacific oceans. Plankton concentrations are low in the central gyres (purple, deep blue), and tend to be high along coasts (yellow, orange and red). The coastal upwelling regions off NW and SW Africa, Peru-Ecuador, and the west coast of Central and North America are apparent. High concentrations in the central oceans at middle and high latitudes of the northern hemisphere are also evident and result from the spring bloom phenomenon and wind mixing. The composite shows the richness of the Arabian Sea resulting from upwelling during the Indian summer monsoon and wintertime convective overturning, and in the Southern Ocean, maxima associated with the ice edge and circumpolar current. Photo courtesy of Gene Feldman, NASA/GSFC, Space Data and Computing Division (Code 636), Greenbelt, MD 20771.

See "Ocean Color: Availibility of the Global Data Set," by Gene Feldman et al., page 634.

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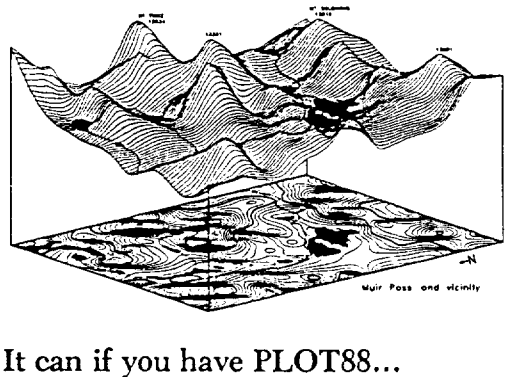

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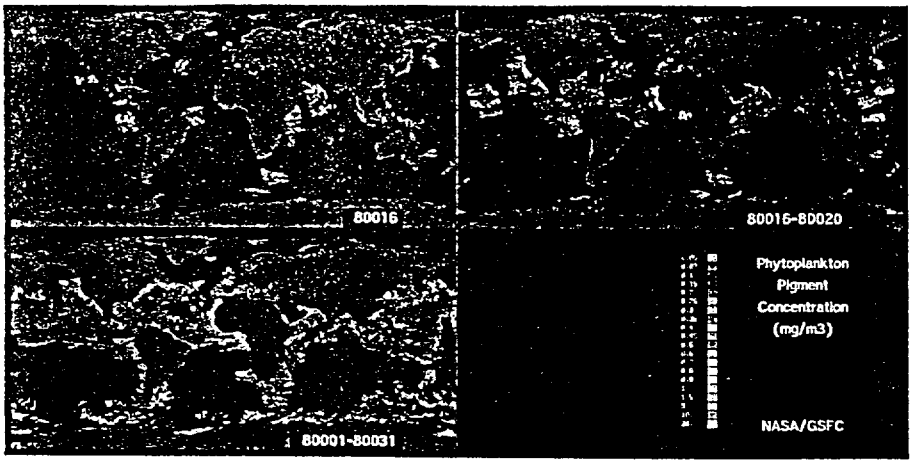

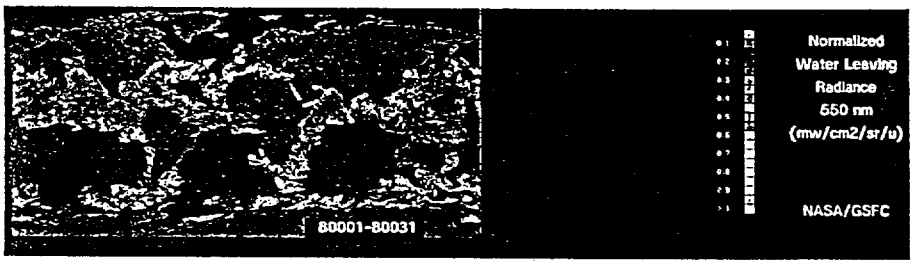

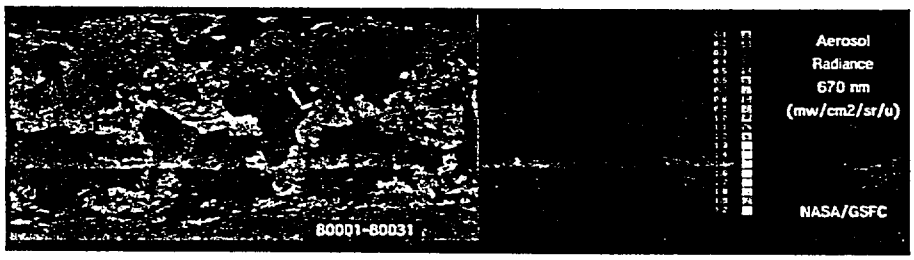

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Plate 2. Examples of Level-3 CZCS products. (*a*) A series of daily, 5-day, and monthly composites for pigment concentration for January 1980. (*b*) Monthly composite of normalized water-leaving radiance at 550 nm for January 1980. Water-leaving radiance at 550 nm is only slightly affected by pigment concentration, and most variations in this image result from scattering not directly correlated with pigment, such as from coccoliths, sediments and detritus. (*c*) Monthly composite of aerosol radiance for January 1980. Note that La670 is not normalized for sun angle and is simply the total at satellite radiance at 670 nm minus the Rayleigh radiance computed using a multiple scattering model with full polarization effects [*Gordon et. al.*, 1988]. High values near the subsolar latitudes (20°S) include some residual sunglint effects, while in areas removed from the subsolar latitude the effects are primarily due to aerosols. (*d*) Monthly composite of valid samples for December 1981 to illustrate the statistical count field of valid pixels within each fixed bin.

ca). Also, we have used a generalized relationship between water-leaving radiances and pigment concentrations [*Clark*, 1981] that was derived from CZCS validation cruises conducted primarily in coastal U.S. waters. Several regional studies, however, have demonstrated the validity of this relationship for other geographical areas [e.g., *Barale et al.*, 1986; *Feldman*, 1986]. As a result of the validation efforts, the estimation of near-surface phytoplankton pigment concentration from CZCS measurements of ocean color has been shown to be accurate to within 35% in Case 1 waters and within a factor of 2 generally [*Gordon and Morel*, 1983].

The number of daily valid chlorophyll measurements that went into a monthly composite image (Plate 2d) shows that sampling is highly skewed. The CZCS had a limited, 10% duty cycle, and coverage was not uniformly distributed around the world. In fact, there are regions where no valid data were collected at all during the 32 months of observations that were used to produce the image on the cover. Temporal sampling frequency also varies widely across the image which can also introduce errors that need to be considered for interpretation of the imagery as representative of a long-term mean.

Whereas the individual images or daily mosaics represent the best temporal resolution for resolving individual features, it is by compositing over progressively longer time scales (weeks-months) that a complete picture of the globe may be obtained. Many of the short-term features (e.g., blooms), or those that propagate over time (i.e., equatorial long waves, Gulf Stream rings), however, may lose their identity in the longer-term composites.

Archive and Distribution

One of the primary motivations behind the global CZCS data project was the desire to make the data readily available to the scientific community. A major impediment to routine use of satellite-derived observations has been the enormous volume of the data sets and the difficulty in quickly locating, acquiring and displaying the imagery. Most researchers have a relatively simple requirement: they want to know whether or not CZCS observations exist at a particular place and time, and then to see whether or not those observations contain information relevant to their particular research interest.

The CZCS browse program was designed to provide a researcher with the ability to quickly search the entire Level-2 CZCS data set and to instantly view pigment fields (browse images are at 4-km resolution; see Plate 3, for example) that meet the search criteria. If the researcher feels that a given scene warrants further investigation, the program provides for the generation of an order file which can be sent electronically to the NASA archive where the digital data are copied and sent to the requestor. A provision for on-line access to selected portions of the data set is also provided. As an example of the time required for browsing the data while running on an IBM-PC, a search, preview, selection, and generation of an order, covering all scenes within the first 18 months (263 images out of 21,000) covering station S off Bermuda was completed in less than 10 min.

In addition, the browse program provides the tools to study a subset of the Level-3 data on global (cover and Plate 2) or regional scales (Plate 1 is an example of the North Atlantic Region; other regions are centered around Australia, India, Japan, Mediterranean, Northeast Pacific and South America). The current version of the browse program allows the user to compare Level-3 pigment fields with coregistered images of water-leaving radiance at 550 nm, aerosol radiance, bathymetry, and the number of valid samples that went into each composite bin. The format allows for potential future incorporation of other correlative data fields such as sea surface temperature, sea level variability, wind fields, land vegetation patterns and in situ observations, thereby providing the researcher with the ability to address multidisciplinary questions.

Finally, researcher-specified "movie loops" can be generated so that temporal changes can be seen. The requirements for the browse facility are listed in Table 4. The browse software, without image display capability, represents a complete data base allowing for searches using up to 18 criteria, including time and location.

Costs for data follow general NASA policy, where the requestor is expected to bear the cost of media (when data on optical discs are requested, user provided discs are preferred) and duplication. Large-volume data requests will be evaluated on a case by case basis to avoid a major impact to other requestors. Orders from browse sites that are part of the Space Physics Analysis Network (SPAN) can be placed automatically by the browse program across the network. Other sites can use other electronic mailing procedures including telemail. An information sheet on the archive and distribution procedures, and a users guide and installation notes for the browse system are available from the authors.

Continued Observations Required

The oceans represent one of the greatest unknowns in our understanding of the Earth as a system of complex interrelationships, not only because of its size, but because of its incredible variability. Phytoplankton concentrations change very rapidly in time, and populations can double in one day or less. In order to study the processes that account for the spatial differences in ocean productivity evidenced here, and to explain year to year variations, and finally to help predict how the ocean responds to and impacts global (climate) change, scientists require continued satellite ocean color observations, coupled with ship and in situ investigations.

It is not clear how well the interannual variability of ocean productivity can be studied with the intermittent CZCS data, and it is obvious that coverage is insufficient in some regions for even the simplest process studies. The CZCS failed in June 1986 during its eighth year of operation (it had a design-life of 1 year). The earliest approved mission for an ocean color sensor appears to be the Ocean Color and Temperature Scanner (OCTS), scheduled for launch on the Japanese Advanced Earth Observation Satellite (ADEOS) in 1995. Following OCTS, the Moderate Resolution Imaging Spectrometer (MODIS) is proposed to fly on the U.S. Earth Observing System Polar Platform in 1997. The Sea-Viewing Wide Field-of-view Sensor (Sea-WiFS) proposed by NASA and EOSAT for launch on Landsat-6 in 1991 appears no longer viable, although alternatives are being discussed.

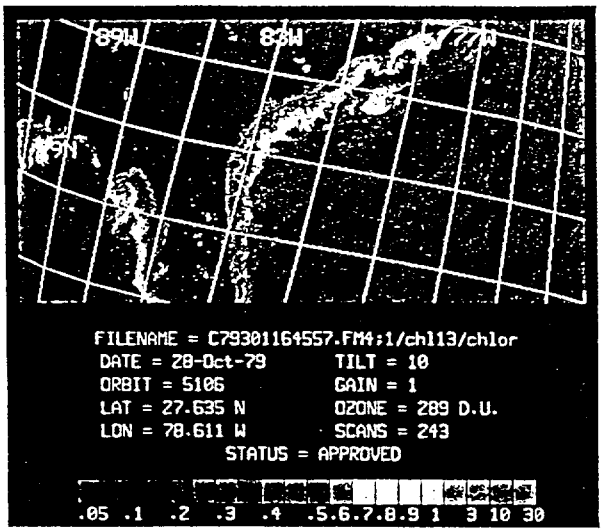

Plate 3. Example of a browse image of an individual Level-2 pigment scene (4-km resolution) for the southeast coast of the U.S. as it would be seen on the video screen of the browse utility. Note that ancillary information including a map grid is also shown on the monitor along with a color bar. The file name provides the starting acquisition time in year, date, hour, minute, second (YYDDDHHMMSS). Earth location and ozone values given here apply to the center pixel of the first (southernmost) scan line. Status refers to the outcome of the quality review and indicates that the valid data are included in Level-3 composites. An error code and reason is given for disapproved scenes. Nonvalid data (clouds and land) are colored gray.

Table 4. Requirements for the Coastal Zone Color Scanner Browse Facility

Facility	Requirements
Browse Program	The program that provides the search, display and order routines for the CZCS data set. Can be used in conjunction with the video disc to preview the images, or without it if desired.
Panasonic 8" Video Disc Player	Model TQ2024 (player) or TQ2025 (player/recorder) or Model TQ2027 (player) or TQ2026 (player/recorder).
Color Monitor	Any monitor capable of accepting video input will work.
Video Cable	Used to connect the video output on the player to the video input on the monitor.
Computer	VAX or Microvax IBM or compatible PC Apple Macintosh* Sun Workstation* PC systems need at least 10 mb hard disk. Need serial port to connect to Panasonic player. Should have ability to send Electronic mail to NASA. *Versions of the Browse program for the SUN and Macintosh should be available by summer 1989.
RS232 Cable	Used for computer control of the video disc player. NASA will provide the pin configurations for this cable.
Video Browse Discs	The entire CZCS video browse data set will reside on three 8" video discs.

Acknowledgments

This work has been funded by NASA's Oceanic Processes Branch and Flight Projects Branch of the Earth Observations Division; the support and encouragement of W. S. Wilson, J. W. Yoder, M. E. Lewis, and G. Esenwein is gratefully acknowledged. The assistance of A. Oakes, R. Garza-Robles, the Republic Management Systems (RMS), Landover, Md., operations support staff, as well as, J. Sissala and other General Electric, Landover, Md., personnel operating the Nimbus operations office at GSFC is greatly appreciated.

This article was contributed by Gene Feldman, Norman Kuring and Carolyn Ng, NASA/GSFC, Space Data and Computing Division, Greenbelt, Md.; Wayne Esaias, Chuck McClain, Jane Elrod, Nancy Maynard and Dan Endres, NASA/GSFC, Laboratory for Oceans, Greenbelt, Md.; and Robert Evans, Jim Brown, Sue Walsh, Mark Carle and Guillermo Podesta, University of Miami/Rosenstiel School of Marine and Atmospheric Sciences, Miami, Fla.

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Meeting Announcements

Ocean Remote Sensing of the Caribbean Basin

Call for Papers

January 28–31, 1990 Symposium on Ocean Remote Sensing of the Caribbean Basin, Mayaguez, Puerto Rico. Sponsors: Marine Sciences Department and Sea Grant Program, University of Puerto Rico, Mayaguez; NOAA; Caribbean Division of the AAAS. (Pablo Clemente-Colon, NOAA/NESDIS-/ORA E/RA13 SPC, Room 302, Washington, DC 20233; tel. 301-763-4244; P.CLEMENTE-.COLON/OMNET MAIL USA.)

Abstracts are due by July 10, 1989. Contributed abstracts should not exceed 300 words and should be sent, along with full names of authors, academic or professional affiliations and complete address of one of the authors via electronic or regular mail to Pablo Clemente-Colon.

Cosponsors of the symposium include the Interciencia Association, the AAAS Western Hemisphere Cooperation Program, the International Oceanographic Commission Caribbean Program (IOCARIBE), and other regional and international groups.

The program of this international symposium will cover present and future utilization of remote sensing technology for ocean and marine-related research and applications in the Caribbean region. The symposium will be divided into four nonconcurrent sessions, described below.

TOR (cont. on p. 644)

News (cont. from p. 636)

AIP Science Report

More than 500 radio stations are airing two-minute radio spots from the latest American Institute of Physics Science Report series. AIP released the 24th edition of its popular science broadcasts in May. The twenty new programs, developed by AIP, include seven about geophysics: lightning, snow glitter, geothermal energy, avalanches, the magnetometer, hurricanes, and northern lights. Each feature includes sound effects and narration by scientists; meteorologist Jo Anne Simpson talks about hurricanes, for example. AGU is one of AIP's ten member societies.

Los Alamos Offers Fellowships

Los Alamos National Laboratory in New Mexico is calling for applications for postdoctoral appointments and research fellowships. The positions are available in geoscience as well as other scientific disciplines.

The laboratory, which is operated by the University of California for the Department of Energy, awards J. Robert Oppenheimer Research Fellowships to scientists that either have or will soon complete doctoral degrees. The appointments are for two years, are renewable for a third year, and carry a stipend of $51,865 per year. Potential applicants should send a resume or employment application and a statement of research goals to Carol M. Rich, Div. 89, Human Resources Development Division, MS P290, Los Alamos National Laboratory, Los Alamos, New Mexico 87545 by mid-November.

Postdoctoral applications are considered throughout the year. The selection committee meets in February, May, August, and December. The renewable one-year positions are open to anyone who has completed a doctorate during the past three years, and have stipends of between $33,640 and $35,445. A resume, employment application, three letters of reference, graduate and undergraduate transcripts, and a statement of research interests should be sent to the above address.

NSF Deadlines

The National Science Board will hold its August meeting on the 18th in the Board Room of NSF. Parts of the meeting will be open to the public. Contact the Office of the National Science Board, 357-9582.

Deadline for receipt of nominations for the Alan T. Waterman Award is December 31, 1989. The award is presented annually to an outstanding young scientist, mathematician or engineer and will be presented in May 1990. Contact Lois Hamaty, National Science Board, 357-7512.

In addition, the National Science Foundation has set key deadlines for grants and proposals. Dates are subject to change; call the NSF staff person listed for more information (all numbers are in Washington, D.C., area code 202).

Proposals received after a *program deadline* are usually returned to the proposer. Proposals received after a *target date* will usually be reviewed at a subsequent panel meeting.

Program Deadlines

July 1, 1989
U.S.-New Zealand Cooperative Science Program. Proposals for joint research and seminars. Contact Carole Ganz, Division of International Programs, 357-9700.

July 15, 1989
Cooperative Science Program with Taiwan. Contact Alice Hogan, Division of International Programs, 357-7393.

August 4, 1989
Science and Technology Research Centers. Formal proposals. Brochure NSF 89–17 available from the Office of Science and Technology Centers Development, 357-9808.

August 21, 1989
Young Scholars Program. Contact Elmima Johnson, Division of Research Career Development, 357-7538.

September 15, 1989
Cooperative Science Activities with Austria, Germany, the Netherlands, Denmark, Finland, Norway, Sweden, the United Kingdom and Switzerland. Contact Christine French or Christine Glendav, Division of International Programs, 357-9700.

Target Dates

August 1, 1989
Studies in Science, Technology and Society, Ethics and Values Studies. Contact Rachelle Hollander, Division of Instrumentation and Resources, 357-9894.
History and Philosophy of Science and Technology. Contact Ronald Overmann, Division of Instrumentation and Resources, 357-9894.

August 15, 1989
Decision, Risk, and Management Science. Howard Kunreuther, 357-7569, or Robin Gregory, 357-7417, Division of Social and Economic Science.

September 1, 1989
Science in Developing Countries. North Africa and Turkey, Ed Field, 357-9402; East Asia, Gerald Edwards, 357-9557; South and West Asia, Osman Shinaishan, 357-9402; Latin America and Caribbean, Harold Stolberg or David Kelland, 357-7421, Division of International Programs.

Geophysicists

Donald R. F. Harleman, a professor of engineering at the Massachusetts Institute of Technology, has been elected to honorary membership in the American Society of Civil Engineers.

Two U.S. Geological Survey scientists have received Meritorious Service awards from the Interior Department, the agency's second highest honor. They are **Philip M. Bethke**, a geologist from Kensington, Md., and **Jesse McNellis**, a hydrologist from Lawrenceville, Kansas.

Mark David Kurz, a geochemist at Woods Hole Oceanographic Institution in Massachusetts, has won the 1988 Rosenstiel Award in Oceanographic Science from the University of Miami.

Edward Sudicky of the University of Waterloo, Ontario, Canada, will be working as a groundwater scientist for HydroGeologic, Inc., of Herndon, Va. from June-September 1989.

In memoriam

Gunnar Bodvarsson, 72, an AGU member since 1950 in the Volcanology, Geochemistry, and Petrology section, died on May 9, 1989.