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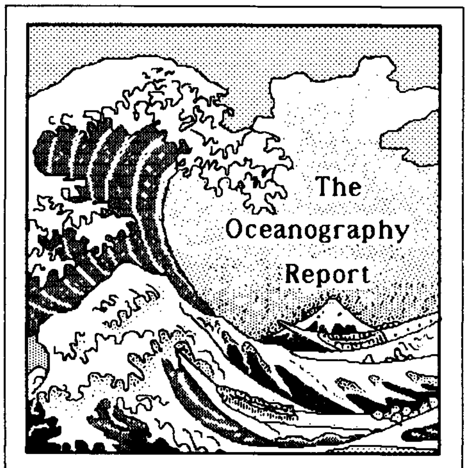

The Oceanography Report: *The focal point for physical, chemical, geological, and biological oceanographers.*

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Ocean Color

Availability of the Global Data Set

PAGES 634-635, 640-641

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

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.

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	Curtis Davis Don Collins
Oregon State University	Mark Abbott
University of Washington	Mary Jane Perry David English

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), 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.

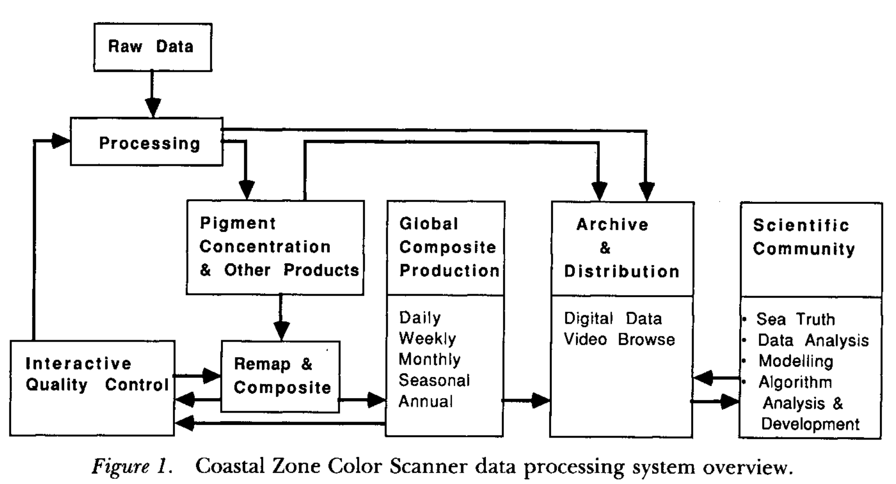


Figure 1. Coastal Zone Color Scanner data processing system overview.

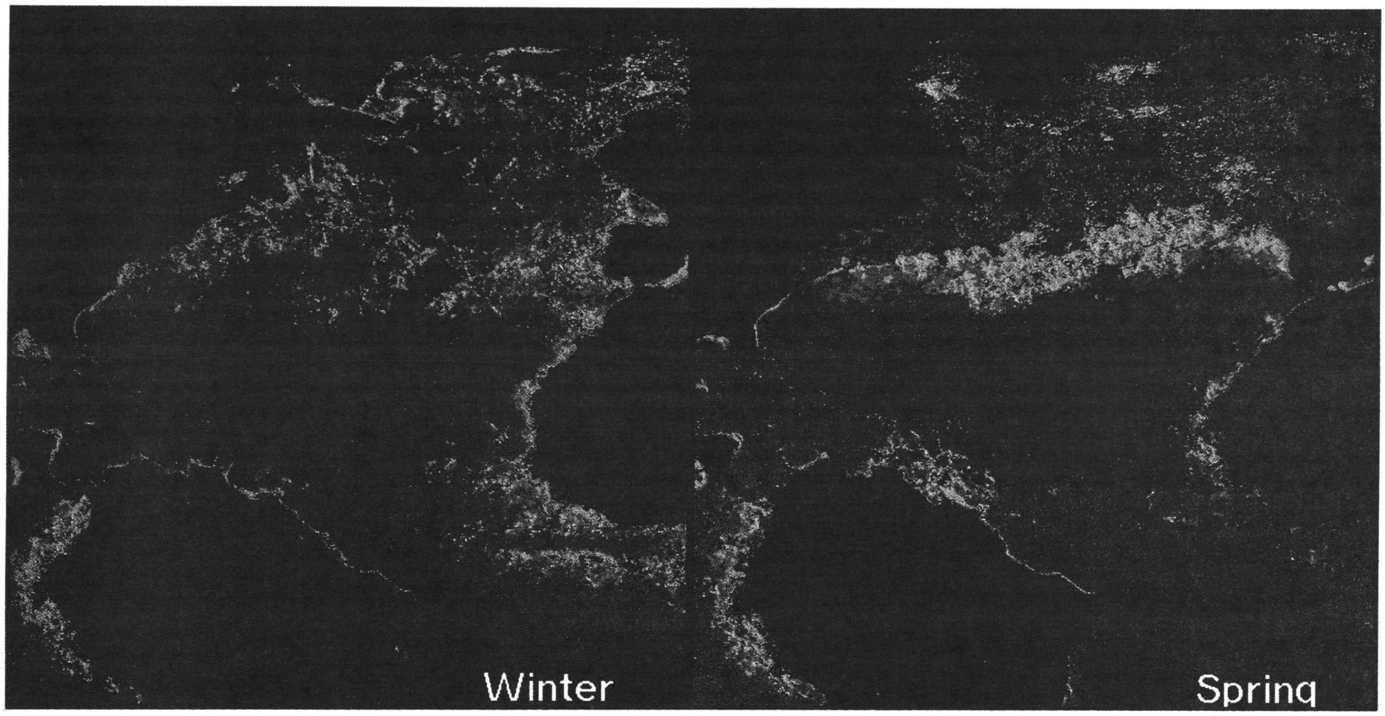


Plate 1. The development and intensity of the North Atlantic "Spring Bloom" are shown in these two seasonal composites of CZCS data acquired during the winter (January-March) and spring (April-June) of 1979 and 1980 (see Plate 2a for color scale). From the temperate regions to the poles the nutrient 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.

This plate originally appeared in full color. See the back of the second volume of 1989 (Volume 70, Numbers 27-52) for the color plate.

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.

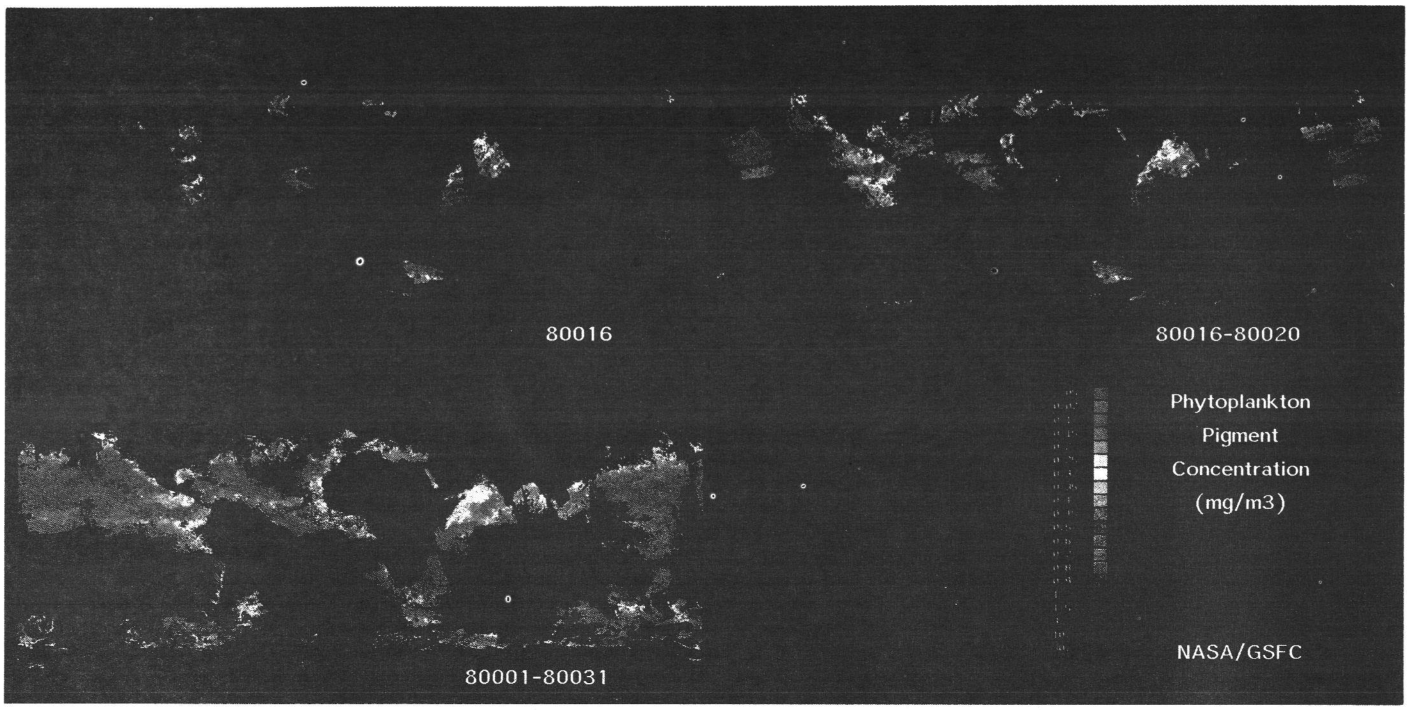
For the production of the global data set we have assumed a standard atmospheric aerosol type characterized by Angstrom exponents equal to zero. This aerosol correction is valid for most open ocean regions but undoubtedly has introduced errors in regions impacted by continental air masses (e.g., off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



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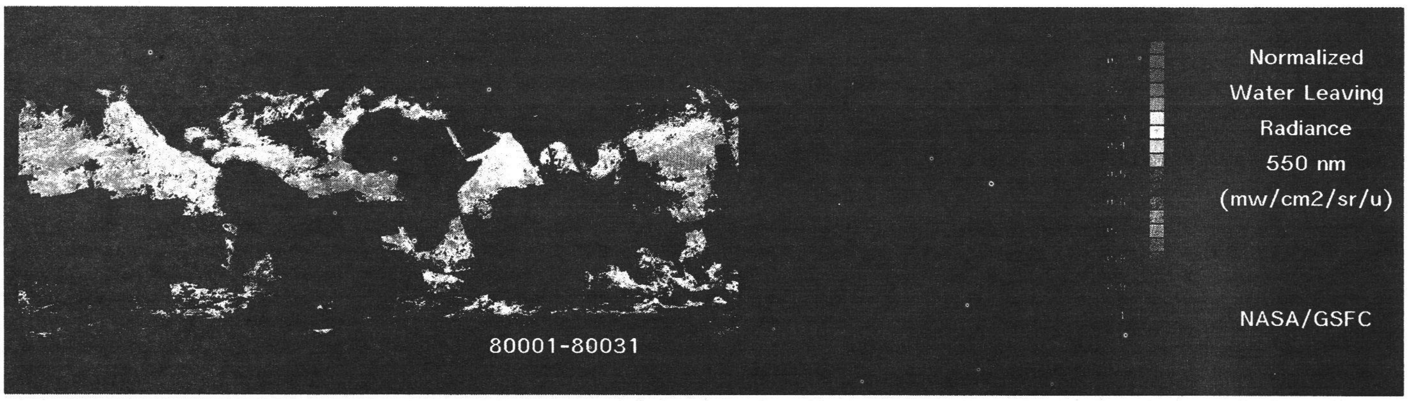

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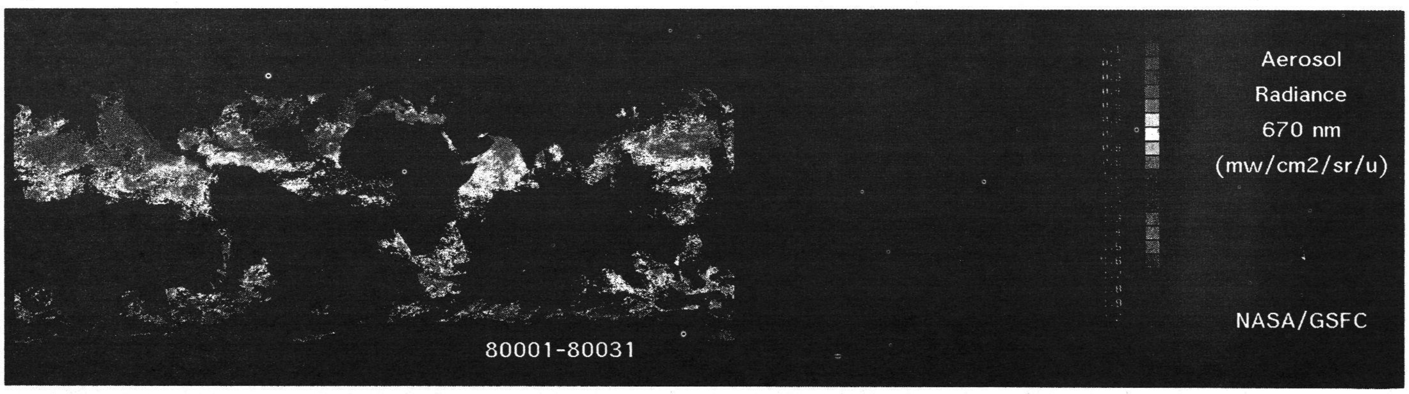

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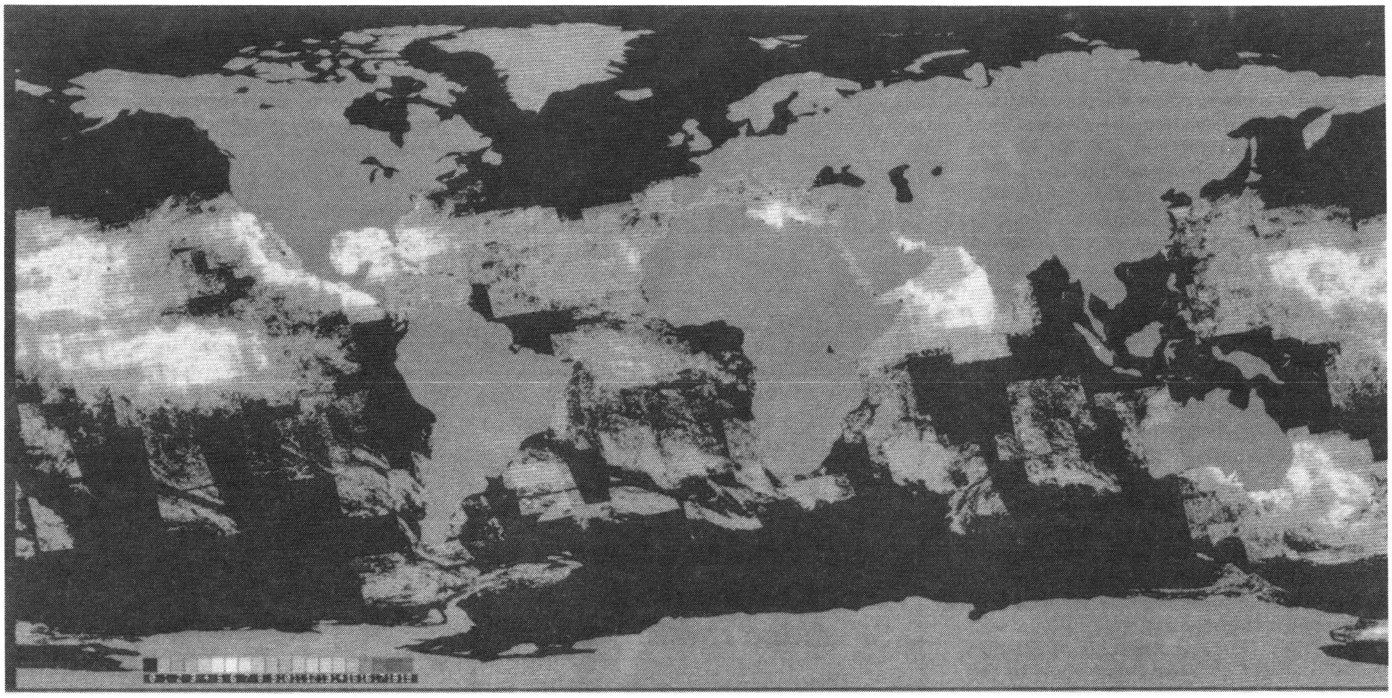
Plate 2. Examples of Level-3 CZCS products. (*a*) A series of daily, 5-day, and monthly composites for pigment concentration for January 1980. (*b*) Monthly composite of normalized water-leaving radiance at 550 nm for January 1980. Water-leaving radiance at 550 nm is only slightly affected by pigment 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*, next page) Monthly composite of valid samples for December 1981 to illustrate the statistical count field of valid pixels within each fixed bin.

This plate originally appeared in full color. See the back of the second volume of 1989 (Volume 70, Numbers 27-52) for the color plate.



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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

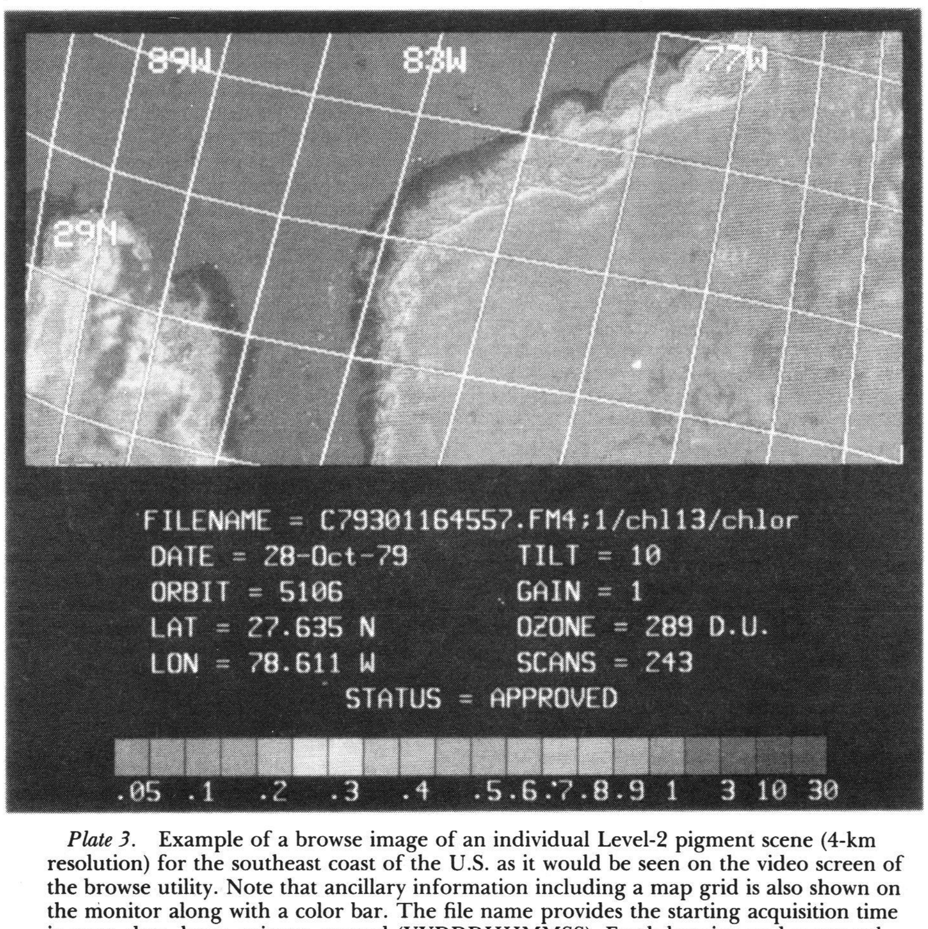

Plate 3. Example of a browse image of an individual Level-2 pigment scene (4-km resolution) for the southeast coast of the U.S. as it would be seen on the video screen of the browse utility. Note that ancillary information including a map grid is also shown on the monitor along with a color bar. The 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 are given for disapproved scenes. Nonvalid data (clouds and land) are colored gray. This plate originally appeared in full color. See the back of the second volume of 1989 (Volume 70, Numbers 27-52) for the color plate.

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 TQ2023 (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.

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.

Acknowledgments

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