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4.6 OCEANOGRAPHIC SATELLITE REMOTE SENSING: REGISTRATION, RECTIFICATION, and DATA INTEGRATION REQUIREMENTS

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INTRODUCTION

Oceanographic remote sensing is still in its beginning stages of development. Results from the early meteorological satellites suggested that parameters of oceanographic interest, such as sea surface temperatures, might readily be obtained by satellite remote sensing. The accuracy of the data, however, was found to be unacceptable. Later instruments, such as those flown on Seasat[4], demonstrated the feasability of obtaining nearly all-weather observations of wind speed and direction, wave height, sea surface temperature and elevation. These data, along with those obtained by the latest generation of weather satellites, appear to be of much greater utility. The relatively limited experience with these systems, however, places much of oceanographic remote sensing at a stage where results are still being verified and evaluated. Calibrated geophysical parameters are available for many of the data items, but the quality and significance of these observations is only now beginning to be understood.

There are many reasons why oceans remote sensing has lagged behind meteorological and terrestrial applications. They cannot all be addressed here, but a significant impediment has been the lack of appropriate tools for acquiring, processing and analyzing remotely sensed data. Until very recently only a few oceanographic institutions had any semblance of an image processing capability - a capability which is mandatory for processing and viewing image data and extremely useful for processing and displaying nonimage data. This lack of computerized tools for remotely sensed data processing, especially data integration, has been an impediment to algorithm development and sensor verification. The lack of appropriate mechanisms for acquiring the data continues to cause problems but is currently being addressed, to a limited degree, by the Ocean Pilot System[1].

Firm data integration requirements are difficult to pin down. Operational applications are in the best position to dictate data integration requirements, but operational oceanographic applications usually require real- or near-real-time data. Data integration services, which are generally quite time consuming, are therefore precluded. For this reason, data integration is largely a problem pertinent to research oceanography and requirements of research projects vary widely in the requirements area. With the launch of Seasat in 1978 and with the improved accuracy and availability of data from meteorological satellites, ocean remote sensing is entering a period in which the necessary analysis tools are being built and investigators are becoming more familiar with the various sensor systems. This should lead to more investigator concern with data integration requirements for scientific and operational purposes.

Table 1 presents a summary of the primary satellite sensors of interest to oceanography. (See also Wilson[5].) Since microwave sensors are so prevalent, resolving the different IFOVs and subsatellite coverages becomes extremely difficult. All presently operating oceanographic satellites primarily contain imaging-type sensors. This makes image processing an important tool for present-day oceanographic studies.

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TABLE 1

Summary of sensors of primary interest to oceanographers

SATELLITE	SENSOR	TYPE	CHANNELS	IMAGING/ NONIMAGING	IFOV	PRIMARY GEOPHYSICAL PARAMETERS
Seasat GEOS-3	Radar Altimeter (ALT)	Active	13.5 GHz	Nonimaging	2.4-12 km (depends on Sea State)	Wave height Wind speed Sea surface height
Seasat NIMBUS-7*	Scanning Multi-Channel Microwave Radiometer (SMMR)	Passive	6.6 GHz 10.7 GHz 18.0 GHz 21.0 GHz 37.0 GHz (Vertical & horizontal polarity)	Imaging (Low rate)	120 x 79 km 74 x 49 km 43 x 28 km 38 x 25 km 22 x 14 km	Sea surface temp. Wind speed Water vapor Liquid water
Seasat	Seasat-A Satellite Scatterometer (SASS)	Active	14.6 GHz	Nonimaging	16 - 23 km x 36 - 93 km highly variable geometry	Wind Speed Wind Direction
Seasat	Synthetic Aperture Radar (SAR)	Active	1.275 GHz	Imaging	~25 meters Dependent on Ground Pro - cessing	Wave Spectra Sea Ice
Nimbus-7*	Coastal Zone Color Scanner (CZCS)	Passive	.433-.453 .510-.530 .540-.560 .660-.680 .700-.800 10.5-12.5	Imaging	.825 km	Chlorophyll concentrations Ocean Color Diffuse attenuation coefficient
NOAA-6/7* TIROS-N	Advanced Very High Resolution Radiometer (AVHRR)	Passive	0.58-0.68 .725-1.1 3.55-3.93 10.5-11.3 11.5-12.5	Imaging	1.1 km Channel 1 slightly less	Cloud cover Sea surface temperature

NOTE: Nimbus-7 and NOAA-6 and 7 are the only currently operational satellites

* NOAA-6 and TIROS-N contain only 4 channels

REQUIREMENTS

Data integration requirements for oceanographic remote sensing[1,6,7] can be placed in several categories. Comparison of one observation with another at the same geographic location is important as it is in all disciplines. Observations must be earth-located and interpolated in order to either initialize or test numerical models. Observations must be earth-located to measure magnitude and motion of features. Finally, observations must be located, interpolated, and map-projected in order to provide maps depicting two-dimensional distributions.

Comparison of observations is an important aspect of not only disciplinary research but also sensor validation. Observations of a physical phenomenon from a given sensor need to be compared with observations of the same phenomenon from other sensors which may be on the same satellite, on a different satellite or on an aircraft platform. High-rate observations, such as AVHRR sea surface temperatures (1 pixel - 0.8 km) need to be compared with other observations of the same parameter from a low-rate sensor such as Seasat SMMR (1 pixel - 18 x 28 km).

The different IFOV sizes and shapes and sensor coverages on even the same satellite make observations difficult to compare (See Table 1). Added to this is the fact that the ocean is a dynamic system so that comparisons of observations taken at different times (even a few hours apart) require temporal interpolation as well as spatial interpolation before valid comparisons can be made.

Correcton of one sensor with data from another leads to an additional integration requirement. A single sensor is often incapable of making all the measurements necessary to derive a particular geophysical parameter. For example, to make efficient path-length corrections to the Seasat Altimeter sea surface elevation measurements, Seasat SMMR water vapor content estimates are used where available. The SMMR is also used to adjust scatterometer (SASS) returns for atmospheric attenuation effects. If an outside correction source is on a different satellite or even in an entirely different form (e.g., map form) the data integration problem becomes even more acute.

Feature identification, measurement and movement tracking requires earth-located data. Examples of these operations are found in the current warm ring analyses[8,9] being performed at several institutions. Satellite projections do not allow distance measurements in the image in line and sample coordinates. A transformation from line and sample to geographic coordinates (latitude/longitude) must be obtained and used. It is also necessary to compute this transformation to measure feature movement through time. The dynamic ocean system precludes simple scene/scene registration and simple differencing.

The two-dimensional display of sensor observations implies mapping. Users are accustomed to reading maps with specific orientations, projections, and cartographical characteristics. Satellites have yet to provide maps directly which satisfy these predictions. In fact, many satellite projections are so distorted that it is unreasonable to expect investigators to become accustomed to them. It becomes necessary, therefore, at some stage of analysis, to place the data into a suitable map projection and create a map using conventional cartographic methods (albeit automated).

Mapping of imagery data seems fairly straightforward. However, it is also important to create maps which are based on data from nonimaging sensors such as the Seasat Altimeter[3]. (See Figure 1.) These data are, in general, randomly spaced. For a number of reasons, a particular sample may be missing or unreadable. Interpolation techniques for establishing a reasonable value are needed. Alternatively, cartographic techniques are required for indicating missing values, yet providing an easily readable map. Oceanographers are concerned not only with two-dimensional distributions but also with three-dimensional distributions shown either synoptically, time averaged, or as a time continuum. The only effective way to display the four-dimensional information, as the latter requirement implies, is via animation. The art and science of computer graphics provides the technological base for animation. It is necessary, though, to map-project, register, temporally and spatially interpolate, and reformat the data to take advantage of that technology.

Positional accuracy requirements for oceanography are not as stringent as for terrestrial remote sensing but are more in line with meteorological applications. Using present navigation (earth-location) techniques for polar-orbiting image data sets[2], accuracies are adequate for all but micro- and fine-scale studies. Open-ocean positional confidence is probably within 5 kilometers with accuracy being within a kilometer near landmarks. These accuracies are adequate for macro- and mesoscale studies. Additional positional accuracy in open-ocean areas would enable much more activity in fine-scale research. Table 2 presents the spatial scales associated with various classes of oceanographic research.

RESEARCH	FEATURE SIZE
macroscale	global
mesoscale	10-1000 km
fine-scale	2-5 km
microscale	< 1 km

TABLE 2

Comparison of oceanographic research areas and spatial scales.

AREAS FOR RESEARCH AND DEVELOPMENT

Data integration is a problem for oceanography just as for any other discipline. Areas where progress is needed include technique development and evaluation, understanding requirements, and packaging techniques for speed, efficiency and ease of use. Some specific topics for futher research and development are presented below.

Figure 1

Shaded relief map of sea surface elevation constructed from Seasat Altimeter data

Source: M. Parke, JPL

TECHNIQUE EVALUATION AND DEVELOPMENT

- Evaluate techniques for establishing geophysical values in areas of missing data.

- Evaluate techniques for temporal interpolation.

- Compare and evaluate alternative navigation strategies.

- Develop algorithms for automated coastline detection and correlation with vector-coded coastline data (e.g., World Data Banks I and II).

FURTHER DEVELOPMENT OF REQUIREMENTS

- Define spatial scale requirements for fine-scale studies.

- Define requirements for band-to-band registration of multiband imagery.

- Define requirements for multisensor data integration, where sensors may be on the same satellite, a different satellite, or on aircraft and satellites.

- Define data integration requirements for operational applications.

PACKAGING AND SYSTEM DESIGN

- Produce a well-organized, efficiently accessed, coastline and landmark file for use in interactive adjustments to navigation parameters.

- Develop automated methods of acquiring, managing, and utilizing orbital parameters and clock adjustments provided by tracking facilities.

- Develop analysis systems with user-friendly interfaces enabling researchers to routinely perform data integration tasks in a short period of time. These systems would also provide the basis for evaluating new integration techniques as they are developed in research activities.

- Provide transportable software so that the minimum amount of effort has to be expended in duplicating data integration capabilities at various sites. This is important because the research nature of oceanographic remote sensing data integration implies decentralized activities. Also, the wide variety of sensors of interest suggests that centralized data integration capabilities will not exist, at least until full-scale disciplinary data systems are built.

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