SUPERFLUX I, II, AND III EXPERIMENT DESIGNS:

REMOTE SENSING ASPECTS

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INTRODUCTION

The Chesapeake Bay Plume Study, called Superflux, was initiated in January 1980 by a group of scientists, marine resource managers, and remote-sensing specialists with the conviction that their mutually complementary goals and interests could be served by a pooling of resources to conduct this study. The result was that the study was undertaken with a multi-faceted set of objectives:

(1) Process-oriented research: To understand the impact of estuarine outflows on continental shelf ecosystems

(2) Monitoring and assessment: To delineate the role of remote sensing in future monitoring and assessment programs

(3) Remote sensing research: To advance the state of the art in remote sensing systems as applied to sensing of the marine environment, thereby hastening the day when remote sensing can be used operationally for monitoring and assessment and for process-oriented research.

It is recognized that to study an estuarine plume and its impact on shelf ecosystems, the coupling of biological and physical processes must be understood. Time and space scales associated with these processes in a highly dynamic, tidally driven estuarine plume require the capability to sample an area on the order of 10^3 kilometers over time intervals much smaller than the tidal period. Figure 1 illustrates the respective sampling regimes associated with boats, aircraft, and satellites as compared to time and space domains of important processes in an estuary-ocean system. Because sampling via aircraft fills a critical gap, an underlying hypothesis of Superflux was the belief that airborne remote sensors, interacting with surface vessels collecting in situ data, could provide the synopticity required to study a highly dynamic estuarine plume. In fact, it is believed that any future monitoring program involving remote sensing would rely on some combination of boats, aircraft, and satellites.

Another premise underlying the Superflux experiments was that the transfer of technology from NASA to the National Marine Fisheries Service (NMFS) could be accomplished effectively and more quickly through highly interactive programs involving marine scientists and the remote sensing technologists at NASA. This interaction would influence the development of remote sensing technology, increase its relevancy to the needs of the marine scientists, and accelerate its availability. At the same time, marine scientists would become familiar with the capabilities and limitations of present remote sensors, and the appropriate protocol for their utilization would evolve.

Because of the importance placed on involvement and interaction, the Superflux study was open to all who wanted to participate and, despite the paucity of funds to support their involvement, many institutions contributed to the project. A list of participating institutions is given in table 1.

DESIGN CONSIDERATIONS

As a first step in meeting Superflux objectives, the NASA remote sensing specialists saw the need to integrate state-of-the-art airborne remote sensors into one or more systems. The eight remote sensors used in Superflux are described in table 2. Prior to the Superflux experiments, these eight sensors were being developed as separate projects at three different centers within NASA. With few exceptions, they had been flown separately in flight missions designed to test the particular instrument under its ideal operating conditions. In the Superflux experiments, the sensors were being asked to provide a meaningful oceanographic data set for characterizing the Chesapeake Bay plume.

In designing the Superflux experiments, consideration had to be given to (1) the sensors operational constraints and their need for performance validation, and (2) the oceanographic sampling objectives. These considerations were not always mutually compatible and, therefore, compromises had to be made. A list of the various considerations is given in table 3, along with other considerations which, in general, added to the logistical complexity of the experiments.

Considerations relative to the sensors' operation and performance included constraints on aircraft altitudes and groundspeeds, solar elevation angles and Sun position relative to the direction of flight, and weather conditions (cloudiness or haze). Each sensor has its own operational envelope with respect to these conditions and these envelopes did not always overlap. Furthermore, good conditions for sensor operations did not always correspond to acceptable conditions for boats. For example, clear skies required for the high-altitude scanners were often accompanied by relatively high surface winds that inhibited boat operations.

Other important considerations were related to the need for remote sensor performance validation and calibration. These included the requirements for coincident sea truth data, the desire to maximize the range of water parameters being sensed, and the replication of measurements (e.g., repeated passes over the same area).

In some instances, the considerations relative to oceanographic objectives conflicted with the sensor-driven ones. For example, the need to have concurrent measurements of temperature, salinity, and chlorophyll _a_ fluorescence required the simultaneous operation of sensors at altitudes and groundspeeds that were less than optimum. The importance of sampling at certain tidal phases sometimes conflicted with Sun angle constraints, and the need for good spatial coverage and appropriate grid densities precluded meticulous sensor validations (e.g., sea truth, replications, etc.).

THE EXPERIMENT DESIGNS

Three experiments were conducted in 1980. Superflux I coincided with high fresh water inflow to the Bay (March 17-20, 1980), Superflux II with moderate fresh water inflow (June 16-27, 1980), and Superflux III with unusually low fresh water inflow (October 15-22, 1980). Each experiment was preceded by a reconnaissance flight made with a VIMS aircraft to determine visually the general location and extent of the Bay plume. The primary experiments consisted of several missions flown by the NASA P-3 aircraft carrying remote sensors and supported by boats collecting water column sea truth data. A NASA Lear Jet also participated in Superflux III.

In most cases, the boats were collecting data along cruise tracks that spanned several hours or days. The sea truth data collections were, therefore, brief incidents in their overall missions. The boat missions are described in more detail in reference 1.

REMOTE-SENSING SYSTEMS

Of the seven remote sensors listed in table 2, six were flown on the P-3. Because of differences in operational constraints (envelopes), two systems of sensors emerged. A system, as defined here, is a group of sensors that could be flown on the same aircraft and operated simultaneously. These two systems are described in table 4.

The low-altitude system consisted of the two lidar fluorosensors (AOL and ALOPE), the infrared radiometer (PRT-5), and the microwave salinity mapper (L-Band). The 20-channel visible wavelength scanner (MOCS) was also operated but only nadir data (directly beneath the aircraft) were analyzed. This system provided one-dimensional nadir tracks of chlorophyll _a_ fluorescence, turbidity, temperature, salinity, and indicators of phytoplankton species composition (or pigment classes) present. Collected from altitudes between 150 and 300 m (500-1000 feet) and at groundspeeds of approximately 100 m/sec (200 kts), the data have spatial resolutions between 10 and 100 m. While these data by themselves provide excellent relative measurements, absolute accuracies require calibration with sea truth, and to obtain good sea truth data for this nadir-looking system, the aircraft has to pass directly over the boats (±50 m).

The high-altitude system provided 2-dimensional imagery from scanners and cameras at altitudes ranging from 1500 to 13 000 m (5000 to 43 000 ft), and groundspeeds between 150 and 200 m/sec (~ 300 to 400 kts). Correlation of the remote multispectral data (backscattered sunlight in narrow spectral bands) with water parameters is still highly empirical, particularly in coastal and estuarine waters which consist of complex mixtures of dissolved and particulate materials. Nevertheless, the qualitative information provided by the imagery is still quite valuable in delineating the spatial extent of the turbidity plume, the location of visible fronts, and other visible evidences of dynamic processes such as upwelling, eddies, horizontal shears, etc.

The missions flown in the Superflux I, II, and III experiments are summarized in table 5. Of the 17 missions flown, all but three were either shelf transects or mappings (see column 2 in table 5). The six shelf transect missions, two with the low-altitude system and four with the high-altitude system, gave high priority to the remote sensing testing and validation considerations discussed above. An example of the shelf transect mission flight track flown on June 20, 1980, is shown in figure 2. These missions generally consisted of a transect that began well inside the Chesapeake Bay or James River and proceeded out the mouth of the Bay and eastward beyond the shelf break. Sea truth vessels were concentrated along the transect and this transect, which maximized the range of water parameters sampled, was repeated several times.

Eight mapping missions, five low-altitude and three high-altitude, placed higher priority on the areal coverage of the plume and other oceanographic design considerations. Figure 3 shows a flight track of the June 23, 1980 low-altitude mapping mission and figure 4 shows a flight track of the June 24, 1980 high-altitude mapping mission. The mapping missions were aimed at delineating the plume with good spatial resolution and synopticity. Attention was given to the tidal phase and to the resolution of features within the plume and along the plume boundary.

In addition to the shelf-transect and mapping missions, missions were flown over the upper Chesapeake and Delaware Bays at the request of participants in those areas. These are also listed in table 5.

OTHER CONSIDERATIONS IN THE EXPERIMENT DESIGNS

Navigation and tracking were especially important for the low-altitude system and somewhat less critical for the high-altitude one. Navigation, referring to the ability to target the aircraft's position to pass directly over a boat, depended on the P-3 aircraft's inertial navigation system (INS) which directed the autopilot. This was found to be somewhat inaccurate and resulted in missed distances between aircraft and boat of as much as a half kilometer on the earlier missions. Once the boat is in sight, the aircraft can maneuver to fly directly over it, but the resultant rolling and banking motions seriously degrade the remote sensing data. As more experience was gained, techniques were devised to allow interruptions in low-altitude flight legs to locate a boat and fly directly over it before resuming the flight pattern.

Tracking, i.e., recording the exact position of the aircraft as a function of time, was an especially successful aspect of the Superflux experiments. A newly-developed airborne Loran-C system mounted on the P-3 recorded longitude and latitude as a function of time at 9-second intervals.

Communications posed major problems at first, but by the time of Superflux III a satisfactory communications network had been worked out. This consisted of two ground stations: a primary station at Wallops with long-range transmitters and receivers for communicating with the P-3 and several of the boats, and a secondary base located at the central boat-docking facility in Virginia Beach. The latter, linked to Wallops via telephone, was manned for extended periods of time to serve as a centralized communications base for the boat investigations. Onboard the P-3 was a high-powered radio for communicating with Wallops and with several of the vessels that had been equipped with antennas borrowed from NASA. One boat served as the central communications link for all other vessels.

A third factor strongly influencing experiment designs was the need to fly through military-restricted air space. Strict procedures had to be followed to receive clearances to enter these areas. When clearances were not granted, or were withdrawn at the last minute, sampling designs had to be adjusted quickly and all participants had to be notified. This was a factor which influenced every mission design but was not one that could be controlled.

CONCLUSIONS

The purpose of this presentation was to give an overview of the experiment designs for the airborne remote sensing missions that were a part of the Superflux experiments. More specific details concerning the Superflux experiment designs are contained in reference 2. References 3 and 4 contain excellent summaries of state-of-the-art remote sensing technology.

The remote sensing instruments, many of which had previously only been test-flown, were here asked to provide meaningful data sets. The challenge was to combine these sensors into systems, i.e. to solve the problems related to sensor interfaces and coordinate the aircraft and boat interactions to accomplish experiment objectives. The Superflux experiments were successful in demonstrating that remote sensing can play an important role in sampling mesoscale oceanographic phenomena which cannot be addressed by any other means.

REFERENCES

1. Thomas, James P.: Superflux I, II, and III Experiment Designs: Water Sampling and Analyses. Chesapeake Bay Plume Study - Superflux 1980, NASA CP-2188, 1981 (Paper no. 5 of this compilation).

2. Annual NEMP Report on the Health of the Northeast Coastal Waters of the United States, 1980. Northeast Monitoring Program, National Oceanic and Atmospheric Administration, Sandy Hook Laboratory, Report no. SHL 80-24, 1981.

3. Curfman, H. J.; Oberholtzer, J. D.; and Schertler, R. J.: An Assessment of the Role of Remote Sensing in the Study of Inland and Coastal Waters. NASA TM-8188, 1980.

4. Esaias, Wayne E.: Remote Sensing of Oceanic Phytoplankton: Present and Future Goals. Primary Productivity in the Sea, P. Falkowski, ed., Environmental Science Research, vol. 19, Plenum Press, 1980.

TABLE 1. - SUPERFLUX PARTICIPANTS

Federal and State Organizations
NMFS/Northeast Fisheries Center (Sandy Hook and Oxford Labs)
NASA-Langley Research Center
NASA-Wallops Flight Center
NASA-Lewis Research Center
NOAA/National Environmental Satellite Service
NOAA/Atlantic Marine Center
U.S. Navy (Oceana and Little Creek)
U.S. Naval Academy
Environmental Protection Agency
U.S. Coast Guard
State of Maryland Department of Natural Resources
State and Private Universities
College of William and Mary (Virginia Institute of Marine Science)
Old Dominion University
Johns Hopkins University (Chesapeake Bay Institute and Applied Physics Laboratory)
University of Delaware College of Marine Studies
Anne Arundel Community College
University of Miami
Research Triangle Institute

TABLE 2. - AIRBORNE REMOTE SENSORS USED IN SUPERFLUX

Name	Type of Sensor	Characteristics	Measurements
AOL	Laser (Lidar) Fluorosensor	Uses single-wavelength laser to induce fluorescence; measures emission in 40 channels; has vertical profiling capability	Fluorescence of chlorophyll a and other pigments; light attenuation
ALOPE	Laser (Lidar) Fluorosensor	Uses two-frequency laser to induce fluorescence; measures single-channel chlorophyll a fluorescence	Chlorophyll a fluorescence; phytoplankton color group diversity
L-Band	Microwave Radiometer	Measures passive microwave radiation from water surface in single channel	Salinity (requires independent measurement of surface temp.)
PRT-5	Infrared Radiometer	Measures passive thermal radiation from water surface in single channel; commercially available	Surface temperature
MOCS	Multispectral Scanner	Measures backscattered sunlight in visible and near-infrared spectral range; has 20 bands, 15 nm wide	Chlorophyll a; suspended and dissolved matter that affects color
TBAMS	Multispectral Scanner	Has 8 bands in visible and near infrared spectral range plus one thermal channel; high sensitivity to water color variations	Two-dimensional imagery; maps of chlorophyll a and suspended sediments
OCS	Multispectral Scanner	Has 10 bands in visible and near infrared spectral range; forerunner of CZCS instrument on NIMBUS 7 satellite; flown on NASA Lear Jet	Two-dimensional high-altitude imagery; maps of chlorophyll a and suspended sediments

TABLE 3. - SUPERFLUX EXPERIMENT DESIGN CONSIDERATIONS

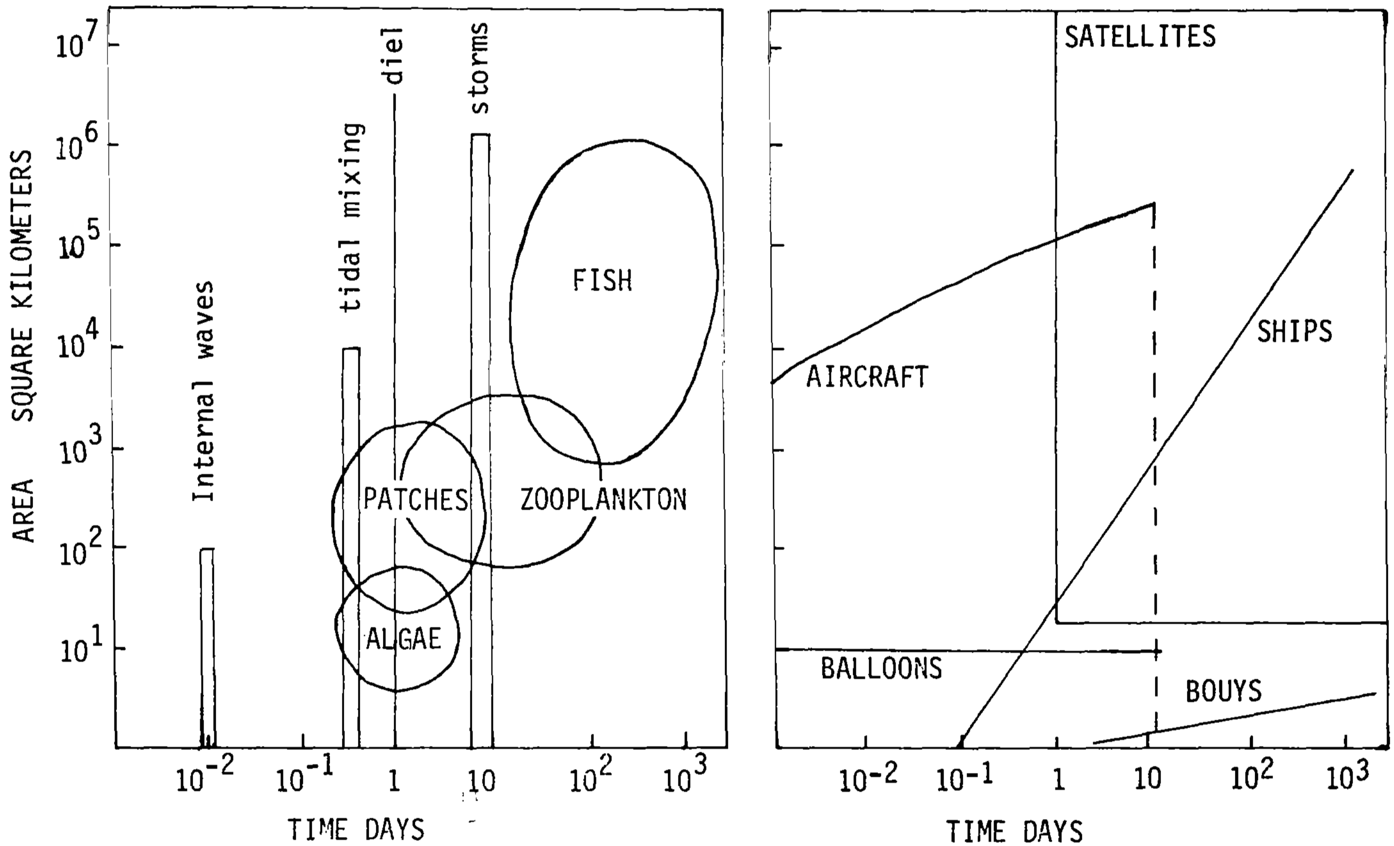
Considerations Relative to Sensor Operations and Performance:
(1) Aircraft altitude and groundspeed (2) Sun angles (3) Weather (4) Sea truth requirements (5) Range of water parameters (6) Repeatability of measurements
Considerations Relative to Producing Good Oceanographic Data Set:
(1) Simultaneous operation of sensors (2) Phase of tide (3) Spatial coverage and grid density
Other Considerations:
(1) Navigation and tracking (2) Communications (3) Restricted air and surface zones (clearances required)

TABLE 4. - TWO SENSOR SYSTEMS USED IN SUPERFLUX

	System	Platform	Nature of Data
Low-Altitude	AOL ALOPE L-Band PRT-5 MOCS	NASA P-3 aircraft at low altitudes (150 to 300 m (500 to 1000 ft))	1-dimensional nadir tracks (directly beneath aircraft)
High-Altitude	MOCS TBAMS Camera	NASA P-3 aircraft at high altitudes (1.5 to 7.5 km (5000 to 25 000 ft))	Digital imagery and photography; 2-dimensional map-pings of parameters
High-Altitude	OCS	NASA Lear Jet (13 km (43 000 ft))	2-dimensional imagery and mappings of parameters

TABLE 5. - SUMMARY OF SUPERFLUX MISSIONS

	Date	Mission Type	System	Aircraft	No. Vessels
Superflux I	3/17/80	Shelf transect	Low-altitude	P-3	5
	3/19/80	Double mapping	Low-altitude	P-3	3
	3/19/80	Shelf transect	High-altitude	P-3	3
	4/2/80	Exploratory	High-altitude	P-3	0
Superflux II	6/17/80	Delaware Bay	Low-altitude	P-3	2
	6/19/80	Chesapeake and Delaware Bays	High-altitude	P-3	8
	6/20/80	Shelf transect	Low-altitude	P-3	4
	6/20/80	Shelf transect	High-altitude	P-3	4
	6/23/80	Mapping	Low-altitude	P-3	6
	6/24/80	Mapping	High-altitude	P-3	5
	6/25/80	Mapping	Low-altitude	P-3	6
	6/27/80	Mapping	Low-altitude	P-3	5
Superflux III	10/15/80	Mapping	High-altitude	Lear Jet	4
	10/20/80	Mapping	High-altitude	Lear Jet	1
	10/21/80	Shelf transect	High-altitude	P-3	3
	10/22/80	Shelf transect	High-altitude	P-3 Lear Jet	1



(a) Processes, indicating periods for physical forcings and excursion-generation times of some biological components.

(b) Sampling, indicating limits of coverage for various platforms.

Figure 1.- Time-space domains for oceanic phenomena (adapted from ref. 2).

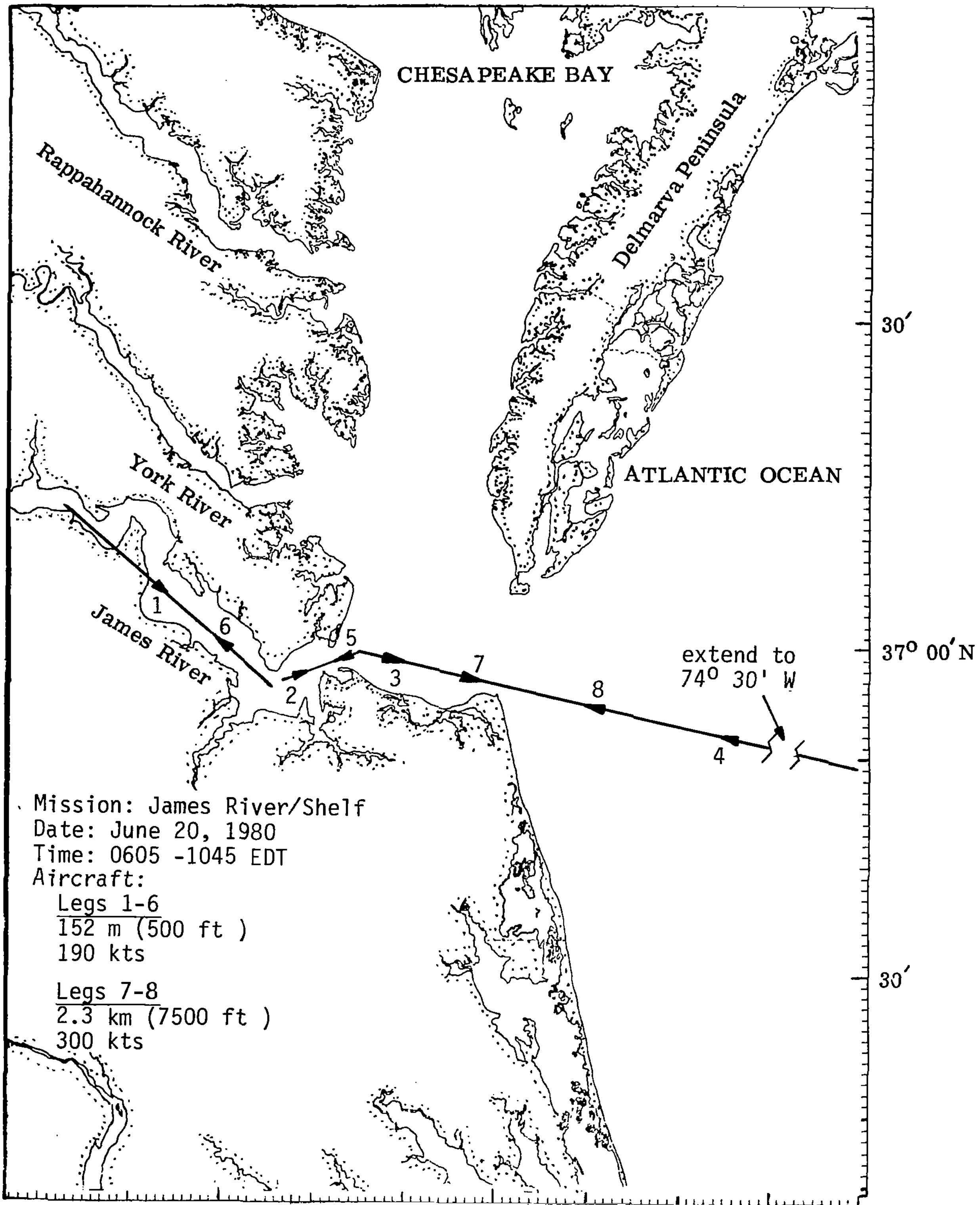


Figure 2.- Flight tracks of James River/shelf transect missions on June 20, 1980. Low-altitude system was flown between 0605 and 0745 EDT and high-altitude system between 0940 and 1045 EDT.

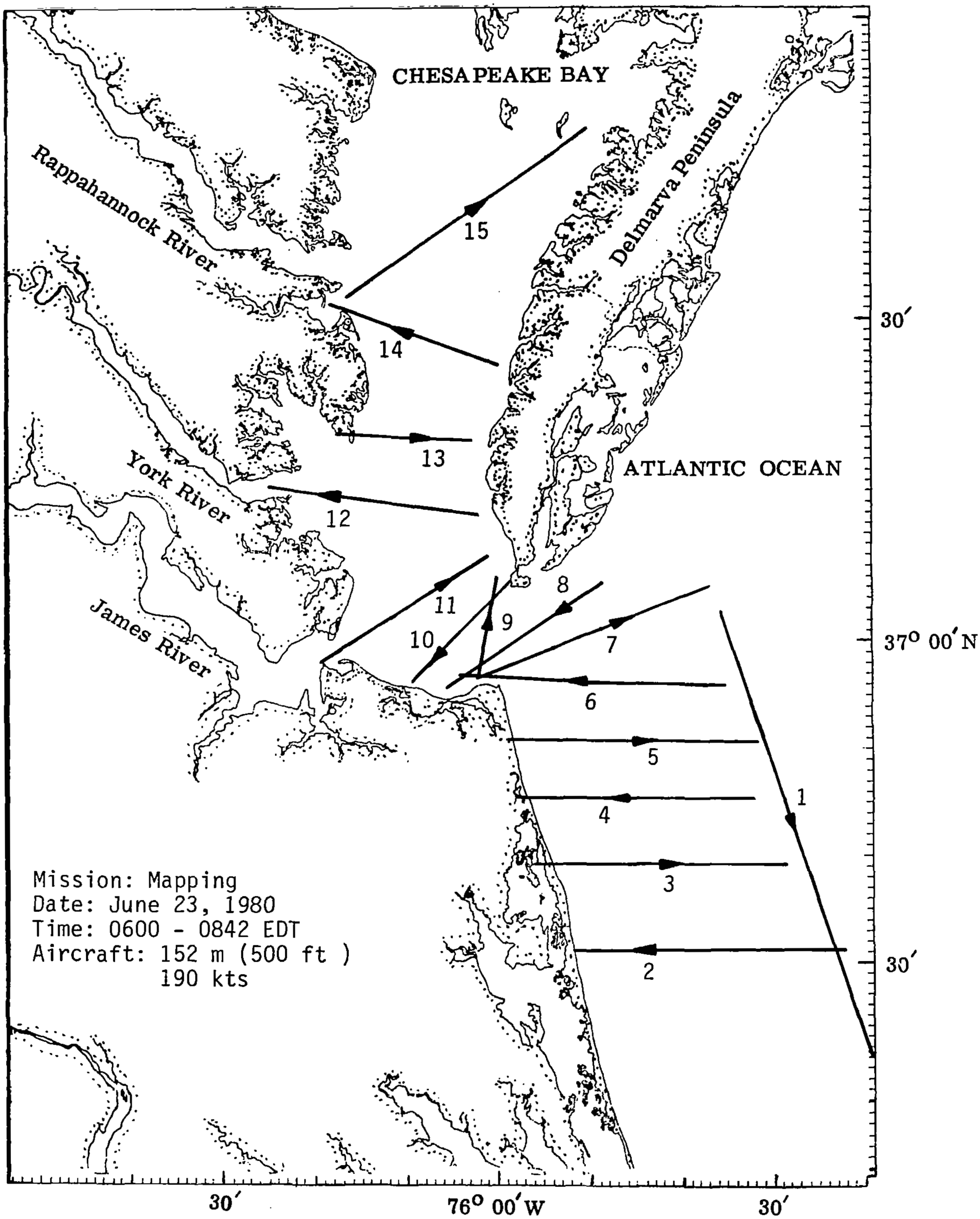


Figure 3.- Flight track of low-altitude mapping mission on June 23, 1980.

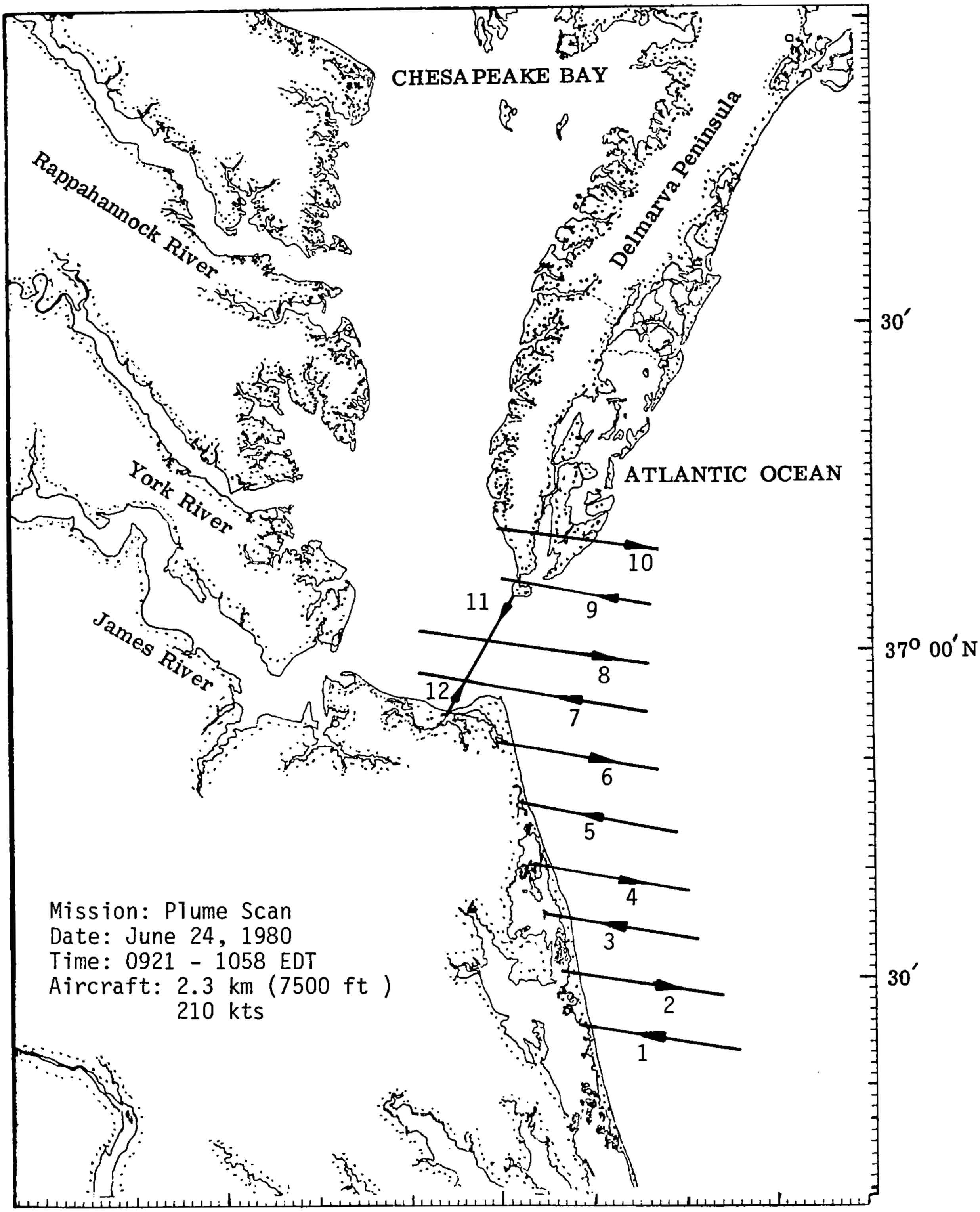


Figure 4.- Flight track of high-altitude plume scan mapping mission on June 24, 1980.