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NAVY OCEANOGRAPHER SHUTTLE OBSERVATIONS

STS 41-G

MISSION REPORT

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Office of the Associate Technical Director
for Research and Technology
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Prepared for

NAVY SPACE OCEANOGRAPHY COMMITTEE

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PREFACE

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This report is a summary of space shuttle Challenger Mission 41-G, 5-13 October 1984, from the point of view of the author who was the first oceanographer in space aboard that flight. It covers the salient events in space oceanography that led to the flight, the spaceflight training at the Johnson and Kennedy Space Centers, the preflight oceanographic planning and observation plan, the on-orbit operations, the data obtained and the results, the postflight phase, and recommendations for the future.

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INTRODUCTION

It's really not a normal thing
To orbit round in space,
Why is it you do not think
Of Earth as your only place?

And furthermore, the pundit said,
How gross of you to mention,
That a vital source of ocean data
Is by visual perception.

. . . with apologies to the Red Queen.

This report is a summary of space shuttle Challenger Mission 41-G, 5-13 October 1984, from the point of view of the author who was the first oceanographer in space aboard that flight. It covers the salient events in space oceanography that led to the flight, the spaceflight training at the Johnson and Kennedy Space Centers, the preflight oceanographic planning and observation plan, the on-orbit operations, the data obtained and the results, the post-flight phase, and recommendations for the future.

The views expressed are solely those of the author, and do not necessarily represent those of the Naval Underwater Systems Center, the Navy Space Oceanography Committee, or of the National Aeronautics and Space Administration.

BACKGROUND

Space oceanography began in the Summer of 1964 when Giff Ewing convened his now classic "Oceanography from Space" workshop at Woods Hole. This was a forward looking meeting that examined the possibilities that might exist in the future for remotely sensing the ocean from space. It was not until two years later, in August 1966, that any real space data was examined with a view to evaluating its oceanographic content.

At that time, Bob Stevenson, then with the Bureau of Commercial Fisheries in Galveston, Texas, and now at the Office of Naval Research, was approached by NASA personnel at the Johnson Space Center to ascertain what could be seen in Gemini photographs of the ocean taken up till then. He soon realized that color photographs of the Gulf of Mexico could be used to identify the spawning grounds and migration habits of Gulf shrimp, information which at that time was unknown. This discovery was passed directly to the fishing fleet and led to Stevenson being invited to brief the crew of Gemini XII prior to their flight in November 1966. He has briefed every U.S. manned spaceflight since then.

The next opportunity came several months later, in April 1967, with the final orbiting of an unmanned Apollo spacecraft. CDR. Don Walsh, then at Texas A&M University, and Stevenson convinced NASA test personnel to mount a Hasselblad in the pilot's window with an inertial switch so that as the spacecraft came into a vertical position the camera would turn on. The results were (1) the first stereo photography ever obtained from space, (2) the first stereo photos of open-ocean cumulus, (3) the first ships' wakes caught from space, and (4) the first photos of internal waves, and of breaking internal waves, exactly in the west African waters where they were first described by Albert Defant in 1938!

The photos from the unmanned Apollo 6 so impressed NASA, Navy (NAVOCEANO) and U.S. Geological Survey scientists that Earth observations and photography were included on the manned Earth-orbital flights of Apollo 7 and 9, even thought the basic flight requirements were strictly engineering in preparation for lunar missions. Briefings of the astronauts in the Earth sciences were still meager, other than lunar landscape corollaries. The resulting photos and photo tests, such as the four-Hasselblad "lash-up" on Apollo 9, resulted in a photo bonanza for every discipline.

All of the crews were impressed by sun glitter and their diligence produced the first photos of an eddy field (Apollo-9). There was also the opportunity to attempt photography of ocean-color variability; to try to catch those subtle colors that every astronaut had seen. It was clear from Apollo 9 that a system other than photographic was necessary to study open-ocean color. Later that year (1969), following a Woods Hole workshop, the basic color scanner was designed at the NASA Electronic Research Center, Cambridge, Massachusetts.

Geologists, geographers, and agriculturists were tremendously impressed by the multi-spectral photography from Apollo 9. They looked to Skylab (1973-74) as an even greater opportunity than previously available to acquire details of the Earth's land surface. A sophisticated photographic experiment was planned, therefore, with two camera systems mounted in Skylab; six assembled and bore-sighted 70mm-format cameras and an Earth terrain, 5-inch film format camera with an 18-inch focal length. In addition, the crew carried two hand-held Hasselblad cameras. All of the cameras provided a tremendous wealth of new Earth-resource information; for oceanographers too, much to the surprise of some. Surprise born more of their intrigue with the first microwave sensors to go into space than with any question of the cameras' quality. It was at this time that the author first got involved in oceanography from space as part of the Earth Observations Support team at Houston.

Microwave sensors were not in the initial planning for Skylab. Stevenson convinced Martin-Marietta, Skylab technical contractor, of the utility of passive microwave sensors; W.J. Pierson, Jr., New York University, was the prime promulgator for the scatterometer; and, several geophysicists, primarily from the U.S. Geological Survey, convinced NASA of the need for a radar altimeter. All of these sensors worked well, providing the orbital "workbench," as it were, for the later development of SEASAT.

Despite the success of the microwave sensors, including the startling sea-level data from the altimeter, the oceanographic "gems" continued to come from the photography; especially that of the sun's glitter field. It provided unique information on (1) eddies along the boundaries of current systems, (2) open ocean internal waves, (3) current-current interaction, (4) wave-current interaction, (5) wave-wave interference, (6) western-boundary current extensions, (7) ocean-currents and turbulence, and (8) a vast plankton bloom never before recorded.

For oceanographers, the photography and the data from the microwave sensors was enough to solidify the desires to put remote sensors in space on satellites and probably stimulated the concept of oceanography from space for the next decade. But as great as these advances were from Skylab, even more far reaching were the visual observations made by the astronauts which were not confirmed by data.

First of all, the astronauts saw northward movement of the brilliant chartreuse-colored Falkland Current meeting with the southerly flowing, brilliant blue of the Brazil Current, both of which then spread across the Atlantic Ocean for more than 2,000 miles. Both currents meandered and visually were observed to have eddies, but neither current seemed to mix together. This spectacular observation confirmed the opinion by many that an ocean-color scanner capable of looking at the blue and green in the ocean was needed to resolve the variations in ocean currents and water masses in the open ocean. This was manifested in the Coastal Zone Color Scanner on Nimbus-7, a very successful sensor launched in October 1978, and also led to the ocean color experiment on the second flight of the shuttle.

Skylab astronauts also observed (1) what they call a "corduroy sea," large parallel swell, (2) a herring bone sea, large swell that intersected and (3) amidst the eddies and meanders of the Falkland Current, they observed differences in ocean texture that they were unable to photograph because of the light conditions at that particular part of their orbit. These three observations firmed up and convinced those who would put an imaging radar in space, that there were indeed textures of the ocean that could be resolved by an L-Band synthetic aperture radar. Those visual observations, coupled with astronaut reports of white caps associated with high winds in areas that were not covered by the scatterometer on the Skylab, indicated further that an imaging radar in space would resolve most sea-surface textures.

Furthermore, Skylab 4 provided the first real time demonstration that the observations and photographs of the ocean by the astronauts were indeed representative of the real ocean dynamics. A navy P-3 dropping AXBT's underflew Skylab as it orbited over the Yucatan Strait and showed conclusively that the ocean surface and subsurface temperature structure corresponded exactly with the photographs of cold core eddies in the Strait. This experiment was carried out by Stevenson, John Kaltenbach of JSC and the author.

The great success of observations from Skylab led to the decision by the American crew of the Apollo/Soyuz Test Project (ASTP), set to fly in July of 1975, that an earth-observation and photography experiment was an obvious effort to carry out. The U.S. oceanographic effort during ASTP was the most ambitious ever attempted. Sponsored by the Chief of Naval Research, four areas of the ocean were to be covered by observations and photography from the spacecraft, with ground-truth from naval forces of New Zealand, Australia, the United States, and Great Britain.

The RNZRV Tui and the HMAS Bombard covered areas in the southwestern Pacific Ocean. RAF Nimrods flew out of Great Britain to cover the Atlantic waters west of Ireland. New Zealand P-3's flew north to cover waters to the Kermadec Islands, and U.S. Navy P-3's covered the Gulf of Cadiz west of Spain. Weather conditions eliminated observations west of Ireland and in the Tasman Sea, but the Bombard confirmed the persistence of the ANZUS Eddy, discovered earlier that year by the author. The Tui with the New Zealand P-3's caught the eddies and current shears north of New Zealand. It was from the Gulf of Cadiz, however, where the observations and photography and oceanographic data resulted in the breakthrough that led to the general application of satellite imagery to space oceanography.

From the spacecraft was observed what we now know to be the Huelva Front. The existence of that cold-water tongue extending out from the coast of Spain was confirmed by simultaneous data from a NAVOCEANO research vessel and the P-3 aircraft. And, in a typical example of serendipity, infrared data from DMSP were taped by the USS Kennedy. The eventual processing of those data not only confirmed the Huelva Front in the Gulf of Cadiz, but the existence of the Malaga Eddy Chain in the Alboran Sea.

The tapes from the Kennedy arrived in ONR Pasadena in a time when no one had yet reduced infrared data from satellites to the sea surface. Up till that time, such data had only been used by the meteorologists for cloud information. Working nights and on weekends, Navy Chief Robert H. Whritner, now at Scripps, eventually developed the algorithms needed;

algorithms still in use today. Thus, it was in November 1975 that the first infrared satellite image was obtained that had enough resolution to show detailed sea surface temperature structure.

Later, in 1978, SEASAT established that all of the ocean-viewing concepts developed during the manned spaceflights through 1975 were indeed correct. The early demise of SEASAT did not alter the recognition that suitable sensing from space could indeed resolve most of the features of the dynamic ocean.

The tremendously successful observations by the astronauts from Skylab and Apollo/Soyuz made everyone eager for the opportunity to continue experiments from the space shuttle.

In the late 1970's therefore, with the prospect of a marked increase in spaceflights with the space shuttle coming on-line, NASA decided to form a small group of earth scientists who would work with each crew to train them in the latest advances in their particular discipline. The oceanographers involved in this team were Stevenson and the author.

Right from the start, important discoveries were made. In the first test flight in 1981, John Young and Bob Crippen photographed two spiral eddies in the Gulf of Oman. They were thought to be isolated examples. But in the very next flight the synthetic aperture radar SIR-A, carried onboard, imaged a well-formed spiral in the Caribbean. Although this was again an isolated example, it did raise the question as to how wide-spread these features are in the world's oceans. But perhaps the most significant event to come out of this mission was the observation by the pilot, Capt. Dick Truly, USN, now Rear Admiral, that he was looking at the ocean "with the wrong set of eyes." By this he meant that he could take photographs of interesting patterns in the ocean, but he had no way of knowing whether such patterns were of scientific concern or interest. Thus was born the concept of flying a trained oceanographer.

Subsequently, the Navy had informal discussions with NASA on this concept and it was originally suggested that two oceanographers should fly back-to-back missions. The flights originally considered were STS-7 and STS-8. However, as those flights came closer, NASA was becoming increasingly concerned with the effects of space adaptation syndrome, and so astronaut M.D.'s were assigned to those crews. Interestingly, it was from STS-8, commanded by Dick Truly, that we obtained the first indication that spiral eddies could be interconnected. They brought back photos of a field of spiral eddies throughout the Mozambique Channel in the Indian Ocean. Even more intriguing was the fact that these spirals in the Southern Hemisphere appeared to rotate in a direction opposite from those we had previously seen in the Northern Hemisphere.

With subsequent flights, all of the available seats aboard the shuttle were already designated for people critical to the particular mission. However, in May 1984, the orbiter flight line-up was changed and the STS-17 mission, which had previously been manifested for the

Columbia, was assigned to Challenger. Because of the on-board configuration, this then provided an extra seat to make a total of seven. However, six astronauts were already assigned, and NASA had never before flown a crew of seven. On the other hand, STS-17 was an ideal mission to view the ocean, since it was an earth sciences mission and was to be put into a high inclination (57-degree) orbit.

Early in June, NASA decided to go ahead with flying an oceanographer on STS-17 and on June 13, the author was selected. On June 27, I reported to the Johnson Space Center, Houston, Texas, to begin training.

PREFLIGHT TRAINING

SUMMARY

INT SIMS

INT DAY 1 . . . 8
LONG SIM
PI/DO PREP
ASC
ENTRY

OTHER SIMS

PI PREP (FB)
DO PREP (FB)
INGRESS (1G)
EGRESS (1G)
EMERG. EGRESS (1G)
ASC (MB)

HAB

HAB EQ
HAB PROC
WCS PROC

MED

PHYSICAL
PSYCHOLOGICAL
CLAUSTROPHOBIA
DENTAL

DSO'S

DSO PROC
SASSE (ETC)

PHOTO

NIKON
HASSELBLAD
AERO LINHOFF
16 MM
IMAX

CLOTHING

CLOTHING FIT CHECK
LEH & G-SUIT

KSC

PAD
OPF
LCC
CEIT
TCDT
EMERG. EGRESS
FIREFIGHTING
SAFETY

FLYING

KC-135
T-38
B-57
STA

EXTERNAL TRAINING

PAX RIVER
EAFB
GEOLOGY FIELD TRIP

OTHER TRAINING

FDF REVIEWS
T/L REVIEWS
BENCH REVIEW
CAP WALKTHROUGH
FD TAG-UP
MED PROC
FIREFIGHTING
QUARANTINE

DETAILED TRAINING

The summary training sheet may appear, at first sight, to be incomprehensible, but it does illustrate one of the basic points of training for payload specialists, i.e., that space flight involves an entirely new world (no pun) with its own set of rules, operations and language.

By far the most intensive and extensive part of the training involved simulations. These are of two types, integrated and stand alone. The integrated simulations are those in which the whole network is up; the simulator with its crew in one building is connected, via communication links only, to the Mission Operations Control Room and the vast network of consoles in the Mission Control Center. These simulations create, in a very real sense, the isolated nature of the orbiter on orbit interacting just as in the real mission with those on the ground. The concept here is to simulate every minute of every hour of every day of the total mission, often several times, so as to ensure that everyone is familiar with every aspect of the day to day operations. Moreover, it has the added advantage of enabling each member of the crew to come together as a team, so that no one crewmember's operations impact adversely on any other crew operations.

These integrated simulations are broken down into each day of the flight, i.e., an INT DAY 3 SIM will go through all operations to be performed on the third day of flight. Furthermore, in order to gain an appreciation for the constrained environment of the crew spaces aboard the orbiter, a long simulation of 54 hours duration is also performed. In addition, the integrated simulations include those for the post insertion, deorbit preparation, ascent and entry phases of the flight.

The stand alone simulations are, as the name implies, those performed by the crew without outside interaction. They include post insertion and deorbit preparation (unstowing/stowing gear for on-orbit operations and system activation/deactivation) in the fixed base simulator, ingress, egress and emergency egress procedures in the 1G trainer (a high fidelity orbiter mock-up), and ascents in the motion base simulator.

The next most important part of the training involves habitability. This includes both the equipment and procedures for food preparation, galley operation, personal lockers, personal hygiene and general housekeeping. In addition, the operations inherent in using the waste control system are practiced in detail.

The medical exams consist of a most extensive medical in which a series of tests are performed on the patient including a rigorous stress test. They also include both oral and written psychological tests, a test for claustrophobia and a dental check.

The crew is also trained in the requirements to carry out the detailed secondary objectives of the flight. This includes medical tests, radiation monitoring, vision tests and other small experiments carried and usually performed on the mid-deck. In addition, the Canadian payload specialist was performing a series of experiments in the life sciences. These included tests on vestibulo-ocular reflex, sensory function in limbs, proprioceptive illusions, awareness of external objects, space motion sickness and taste in space. Since I had volunteered to be a subject for these experiments, a number of baseline tests and practices were included in my preflight training to cover these topics.

Extensive training in photographic techniques and the various photographic equipment is also given to the crew. For an oceanographic observer, whose main method of data recording is through photographs, this training was particularly important and vital for the success of this aspect of the mission. The equipment covered included the use of 35mm Nikon cameras, 70mm Hasselblad cameras (the main oceanographic recording instrument), the 5-in. format Aero Linhoff camera, the 16mm movie camera and the huge IMAX panorama camera carried specifically to obtain footage for the space film "The Dream is Alive."

Clothing used for launch, on-orbit and landing needs individual fitting and check-out. Also, the special equipment such as the harness, vest, launch and entry helmet, and G-suit need to be tailored to individual requirements and instruction given in their use and operation

So far in this description, all of the training related to the Johnson Space Center, Houston, Texas. Extensive training was also undertaken at the Kennedy Space Center, Cape Canaveral, Florida. This training, which occurred closer in to flight, consisted of walkdowns (familiarization) with the launch pad, the orbiter processing facility and the launch control center. The crew equipment interface test consisted in a hands-on check of all crew equipment aboard the actual orbiter, and the terminal countdown demonstration test, a most vital part of the training, consisted in a dry-run of all procedures and operations on launch day, including boarding the orbiter which was already on the launch pad. Other training at the Cape included emergency egress procedures from the orbiter on the pad, the slide wire operation, emergency vehicle operations, firefighting and extensive safety procedures

Flying training consisted of weightlessness, high performance flying, very high altitude flying, and shuttle approach and landing flights. All were intended to give a neophyte an appreciation of the alien environment he would experience and the sensations encountered aboard the orbiter. The weightlessness consisted of flying parabolic arcs aboard a KC-135, a militarized version of the 707, in which you would essentially free-fall within the aircraft for 10,000 ft., thus relative to the aircraft you would be floating weightless for about 30 secs. The high performance flying was done in the backseat of a T-38 supersonic fighter, in which the crew commander would build confidence with the payload specialist through a series of shared experiences in tight maneuvers. The very high altitude flying, an elective chosen only by myself, involved 60,000 feet flights in a B-57. Flying at this height necessitates using a full pressure suit and enabled me to gain experience in operating the flight camera equipment from a perspective that was closer to the field of view from orbit. Finally the shuttle approach flying was experienced aboard a shuttle training aircraft, a Gulfstream jet specially modified to handle like the orbiter on final approach when the glide angle is about 19 degrees.

Training not performed at either JSC or KSC included aviation training at the Naval Air Station, Patuxent River, MD, and Edwards Air Force Base, CA, and a geology field trip in New Mexico. Pax River consisted of aviation physiology, a high altitude chamber run and ejection seat use and firing. The Edwards training was for the B-57 flights and involved full pressure suit fitting and use, and a 100,000 ft. chamber flight in which there was a preprogrammed very rapid decompression. The geology field trip is standard for all astronauts, and is the hands-on part of the geology training which, like oceanography, is one of the basic elements to their earth observations training.

The remaining training consisted of flight data file reviews (i.e., all of the onboard documentation carried), time line reviews, the Bench review of all onboard crew equipment, crew activity plan (CAP) walkthroughs, flight director meetings, onboard medical procedures and firefighting. For an appreciation of the documentation involved, one page of the 102 page CAP is reproduced in Figure 1.

One week before flight the crew goes into quarantine at JSC to minimize contact with colds, flu, etc. and three days before flight we went to crew quarters at KSC for final briefings and preparation. All in all, the preflight training can be likened to three months of "drinking at the end of a firehose."

DISCUSSION

In terms of preflight training, I think one of the good experiences was actual flying training for people like us who have not really had much flying experience. It was very good because, for a start, it tends to tell you you're operating in a different environment. For example, the STA flight showed us that the glidepath of the Orbiter was distinctly different from what we're all used to in a commercial airliner. And I think the T-38 flying was good because it gave us a feel for operating as an aviator, if you will. And the third thing, the B-57 I felt was very useful, particularly insofar as it brought home to me at least that we're operating in a very alien environment, and that's a message we as PS's could very easily lose because the Orbiter is a shirt-sleeve environment. I think it brings home to us the fact that we have to be very careful and very safety conscious; otherwise, one small mistake could create problems for everyone.

From the point of view of the participation in the SIM's, I think it's essential that we PS's do that. I think it's doubly essential to start off from the concept that we absolutely must be part of the 3-day SIM. And at least from my perspective, each time we SIMed together in an integrated SIM, I felt that we were going from—at least for myself—being an individual added to the team to becoming part of the team and trying to understand what the team was trying to achieve in the mission. In terms of overall participation in the integrated SIM's, I would think that what we did was certainly an adequate amount. And if we were trying to put some bounds on this, I would think if you ever got down to less than 80 percent of what we did, then that's not enough for us as PS's to become integrated with the crew.

I think one of the extra points that comes up with training can all be said in terms of the opportunity we had to do some ascents on the motion-base simulator. Of course, I've heard a lot of people talk about ascent, and different people have different views on it, but when you actually go through the simulator, you yourself get a real feel for what it is. And I think that's illustrative of a general thought that I've had throughout this whole training, and that is that the more you can replicate what you're actually going to do in going on a space mission, the less apprehensive you're going to be because, obviously, the more experiences you can have the better—it's always fear of the unknown. And the more we can get away from that, the better we are.

I think another good experience I had was the opportunity to go on the geology field trip. For someone like me who's never done any geology, it was very useful, once we got on orbit looking out the window, to look at the solid Earth and be able to recognize some of the things we learned on the geology field trip. And so, conversely, I would think that someone who's a nonoceanographer, going up on orbit, would need to have a set of oceanographic experiences as well as a set of geology experiences.

The TCDT is an absolutely essential feature of the training. That one-time experience of going through the terminal phase prior to launch is invaluable from the point of view of giving confidence and learning what has to be done during that time. It is essential that PS's go through those sort of experiences.

The theme that runs through all of the training is that the more of the unknown that you can eliminate preflight, the better the performance of the mission is going to be.

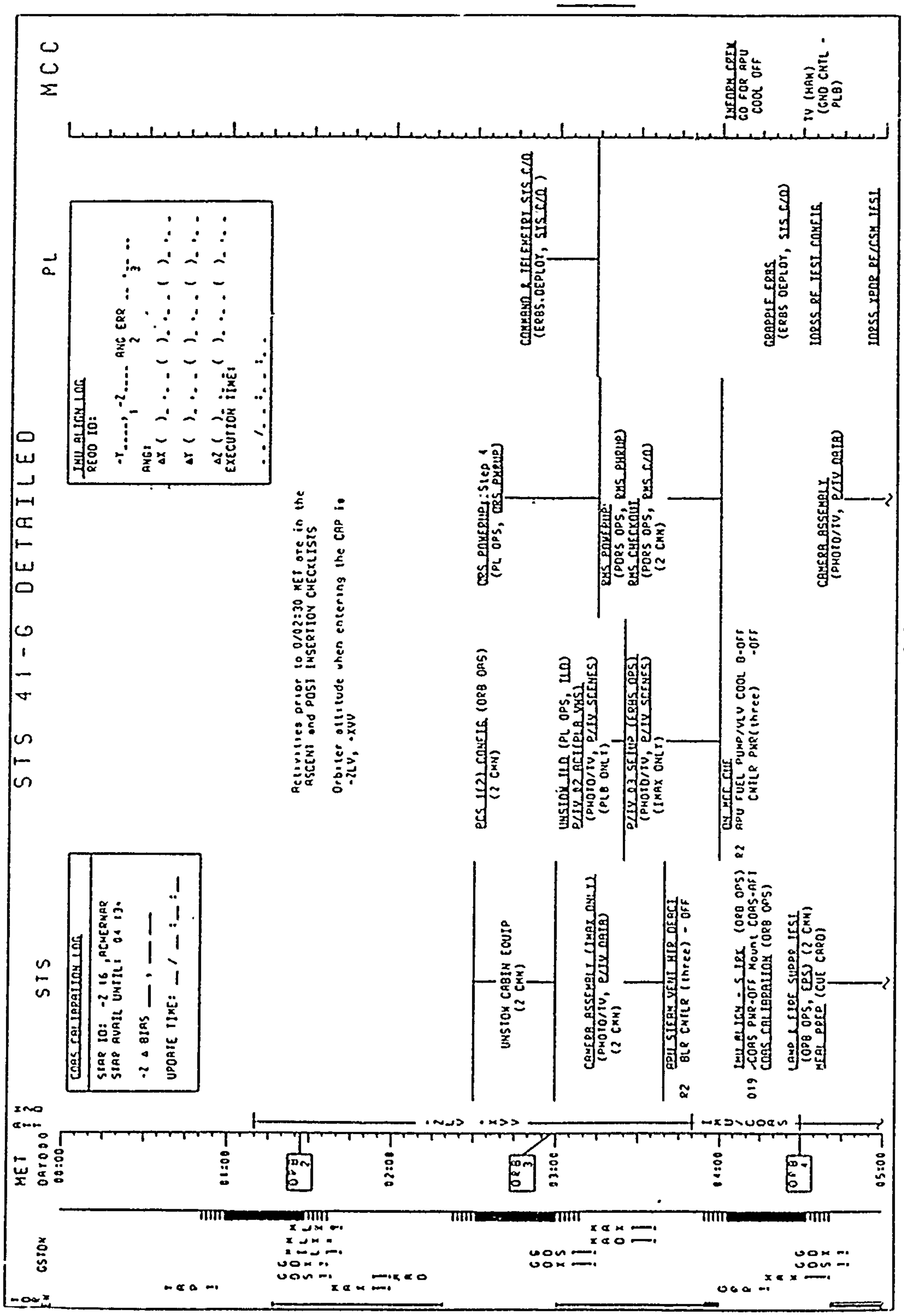


Figure 1. Crew Activity Plan—First Five Hours

OCEANOGRAPHIC PREPARATION

During the three month period of my preflight training, CDR John Hughes, USN, of the Naval Underwater Systems Center, LCDR Ty Aldinger, USN, Oceanographic Liaison Officer, Astronaut Office, Johnson Space Center, and Dr. Dennis Conlon, Office of Naval Research, did an outstanding job of compiling the Navy Oceanographer Shuttle Observation Plan for STS-41G. The plan was formally issued by the Navy Space Oceanography Committee on 14 September 1984. It was formulated with primary emphasis placed on coordinating shuttle observations with *in situ* field research programs. This coordination would not have been possible without the active participation of many scientists in the oceanographic community, and their assistance is gratefully acknowledged.

The plan was in three sections. oceanographic operations, science issues, and mission graphics.

Section I of the Plan was a matrix layout by geographic area of features of interest, science investigators, and coordinating assets (ships, planes, satellite data). It should be noted that the STS-41G, combined with other satellite assets, provided a unique opportunity to view the ocean with IR sensors (NOAA-7), color sensors (CZCS), synthetic aperture radar (SIR-B), cameras and manned observations. In developing the plan, emphasis was placed on insuring maximum benefit from this suite of sensors.

Twelve specific oceanographic sites were identified which involved twenty-nine science investigators from seventeen institutions. The institutions represented were:

SCRIPPS	BIGELOW	NORDA
WOODS HOLE	IOS	NAVOCEANO
LAMONT	GODDARD	NEPRF
JOHNS HOPKINS	JSC	USNA
U. MIAMI	NOAA	NUSC
U. WASHINGTON	ONR	

Section II laid out the science issues to be addressed, with cross referencing to the areas noted in Section I. Although the oceanographic instrumentation was limited on this mission to hand-held cameras with polarizing filters, a large number of interesting scientific issues were identified which fell into three basic categories. First, there are problems which can be attacked solely through direct observations (soliton packets, submesoscale eddies, etc.). Second, there are problems for which observations will form a complementary contribution (e.g., eddy fields in the Brazil-Falkland Confluence). Finally, there is a category of scientific exploration that cannot be defined *a priori* because we cannot predict what will be observed.

The major scientific topics identified were:

INTERNAL WAVES AND SOLITONS
OCEANIC EDDIES
COASTAL FRONTS AND JETS
ISLAND WAKES
EQUATORIAL DYNAMICS
OBSERVATIONAL TECHNIQUES

Of particular note was the multifaceted research effort by NORDA in the Strait of Gibraltar and the Western Alboran Sea in which ships, aircraft and satellites were organized to take measurements in that area simultaneously with specific shuttle overpasses and onboard photography.

Section III provided basic information on orbital ground tracks, viewing opportunities and positions of *in situ* assets.

The whole shuttle observation plan was finally summarized into an oceanographic MET List which sequentially logged orbit number, MET, f-stops, sites, features and viewing comments. This list, which flew on the orbiter as part of the official flight data file, is reproduced in Figure 2.

In addition, as part of the oceanographic preparation, the sun glitter points were computer calculated for each orbit pertinent to specific oceanographic sites. A typical example is given in Figure 3.

Finally, to give an idea of site locations and orbital coverage, an orbital plot/site location chart is reproduced in Figure 4.

ORBIT	M.E.T.	EXPOSURE f-Stop	SITE NAME	FEATURES	SPECIAL VIEWING COMMENTS
3	0/03·31	5 6/8	Western Med	Alboran Front, Tidal Pulsing Gibraltar, Coastal Eddies	Best sun-glint opportunity of Gibraltar to southwest on low oblique
7	0/09:40	5 6/8	Gulf of Mexico	Loop Current, Eddies	Only opportunity for Yucatan Channel, near vertical to southwest, good glint
8	0/11:09	5.6/8	Socal/Baja	Coastal Eddies, Internal Waves/Tides	Only opportunity this region Very low oblique coastal Ca, good NV over Glf of Ca
8	0/11:18	5.6	Equatorial East Pac	Island Wakes	Near vertical of Galapagos
16	0/23:09	5.6	Great Britain	Internal Waves, Ship Wakes	Note North Sea oil platforms for visibility
16	0/23:26	5 6/8	Indian Ocean	Ocean Color, Internal Waves	Look for sediment discoloration mouth of Indus, Internal Waves in N. Equatorial Current south of Sri Lanka
17	1/00:43	5.6/8	Great Britain	Ocean Color, Ship Wakes	Color important west of Ireland, wakes in northern approaches of Dover
17	1/01:01	5.6/8	Indian Ocean	Eddies, Fronts, Current Shear	Only opportunity for eddies, Glf of Aden; Somali Front south of Socotra, look for any discrimination of Somali Current
18	1/02:24	5.6/8	Western Med.	Coastal Eddies	Good sunglint southwest along Algerian Coast
21	1/06:56	5.6/8	New England Shelf	Internal Waves Ship Wakes	Glitter southwest to Cape Cod
21	1/07:06	5.6/8	Equatorial Atlantic	Current Shears	Glint southwest for equatorial dynamics
22	1/08:18	5.6	Gulf of Alaska	"Sitka" Eddy	Warm Core eddy shed, near coastal
22	1/08:35	5.6/8	Lesser Antilles	Eddies, Internal Waves	Only opportunity this site
23	1/09:53	5.6/8	Juan de Fuca	Fresh water Outflow	Possible sunglint southwest. Only opportunity this site
23	1/10:02	5.6/8	Gulf of Mexico	Mesoscale Dynamics	Should be good oil enhanced surface, extreme western Gulf
23	1/10:08	5.6/8	Equatorial East Pac	Ocean Fronts, Currents	Watch for coastal features along Ecuador
24	1/11:38	5.6/8	Equatorial East Pac	Fronts, Current Shears	
32	1/23:16	5.6	Great Britain	Ship Wakes	North Sea of interest
32	1/23:31	5.6/8	Indian Ocean	Eddies, Wakes, Pollutants	Best opportunity for Hormuz

Figure 2. Oceanographic MET List

ORBIT	M.E.T.	EXPOSURE f-Stop	SITE NAME	FEATURES	SPECIAL VIEWING COMMENTS
34	2/02 26	5 6/8	Western Med	Internal Waves, Coastal Eddies	
36	2/05 20	5 6/8	New England Shelf	Internal Waves	Shoaling processes along Newfoundland
36	2/05 32	5.6/8	Equatorial Atlantic	Ocean Fronts, Current Shears	
37	2/06 51	5.6/8	New England Shelf	Internal Waves	Coastal/Island interaction, Nantucket
37	2/07:01	5.6/8	Equatorial Atlantic	Ocean Fronts, Currents, Color	Start looking for Amazon sediment to southwest
38	2/08·13	5 6	Gulf of Alaska	"Sitka Eddy"	
40	2/11.29	5.6/8	Equatorial East Pac	Equatorial Current	
48	2/23·01	5.6	Great Britain	Internal Waves Ocean Color	Both on Western Approaches and North Sea
48	2/23 14	8	Indian Ocean	Ship Wakes, Eddies, Surface Pollutants, Island Wakes	Good opportunity for anchorage off Masirah; Island effects through Maldives
52	3/05:04	5.6/8	New England Shelf	Internal Waves	Interaction w/continental slope/shelf along Grand Banks
52	3/05:15	8	Equatorial Atlantic	Ocean Fronts, Color, Currents	
53	3/06.35	8	New England Shelf	Internal Waves, Ship Wakes	Note shipping out of New York Bight
53	3/06:44	8	Equatorial Atlantic	Ocean Fronts, Color, Currents	
54	3/07:56	5.6	Gulf of Alaska	"Sitka" Eddy	Last opportunity this site.
54	3/08:08	8	Gulf of Mexico	Mesoscale Dynamics	Good glint southwest along Fla. coast, low oblique
56	3/11:13	8	Equatorial East Pac	Equatorial Dynamics	
63	3/21:34	8	Indian Ocean	Internal Waves	Look for propagation in North Eq. Current
72	4/10:56	8	Equatorial East Pac	Equatorial Dynamics	Good polarizer opportunity
79	4/21:16	8	Indian Ocean	Ocean Fronts, Color, Internal Waves	
80	4/11:39	8	Indian Ocean	Eddies, Ship Wakes, Surface Pollutants, Color	Best opportunity for Persian Gulf
83	5/03:13	8	Equatorial Atlantic	Coastal Plumes, Equatorial Dynamics	Ivory Coast views

Figure 2. Oceanographic MET List (Cont'd)

ORBIT	M.E.T.	EXPOSURE f-Stop	SITE NAME	FEATURES	SPECIAL VIEWING COMMENTS
84	5/04:28	5.6/8	New England Shelf	Internal Waves	Shelf Interaction
84	5/04 41	8	Equatorial Atlantic	Current Shears, Ocean Color	Polarization
85	5/06:00	8	New England Shelf	Internal Waves, Ship Wakes, Hudson Outflow	Near Vertical over NYC, Hudson River outflow
85	5/06:10	8	Equatorial Atlantic	Sediment Plumes	Look southwest to Brazil Coast for Amazon Effluent
86	5/07.32	8	Gulf of Mexico	Eddies, Loop Current	Best opportunity for Loop Current
88	5/10:38	8	Equatorial East pac	Ocean Front, Current Shear	
95	5/20:58	8	Indian Ocean	Internal Waves, Eddies	Low oblique to Sri Lanka, good glint
96	5/22:21	8	Indian Ocean	Eddies, Ship Wakes, Surface Pollutants, Color	Good near vertical entire Persian Gulf, also Diego Garcia
97	5/23:40	5.6/8	Great Britain	Internal Waves, Ocean Color, Ship Wakes	Best look northeast to Dover, High oblique
97	5/23:59	8	Indian Ocean	Current Shear, Island Wakes	Somali Current, Wakes downstream Mauritius
98	6/01:17	8	Western Med	Internal Waves, Ocean Fronts, Color	
98	6/01:34	5.6/8	Indian Ocean	Eddies, Current Shear	Look north through Mozambique Channel, also Agulhas Current
99	6/02:56	8	Equatorial Atlantic	Equatorial Dynamics	
99	6/03:08	5.6/8	Indian Ocean	Current Shear, Gravity Waves	Agulhas Interaction
101	6/05:53	8	Equatorial Atlantic	Sediment Plumes	Best opportunity, high oblique to Amazon Delta
104	6/10:20	8	Equatorial East Pac	Ocean Fronts, Color	
113	6/23:23	5.6/8	Great Britain	Ship Wakes, Internal Waves	Last opportunity this site
113	6/23:41	8	Indian Ocean	Current Shear, Island Wakes	Last opportunity for Somali Current as well as Mauritius
114	7/00:59	8	West Med.	Alboran Front, Tidal Pulsing, Coastal Eddies	Excellent chance for Gibraltar, good sun, high oblique to southwest. Last opportunity this site

Figure 2. Oceanographic MET List (Cont'd)

ORBIT	M.E.T.	EXPOSURE f-Stop	SITE NAME	FEATURES	SPECIAL VIEWING COMMENTS
114	7/01 17	5.6/8	Indian Ocean	Current Interaction, Eddies	Agulhas, also temporal revisit features orbit 98
115	7/02 38	8	Equatorial Atlantic	Equatorial Dynamics	Polarization
115	7/02.50	5.6/8	Indian Ocean	Ocean Currents, Eddies	Last opportunity Agulhas region
116	7/04:06	8	Equatorial Atlantic	Ocean Fronts, Color, Current Shear	Last opportunity, good transit of Mid-Atlantic Ridge
119	7/08:34	8	Equatorial East Pac	Island Wakes, Ocean Color	Best opportunity Galapagos
119	7/08:46	5.6	Brazil-Falkland Confluence	Eddies, Ocean Color	Only opportunity this site.
120	7/10:02	8	Equatorial East Pac	Equatorial Dynamics	Polarization. Last opportunity this site.

Figure 2. Oceanographic MET List (Cont'd)

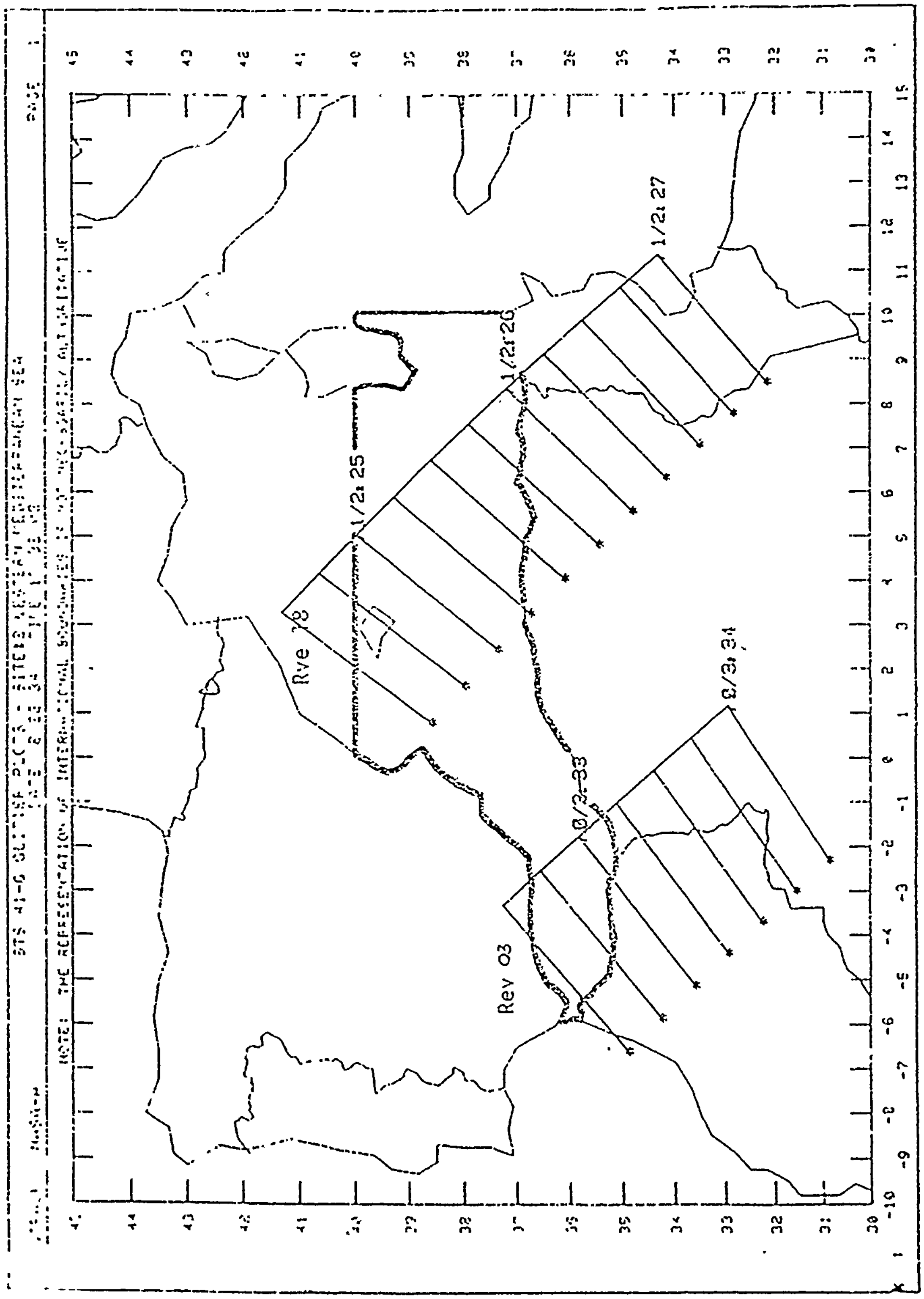


Figure 3. Sun Glitter Plot

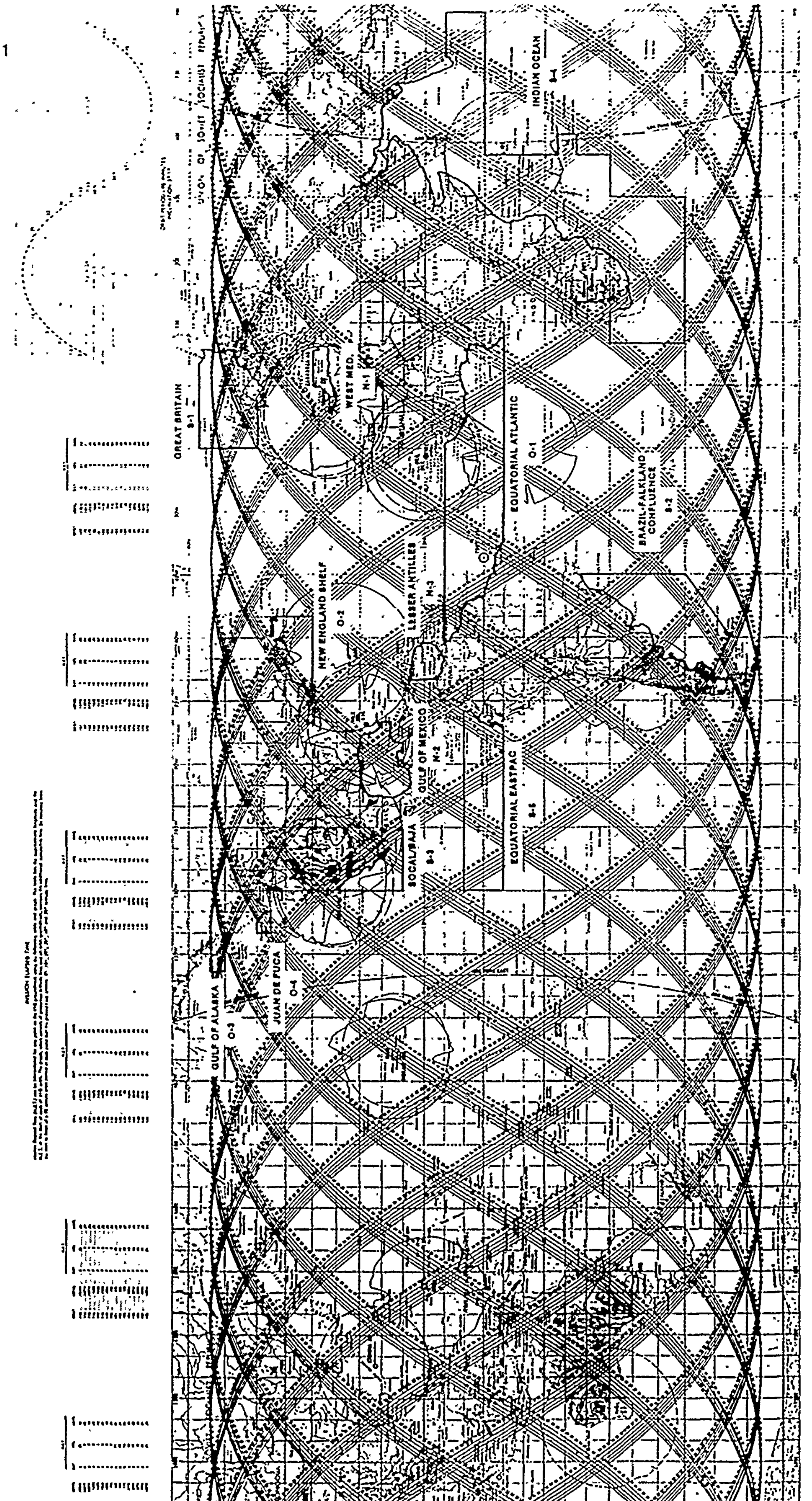


Figure 4. Orbital Plot/Site Location Chart

ON-ORBIT OPERATIONS

Much have I travell'd in the realms of gold,
And many goodly states and kingdoms seen;
Round many western islands have I been
Which bards in fealty to Apollo hold.
Oft of one wide expanse had I been told,
That deep-brow'd Homer ruled as his demesne:
Yet did I never breathe its pure serene
Till I heard Chapman speak out loud and bold:
Then felt I like some watcher of the skies
When a new planet swims into his ken;
Or like stout Cortez when with eagle eyes
He stared at the Pacific—and all his men
Look'd at each other with a wild surmise—
Silent, upon a peak in Darien.

John Keats
On First Looking into Chapman's Homer

The Challenger was launched from Pad 39A at the Kennedy Space Center at 7:03 AM EDT on Friday, 5 October 1984, and landed back at KSC (Runway 33) 8 days, 5 hours, 24 mins. and 45 seconds later on Saturday, 13 October, at 12:27 PM EDT. It was launched into an orbit with a 57° inclination, at an altitude of 190 nmi. (Day 1), 148 nmi. (Day 2) and 121 nmi. (subsequent days). Challenger travelled 2,984,397 nmi. and completed 132 orbits of the earth, landing on orbit 133.

The on-orbit operations were recorded in real time by two methods, a hand-held tape recorder and written notes. The procedure used was to Velcro the tape recorder to the side of the window I was looking out and to verbally record what I was seeing as I was seeing it. This left both hands free to simultaneously take photographs of the significant ocean features within the field of view. During the dark side of the orbit, I would then float down to the mid-deck and write up the notes from that orbit. In addition, on the dark side, I would assist the Canadian Payload Specialist with his experiments.

The tape recorded and written notes are reproduced here without modification so that the reader can not only gain an appreciation for the on-orbit operations, but also begin to feel the sense of discovery that resulted in looking at the ocean from this new vantage point. Mission Elapsed Time (MET) starts at launch and is counted in days:hours:minutes. The orbital period is 90 mins.

ONBOARD TAPE RECORDED NOTES, FLIGHT 41-G

MET: 00:00:26 O.K. This is PSP on orbit at MET zero hours and twenty-six minutes with some first impressions. Let me just do a check on the system.

MET: 00:00:39 O.K. This is PSP back at zero hours and thirty-nine minutes. First impressions. The launch was very smooth. I think the biggest vibration was with the gimbaling of the nozzles of the three main engines prior to flight. After that when the main engines ignited it was very smooth; when the SRB's ignited it was again very smooth. I think the hardest thing on launch was the 3-g's acceleration; it wasn't hard in itself, it was just the fact that you had to hold this 3-g configuration for quite some minutes. And then the biggest transition I think was that of main engine cut-off when we went from about 2½-g's to zero-g very, very quickly. First impressions when you do that is that your body floats up, but then you see particles of dust wandering around the cabin and as soon as you see these particles of dust wandering around, you immediately know that you are in zero-g. We then unbelted, started to stow our helmets, and then I got over to the side hatch window for my first view; and the view is certainly spectacular, it is far better than any photographs. You can see far clearer than any photographs and the colors seem to have a far better contrast. Currently right now we are going about our business putting things away, securing before the OMS-2 burn. (Time gap.) Again first impressions, you look out the window and you can certainly see the curvature of the earth out to the horizon. I think more spectacular is that, above the horizon, it is totally black with one bright star—the sun—shining. Then you look down and you see: the first impression of the earth is all blue with white clouds in patterns underneath. It is certainly a spectacular sight. The all black sky (so called) is certainly dramatic.

MET: 00:00:53 I am now on the flight deck looking out the overhead windows looking at our first sunset coming up and again some first impressions is that you can see some depth expression in the clouds—you definitely can see depth expression—and secondly, from on orbit the earth sure doesn't look as far away as it is—it looks real close, real close. (Time gap.) That was another first impression I should have mentioned and that is that zero-g up here is a totally different feeling from zero-g in the KC-135. This is a far more "floaty" type of environment; you seem to be more suspended, with not any sense at all of gravity up here, whereas I think on the KC-135, now that I've experienced this, there is a change.

MET: 00:01:32 We've just gone through our first sunrise. The interesting thing about that is that on the horizon, on a far oblique, the earth is in sunshine whereas at low oblique below us it is still totally in the dark.

MET: 00:01:43 I took my first look out into the payload bay and the sun is now shining on everything in the payload bay. The doors are open and the earth is below and it's a spectacular sight, just spectacular.

MET: 00:02:02 I'm looking out at sunlight over water. A pass without any cloud and it was certainly a what I call a mottled and textured ocean; a whole bunch of curlyques with some frontal structure which is quite subtle in the sunglint. It didn't seem to show any particular pattern.

MET: 00:02:08 Another first impression. One is really impressed by the amount of cloud cover that is around the world. It's not solid, it's broken up, but boy, there's a lot of cloud.

MET: 00:04:10 We took our first oceanographic site which is Gibraltar. The notes and the observations are logged in the notebook. I am now on the mid-deck.

MET: 00:07:11 We have just finished a pass down the entire Atlantic, both north and south. Some observations are that there was an extreme amount of cloud. By extreme, I mean relative to what I expected. It's not solid cloud, it was broken. There were patches of clear but mostly you'd have to say the whole Atlantic was scattered cloud. Interestingly enough, in the clear, if you used the gyro-stabilized binoculars, you can indeed see without any problem at all, the surface wave field. You can see this in the sunglint specular point or specular area. The specular point turns out to be quite a large area, at least on this orbit, and anywhere in that area using the binoculars you could easily make out the surface wave field; you can make out the direction in which the swell was moving. Saw my first sunset throughout its entirety; it's certainly spectacular. The one thing that I guess was unexpected is that above the horizon the height or depth if you will of blue before you get to that black void of space is much bigger than you would expect. It's about, I would say, five to ten times thicker than the red and yellow and purple banding of the actual sunset.

MET: 00.08:06 We're just passing over Cape Cod, which is not cloud covered, and Kathy is taking a photograph with the Aero Linhoff. It looks absolutely spectacular. You can see the detail, including the sharp hook to the north. (Time gap.) The thing that is really hard to get over is the ice particles that follow us everywhere. When you look out you see them against the void of space and you may see just one or two and sometimes quite a bunch of them. And they follow you around; some of them seem to be heading towards the earth very fast, others are just seemingly to be moving all along with us.

MET: 00:10:02 Looking out the side hatch window and we have the ERBS satellite right alongside the side hatch window. In fact it's so close it almost seems to be tucked under the port radiator, and we have the earth below at an unusual attitude. Just now coming from daylight into dusk.

MET: 00:11:01 Just recently in the last few minutes have taken two photographs with the Hasselblad, both on f11. One was of the ocean just south of a point of land which I think was Sakhalin Island, and the next one was of frontal structure in the ocean—check, the second one was a front in the ocean just south of a second tip of land which I think was the tip of Kamchatka Peninsula. At 11 hours and 2 minutes it was 56.5° N, 166.8° W.

MET: 00:23:18 Going over the Black Sea. Shot two shots on the Hasselblad, 100mm lens. First one showed some frontal features, and the second one showed a neat spiral near the coastline on the Black Sea.

MET: 00:23:23 Just gone over the Caspian Sea, very heavily cloud covered.

MET: 00:23:25 Orbiting over the Persian Gulf, low oblique. Just coming up now into the Gulf of Oman. Small frontal feature seen in the Strait of Hormuz.

MET: 00:23:28 We have just passed over the Gulf of Oman. There were some super shots in sort of mid-oblique right in the sunglint, shot with the Hasselblad, 100mm lens. One exceedingly well formed spiral eddy, a bunch of linear frontal band type streaks, and one very strong front.

MET: 01:00:46 Just orbiting now over Ireland and England. England and Scotland are very cloud covered. Ireland has row after row of puffball cumulus. Just coming up over the Strait of Dover now and Crip's up forward looking in the gondola position and Crip is going to take some shots of the Strait of Dover in the sunglint.

MET: 01:00:52 Just came over the Mediterranean with Italy in the background, shooting south. It's superb spirals and fronts in the central Mediterranean which we've shot.

MET: 01:00:53 Tremendous ship wake in the Gulf with just incredible spirals and contorted structure. Just spectacular spiral eddies throughout this whole region, just spectacular.

MET: 01:00:54 We're coming up over Cyprus now. Right across the Mediterranean there is just spectacular oceanography, just spectacular. There's two sets of long internal waves on both sides of Cyprus. They're both heading over towards Israel, but that's the normal propagation direction, is towards Israel. The more you see here, the more you just see of more spiral eddies, fronts and of very long internal waves. They're not quite as long as solitons but getting that way, they have soliton structure. The Mediterranean is equally as complex as the Mozambique Channel, if not more so. There's connected spirals all the way across from coastline to coastline, just spectacular dynamics. Perhaps the more interesting thing is that these quasi-solitons that I've seen are laid right across the spiral structure, which we did not see in the Mozambique Channel.

MET: 01:00:57 Solitons in the Red Sea. There's one, two, three, four, five, six, seven, eight, nine, ten waves; each one seems to be a double wave. The normal soliton packet with two crests right close together in each one that I cannot easily distinguish it. But definitely a double-humped soliton for each wavelength. As we've come down the Red Sea the specular point has kept on tracking straight down the middle of it; just one spectacular pass, just one spectacular pass.

MET: 01:01.04 We have just come across the Gulf of Aden, the perfect specular point for the sun glitter but there was absolutely no structure there whatsoever. I have the Linhoff with a 100mm lens set on f11, 1/250th of a second. I took one shot of the whole Gulf of Aden in the sun's glitter pattern but there is no structure.

MET. 01:02.49 Since our last report I've moved from the overhead windows up into the pilot's window in the gondola position. This gave me a view of the sunglint through the Mozambique Channel. There was some structure; I photographed it with the Aero Linhoff camera, but there certainly wasn't the spiral eddies that are usually in that channel.

MET. 01:04.00 Now on Rev #19. We're just crossing the coast of Africa. There was a clear patch of about fifty miles of water before we got to the coast, and near the coast there appeared to be a whole cloud of white particles just hanging over the water about ten miles offshore. I photographed these with the Hasselblad with the 250mm lens, 1/250th sec at 11/16 f-stop.

MET. 01.10:00 We have just recently flown over the Strait of Juan de Fuca. There is a solid cloud, solid cloud. Took a shot, but no possibility of seeing the Sitka eddy.

MET. 01.10:26 We have just passed over Montevideo. It was not cloud covered but it was very hazy. We all shot it with the different cameras including the Linhoff. It could turn out well.

MET. 01:11:18 Just flown past the tip of the island and the coastline of Sakhalin Island and got one or two good internal waves in the sunglint photos. They may have been shot with the camera on an f-stop of 4 or 4/5.6.

MET: 01:11:29 We have taken some shots of very distinct swell in the ocean, using a Hasselblad, 250mm.

MET: 01:23:24 We have just recently come over the British Isles, looking out, good sunglint but totally cloud covered.

MET: 01:23:29 Just came over a bunch of lakes and seas, one of which I think was the Caspian. Tremendous sunglint. We've taken it on a Hasselblad 100, 250, and the Linhoff.

MET: 01:23:37 We have just finished a spectacular pass over the Persian Gulf, the Strait of Hormuz and the Gulf of Oman. It was clear all the way. We could see everything from the northern part of the Gulf with the burning oil rigs off Kharg Island right down the Gulf. There is a lot of large surface oil patches in the southern part of the Persian Gulf and on the Arabian Peninsula there was one heck of a lot of sunglint dynamics showing. The orbit was such that we weren't far enough north to get the sunglint over the Gulf of Oman. We in fact orbited right over the Gulf of Oman. In the color there was no dynamics but I know yesterday there was a big spiral eddy there—a very large spiral which was there yesterday, which we had the right angle for the sunglint. We also photographed the oil tankers which are sitting there in a little embayment along the Arabian Peninsula. They were very visible and easy to see with the naked eye as well.

MET: 02:01:01 We have just come over the eastern Mediterranean with the most spectacular sunglint pass you have ever seen; mile after mile of arranged, in a line, spiral eddies. ! have taken them all with a Hasselblad, 250mm lens, on an f-stop of 13.

MET: 02:06:54 We've just done a spectacular pass down over Boston and Cape Cod which was in the clear. We took photographs on all cameras; the Linhoff may have been pulling empty film. Then we came out on the water which was clear for about 40 miles. There was some structure in the sunglint. There was one or two small spirals and quite a number of long linear streaks; they did not seem to be organized in any particular pattern.

MET: 02:09:58 We've just got a giant series of internal waves crossing a coastline. It's the coastline of South America.

MET: 02:23:19 I see in the Gulf of Oman there are two tanker anchorages, one just before you go into the strait, and the other one further down in the Gulf of Oman on the southern side. Right now we are just coming down the Indian Ocean past Masirah, at the point which is just the big point of land, the next point south of Masirah. There is a frontal structure that extends a good 150 to 200 miles out into the Gulf of Oman. It's very subtle. You can see it both in the sunglint and the color but it's extremely subtle; and it's a continuous front running at right angles to the coastline for about 150 to 200 miles. In the Persian Gulf, apart from all the super spiral structure there was just some incredible ships' wakes which we shot. Most of the ships' wakes were just inside the Strait of Hormuz.

MET: 03:23:00 We're just orbiting once again over the Persian Gulf. Down into the Gulf of Oman, Indian Ocean area, there is one incredible dust storm over this area today. The dust is going well out into the Gulf of Oman, it's covering two-thirds of the Gulf and all the way down to about 30 miles south of the southern tip of Masirah. The viewing conditions therefore are not nearly as good as they were yesterday. When we passed Lake Van back a few minutes ago, there's a neat set of spiral eddies in the middle of that which seem to have a constant pattern; they've been there the last three days. Once again, out over the Gulf of Oman, that long linear front. It starts at the headland that's just south of Masirah and . . . once again, that long front that stretches for about 150 miles out from that headland by Masirah. Again today it was in fact, I think, more visible today than it was yesterday, and Crip just took a series of 250mm Hasselblad's right along the length of that.

MET: 04:10:50 We're on Rev #72, coming down the eastern North Pacific. We're several hundred miles from the California coast, opposite about Los Angeles and Monterey. The interesting thing is that for the first time out here I've been able to see parts of the ocean between the clouds; the clouds are thinning and you see patches of ocean. When you see the ocean out here even this far from shore, once again you continue to see these spiral structures connected by a linear front; some of them are linear, some are not linear but at least they're slick patterns, long thin slick patterns connecting the spirals. Again, once again, you see the same kind of thing, so maybe the whole ocean is like this, I don't know.

MET: 05:00:03 We've just come over Ireland and England. For the first time Ireland and part of England are not covered with cloud, and there's a whole mess of small spiral eddies between Ireland and England. We orbited over the southern tip of England, and from there on it was cloudy. Took wonderful photo with the Hasselblad, 100mm, of the spiral eddies between Ireland and England.

MET: 05:00:04 We are now starting to orbit over the Mediterranean, the Mediterranean is cloud covered. We've come down, I guess it's the western shore of Italy there. A small front and some small spirals along the coastline. From there on right through almost to Gibraltar it's solid cloud cover. Down there, on the coast of Italy, interesting that every headland seems to have a small front associated with it and I estimate the fronts are about 25 miles. We're working down the Mediterranean now and it's interesting to see there's a what looks like a formation, a big storm that is covering the entire central Mediterranean, going up into Spain and Portugal and sweeping back again. Coming down towards the southern shores of the Mediterranean now, the cloud is clearing and you see the water and once again there's some small spirals. There also appears to be pretty long streaks, not internal waves, but long streaky patterns in the water. They're fine streaks forming streaky patterns that are running parallel to the coastline. As we come up on the coast of Egypt I guess what we're looking at is some long lines of internal waves and then right near the shore we go from that pattern into the classic spirals connected with long streamers. You can see the spirals both in the sunglint and in the off specular point where it becomes dark blue. They stand out very, very easily.

MET: 05:00:19 We're currently orbiting over the northern part of the Mozambique Channel. I'm looking south into the sunglint; so far I see no structure at all. Very scattered cumulus all over the Mozambique Channel. We're about half way down the channel now; I can just see Madagascar coming up through the tip of the window off to my left. Again looking at the specular point which is quite close in, the specular point is probably with a depression angle of about 15 to 20 degrees. Once again, although we're in the -ZLV, in this case tail forward position, the front windows are still the best for the sunglint in the gondola position. We've now come right across the Mozambique Channel, just coming over the western shore of Madagascar. Have not taken one shot across here because I've been watching the sunglint the whole way across and it's been flat. There's a little bit of structure right on the western shore of Madagascar; just a little bit of structure, one front off the northern tip.

MET: 05:00:26 I've been quietly doing a sun angle test here. It is interesting; you get good glitter down to about 25 degrees. I'd say, down to about 25 degrees you get beautiful sunglint. It is interesting that as the sun gets lower in the sky, of course, the sunglint pattern elongates, along the line of the sun and the orbiter and therefore low sun angles in the glint can be very useful if you're trying to scan a rather long area and the angles are right, i.e., the angle and the area you are trying to scan relative to the plane of the sun's rays relative to the orbiter. With a low sun angle, you can indeed scan a rather long area looking into the sunglint pattern. Round about this 25 degrees I'd say the specular point, which I can see right now, is quite a ways from the flight path. I'd estimate it's probably of the order of about 500 or 600 miles away.

MET: 05:03:12 We're now in orbit #83 and we've just come over the Canary Islands off Africa. There were some interesting structures around the Canary Islands and we took one or two photographs of that. And right at the African coast at Mauritania there, the Mauritanian coastline, some structures near shore. Looks like the usual coastal dynamics there with some slicks, a whole bunch of them that ran at right angles to each other like cross streets laid out in the cities. We've seen that before and took some photographs of that. Now a little ways into the Sahara, there's a super impact crater with many circular features within it. I took one photograph of that. We are now currently orbiting over the Sahara, we've just crossed the Sahara, now in the Upper Volta going down over the Ivory Coast, and pretty soon we will be orbiting over the equational eastern Atlantic.

MET: 05:07:34 We're currently orbiting over the Gulf of Mexico. The sun's specular point is pretty close to being right below us. I'm looking over to the Yucatan Peninsula; I can't see any structure there because it's high color, but in the sun glitter here there's plenty of spirals going across the Gulf, plenty of spirals. It's not obvious where the Gulf Loop Current is; I cannot see, there's quite a fair amount of cloud, progressively getting worse as we're going south. There's a cloud line that starts at the Yucatan Channel. As it goes around it's a sort of direction that the Gulf Loop Current would go. And it's clear on both sides of that; that could be a marker. We're getting into more and more cloud, we're about halfway across the Gulf now. And on this same pass we're now coming up directly over Lake Maracaibo. There's a big thunderstorm just to the north of Lake Maracaibo.

MET: 05:10:45 We're orbiting over the eastern equatorial Pacific and just south of the equator. Up till now I've seen nothing, but at precisely 8.2 degrees south there was a distinct change in the cloud pattern, with a very clear passage heading right across the clouds with the cloud cover forming on both sides of it. This is exactly at 8.2 degrees south. It's probably the equatorial counter current; and not only that, when you got it in the sunglint there appeared to be a series of half circular fronts probably about 50 or 60 miles across. The other half could have been under the clouds, and so they could even have been mesoscale eddies along the current boundary, half of which was in the clear and half of which are under the cloud cover. Anyway, it was precisely at 8.2 degrees south. There's a band of different clouds again coming up. Need a code L on SPOC. Latitude is 23.2 degrees south. We have another clear band in the clouds stretching probably at least for a thousand miles; like the last one but at 23.2 degrees south. No eddy structure in this, but there's a crenulated structure in the sunglint; and now looking right down on the clear area, there's a couple of very small spirals and there's quite a number of streaks and slicks. Certainly in the sunglint, a crenulated ocean. Also, recorded by Big Jon on Linhoff, photo frame 52 on reel number 2.

MET: 05:23:46 We have just come over the Strait of Dover. There's the first clear pass over the Strait of Dover we've had. Clouds on both sides of the Strait, but the Strait itself is clear. We're looking in the sunglint for what has become now the standard pattern of slicks and tight spirals. Took a couple of photographs of that. Also, not in the sunglint we saw a whole bunch of ships and wakes. I think Dave Leestma was able to get a photograph of that through the overhead, I'm looking in the gondola position up forward. Certainly a dynamic strait. (Time gap.) Going over the Mediterranean now. There's some tremendous wave patterns south of a small island here looking south. Now coming over the southern Mediterranean. Again you can see the long streaks, fronts and spirals. In fact, they're scalloped spirals just near the coastline here as we're crossing over, it's Rev #97. Once again as we approach the coastline here, there's just a whole series of convoluted spirals, just like the Stevenson spiral in the Agulhas current.

MET: 06:01:13 We're right at the top of the world; and I just photographed on a Hasselblad 100, an interesting cloud structure. It's two small lows in the clouds, both spirals, both anticlockwise, they're side by side, except their long tails are on opposite sides so they're coming together. Quite an interesting piece of dynamics.

MET: 06:01:15 We're still over mid-ocean but there is some structure in the sunglint. When there's some cloud free areas, it's what I would call the mottled ocean with a little slicking. Now coming over the coastline and there's tremendous eddy structure in the clouds; I'm going to take one photograph of it. And coming into the Mediterranean now, really hazy, but there is some structure we can see. Coming up into Gibraltar itself, high angle, very high angle, lot of structure. Also a lot of structure before you go into the Strait, there's internal waves, there's long quasi-solitons, and there's internal waves near the coastline. There's a beautiful tidal pulsing that we can see now, just beautiful tidal pulsing.

MET: 06:01:19 We've just come over Gibraltar. Just some spectacular ocean dynamics. The internal waves I called outside into the strait, were on reflection, really just inside the strait. They are in fact the tidal pulsing. Because of the bad angle, as we approached it looked as though we were on the other side of the strait. All the dynamics I shot were on the inside of the strait; a combination of tidal pulsing through the strait, quasi-solitons in the mid-Alboran Sea, and internal wave packets on the southern shores of Morocco. Shots of the Mediterranean were taken with a Hasselblad with a 100mm lens. It is Hasselblad roll number 34 with a data back, and its frame numbers approximately 75 to 82.

MET: 06:01:38 We're just crossing over the coastline of Southeast Africa, and about 30 miles offshore there were two long, about 100 miles, linear fronts separated about 20 miles wide. They could be the boundary of the Agulhas Current. I'm looking south now. Just having crossed the coast of Mozambique. We saw the deltas of the Zambezi River, and it's just south of there that I saw those long linear streaks. Just two of them, both paralleled, 20 miles apart. That's on Rev #98.

MET: 06:02:50 We're just coming over the Atlantic, just coming up on the southern coast of Morocco and there's a giant dust storm that's extending out to sea, just as far as the Azores. We're going over the Azores right now, they're right below us. You can see the Azores very clearly, except for the dust which is just starting to overlay them. The dust storm comes out to, I guess, 100 miles or so. And it stretches in a long arc down the coastline and then it goes further out to sea. There's an interesting wake behind the southern island of the Azores. The wake trails out into a series of linear, about 15 miles long, linear slicks. This dust storm is enormous. It's about 100 miles out from the coastline. As it goes south, it goes, I guess, 600 or 700 miles and it goes further out to sea, probably 500 miles out to sea, further down. It is really big. Some mottled ocean structure just closer into the shore of Morocco here. That dust storm is huge, it really is huge. There's a nice ship's wake just near the shore here. Can probably see about 20 miles, 25 miles of ship's wake. And then right close to the shore there's the now classical intertwined slicks with a couple of spirals and another two ships' wakes, again about 20 miles long each. There also appears to be a few quasi-solitons running at right angles to the coastline here. The total packet of them is probably about 50 miles long and there's probably 30 or 40 in the packet. Not very well defined though.

MET: 06:02:52 And 54 seconds. We are coming over that circular impact crater in the Sahara, which has the concentric rings on the inside of it. Interesting to know when you go from the Sahara into some green foliage underneath, the atmospherics change from almost no cloud to streets of puffball cumulus, just miles and miles of puffball cumulus. As soon as you get to the river systems and the green land, you can sure tell by the cloud patterns. Interesting enough, that puffball cumulus ends precisely at the coastline. I can look around the coastline for about 140 or 150 degrees as it bends around the western hump of Africa, and that puffball cumulus ends precisely on the coastline, then out to sea there's a totally different cloud structure, more like towering cumulus. And coming over that coastline there were some internal waves along the shoreline. I shot one Hasselblad 250mm just to capture them.

MET: 06:03:11 We are on orbit #99 and have just come over the southernmost tip of Africa. And looking south along that tip were a bunch of waves running pretty much at right angles to the coast. There's probably eight or ten of them. They look like short quasi-solitons. By short I mean short not in wavelength—the wavelength is about a quasi-soliton length—but actual crest length is about half to a little less than a quasi-soliton. Maybe these are the rogue waves people refer to. Did not take a photograph of this. As of this stage the cameras are rather limited because they're all loaded with the film for the EVA.

MET. 06:07:15 We're just right in the middle of the EVA, but coming over the Gulf of Mexico and looking south into the sunglint. Gulf coast is coming over now. Visual plumes, and there's a lot of scattered puffball cumulus all over the whole Gulf. It's fairly scattered and you can see in between it. There's an indication of an eddy or the Gulf Loop Current. Looking all over the Gulf; it's hard looking between the clouds, no loop current.

MET: 06:07:17 About two-thirds of the way over the Gulf now. Looking all over the Gulf. Again, I cannot see the Loop Current or an eddy. Once again the puffball cumulus makes it difficult to see. Now coming over the other side of the Gulf. The coastline. Again no big indication; nothing in the sunglint or in the color. Still no indication. Just going past the Yucatan Strait right now. Again no indication. Now in the Caribbean. There's a mottled ocean on the southern shore of Cuba in the sunglint. The Caribbean has pretty solid cloud cover all over, not the puffball cumulus as the Gulf of Mexico had. Pretty solid cl ud, just about all over, a few gaps in the clouds. It's very hard to see through the cloud cover over the Caribbean, but you can see through the cloud pattern—structure. The structure I saw was near the southern side of the coastline of Cuba. In fact, there's clouds as far as the eye can see in the southwest. Coming up over the northern coast of South America. The coast of Venezuela. Again all cloud covered, a combination of solid cloud and puffball cumulus. Also some cirrus overlaid over the top. Lake Maracaibo is a little bit to the north, so we're just south of Lake Maracaibo. As we go over the Venezuela coast, apart from some river outflow which is semicircular, there's the delta of the river, there's a little bit of dynamics in the sunglint, but that's about it.

MET: 06:07:45 We're just coming to the bottom of our orbit, halfway between the vertical line through South America and the vertical line through South Africa. Coming into the terminator. It's the first time I've seen ice in the water. It's long, curly streamers of ice, quite similar to the ice photographed by John Young on STS-9. It's not pack ice, it's long streamers.

MET: 06:07:50 The two EVA's are starting the process of reentry to the vehicle.

MET: 07:10:06 We're just crossing the equatorial eastern Pacific. Nothing in the glint, nothing in the color. However, there does appear to be a clear area in the clouds running east-west, with clouds on both sides. The edges, especially on the southern side, appear to be scalloped edges. The width of this clear patch here is, let me count, one, two, . . . thirteen seconds. So it's about 50 nautical miles wide, and it seems to have a sine wave appearance to it, with a wavelength of about 500 to 600 nautical miles. That could be related, I think we're just south of the equator, it could be the equatorial current or the equatorial countercurrent. On both sides of this clear patch, there's a reasonable amount of cloud. I'd say it's about 50% covered. Sort of big blobs of cloud I'd call it.

MET: 07:10:11 In the central southeastern Pacific, there's a whole bunch of eddies in the clouds which are lining up. I'm going to take some photos with the 100mm. Taken two in a row, now I'm going to try and take the whole line, starting with the third one. This line I guess stretches for a good 300 to 400 miles. We're crossing the line right now; it's heading east-west; it's MET 07:10:12:00 seconds. Now heading over the western shores of South America. Short pass over land and I'm going to try for the Falklands one last time. Took a photo of a neat green lake right down the bottom of South America. Really a milky green.

ONBOARD WRITTEN NOTES, FLIGHT 41-G

Flight Day #1

First set of oceanographic photos

MET: 00:03:31
Hasselblad, 100mm, 1/250, f8
Approx. 8 frames shot.
Scattered puffball cumulus.
The atlas mountains in Morocco seemed much higher than expected.
Large patch of coastal coloration in the Gulf of Cadiz, probably around Rota.

MET: 00:09:40. Gulf of Mexico.
Orbiter in wrong attitude due to ERBS problems.

MET: 00:11:02. 56.8° N, 168.3° W, approx.
This is just after two photos
(a) off tip of Sakhalin Island
(b) off tip of Kamchatka Peninsula
Hasselblad, 100mm lens, 1/250 sec, f11—see notes on tape recorder.

MET: 00:11:09. Not on flight deck due to ERBS deploy in a few minutes.

MET: 00:11:18. Not on flight deck due to ERBS deploy approx. 3 minutes ago.

On orbit #9, the track went right across the Pacific. I watched both the sunglint and the high color but only saw one front the whole time. This front was north of the equator and about 30 nmi. in length. The rest of the Pacific appeared flat. End at MET: 13:00.

Flight Day #2

MET: 00:21:30 (approx.). Arise.

Teleprinter:
01:04:09 Volcano. 4° N, 9° E Atlas P15.
View vertical, f5.6, 250mm

01:06:57 Two warm core eddies, vicinity of Gulf Stream northwall crossing. View south, 100mm, f8.

SITKA: Attached cold front system, 100mm, f8.

For PSP. Record earth orientation (cardinal compass points) of significant ocean features photographed.

MET. 00.22.05 (approx.). Shot 2 photos with H(100), one of near coastal off northwestern Australia (f11) and of colored "salt" lake in Australia (f8).

MET. 00:23.11 (approx.). 2 or 3 shots of England. Lot of cloud. One shot of tidal pulses H(100), f8, looking low oblique to the south.

On orbit #16, best oceanography yet. Great spiral in the Gulf of Oman, together with many linear slicks and one strong front approx. 30 mi. long. Took series of H(100) photos—see tape recorder for further details.

Notes. I'm staggered at the amount of cloud covering the earth—not solid but much scattered.

The ocean colors appear different out the back vice the overhead windows—overhead appear blue/green, back appear sky blue. Suspect the purple filter you can see in the overhead windows.

Rev #17. A just spectacular pass right across the Mediterranean and down the Red Sea. The most spectacular part was the Mediterranean which was as equally complex and dynamic as Dick Truly's Mozambique Channel. The Red Sea has some structure, but the Gulf of Aden had none. All is recorded on film and comments are on the tape recorder.

Rev #18. Another Mediterranean pass, not nearly as spectacular. We tracked the Mozambique Channel in great detail and took photos. Detailed comments can be found on tape. Some structure, but not really like Dick Truly saw it.

I am becoming more and more convinced that the best place to watch and photograph sunglint is from the forward windows once you put yourself in the "gondola" position. This is because the specular point is some distance away (i.e., at an angle to you) and the forward windows in -ZLV are angled at the same slant as the direction to the sunglint.

I still haven't resolved in my mind the discrepancy between the f-stops as given in the oceanographic MET list (even after they have been stopped up 1/2 f-stop as requested) and the f-stops given for the generic ocean matrix (glint, high sun and low sun). Even after corrections have been made to the oceanographic MET list, the f-stops are still too wide by 1/2 to a full f-stop, i.e., the oceanographic MET list is too wide relative to the generic matrix (and that is making the comparison for high sun and **not** sunglint!)

Rev #20. This went right down the Atlantic—got Niger River Delta and Dakar. Looked at whole ocean through overheads. (Glint was too oblique.) The entire ocean has relatively high density of scattered cloud and no dynamics were observed in the vertical except a couple of cold core eddies which were together (approx. 25 mi. diameter).

Rev #21: Watched pass from tip of Long Island to terminator, right down the Atlantic. Took good shots of Long Island, Long Island Sound and Connecticut (Thames and Mystic Rivers)

Looked for two warm core eddies near north wall of the Gulf Stream as reported this morning on the telecopier but it was too cloudy to discern anything. Got good shot of the eastern tip of South America.

Rev #22: SITKA Eddy—too much cloud
Lesser Antilles—some shots, but a near inertial attitude due to proximity to OMS burn. I looked in the color (no sunglint) but did not see any island wakes.

Rev #23: Juan de Fuca—cloud covered
Gulf of Mexico—mostly cloud covered, some glint, some photos taken
Equatorial East Pacific—clouds
Montevideo—hazy but no cloud cover. Low light, much photography.

Rev #24: Down the California coast, then dinner and SASSE.

Rev #25: Right down the Pacific. Ocean swell is easily seen even in high color (not glint).

Flight Day #3

Rev #32: A spectacular rev. Great sunglint in the Black Sea, Persian Gulf, Strait of Hormuz, Gulf of Oman and the Arabian Peninsula. In the Persian Gulf, the burning oil wells could easily be seen by the naked eye (black smoke) and were photographed. The reefs around Qatar were also clearly seen in the distance. In the southern part of the Gulf around UAR, you could see large patches of surface oil in the sunglint. The oil rigs in this area (about 3 of them) seemed to have white smoke coming from them. Some dynamics could be seen in the southern Persian Gulf and the Strait of Hormuz. In the Gulf of Oman, our orbit was too close to get sunglint. In the color, no dynamics were present. However, along the Arabian Peninsula, the anchorage for the super tankers was clearly visible, with about 35 tankers (by eye) there. Also, good shot of the Maldives. This rev., which was highlighted in the morning message traffic, was reported as successful back to the ground.

Rev #33. Just one spectacular pass down the Adriatic Sea, the central Mediterranean, the Red Sea and the Gulf of Aden. The Adriatic/Mediterranean section was incredible dynamics in the sunglint. Hundreds of miles of connected spiral eddies. I took a whole series of overlapping stereos throughout this pass with the H(250). At one point, there were 4 or 5 spirals connected on a line like a Von Karman vortex street.

The Red Sea and the Gulf of Aden were not as spectacular as the other day, since the sun's specular point went down the western bank. At the Gulf of Aden, I looked carefully but saw no dynamics other than some slicks paralleling the southern extremity which was the only part in sunglint.

Rev #34. Western Mediterranean pass. Bad attitude (inertial). However, did see some internal waves travelling east. They looked more like a group of 4 to 5 solitons. Captured them on H(100). Also difficult since it was a critical time for SIR-B deploy operations.

Rev #39: 45.4° S, 46.7° W—soliton fronts off Montevideo.

Also, a few minutes previously, possibly the best set of internal waves as we came over the coastline off Guatemala.

N.B. Many of the attitudes were off nominal today, since the orbiter had to be pointed so the Ku-band antenna could dump the SIR-B data through TDRSS. Ku cannot be pointed independently due to a malfunction.

Flight Day #4

Rev #48: British Isles totally socked in.

Spectacular pass over Persian Gulf. (See tape recorded notes.)

Spectacular ships' wakes in southern Persian Gulf. Two tanker anchorages in Gulf of Oman. Linear front 200 nmi. perpendicular to coastline starting from the headland next south from Masirah. All (except front which was subtle) were shot with H(250).

Rev #49. Great dynamics in the Adriatic Sea and the Central Mediterranean—many photos.

Rev #50. Just spectacular dynamics in the Alboran Sea. Attitude terrible (due to TDRS SIR-B data dump). You had to be a contortionist out window-6 to see it, but many overlapping photos taken with H(250). Also thought I saw the Huelva Front in the Gulf of Cadiz, but angle too oblique to photograph it.

Went over southern Mozambique Channel. Attitude terrible but no cloud cover. No glint. Just a suspicion of long slicks—almost positive there would be good dynamics in the sunglint.

Rev #51: ORS Transfer

Rev #52. Some structure just east of the Grand Banks, 1 photo. Could see because there was less cloud cover than the previous 3 days.

Rev #53. Boston, Mystic, Long Island, New York Bight totally cloud covered. Tracked right down the Atlantic on this pass (attitude. right wing down, tail forward). [Note: this attitude assumed right after N.Y. Bight.] Saw nothing, but much cloud.

Rev #54: SITKA Eddy—ORS transfer—no photo.

KSC, Cape Canaveral—perfect, see pads 39A, 39B and the SLF. No photo due to IMAX filming.

Gulf of Mexico—no photos—too many on flight deck

Lake Maracaibo—great internal waves in sunglint/none in high color, no photo—too many on flight deck.

Rev #55. Internal waves off Costa Rica. Not a strong signature but they went for hundreds of miles with intersecting patterns. Also a ship's wake between 100 and 150 nmi. long

Rev #56: Saw the Falklands. Right at the terminator. They were in the clear but not enough light to photograph.

Flight Day #5

Rev #64. Persian Gulf very hazy—bad viewing conditions. Dust storm over Gulf of Oman as far south as 30 nmi. south of Masirah.

Long front again present off headland at 19° N, the first main headland south of Masirah. Front has to be in excess of 150 nmi.

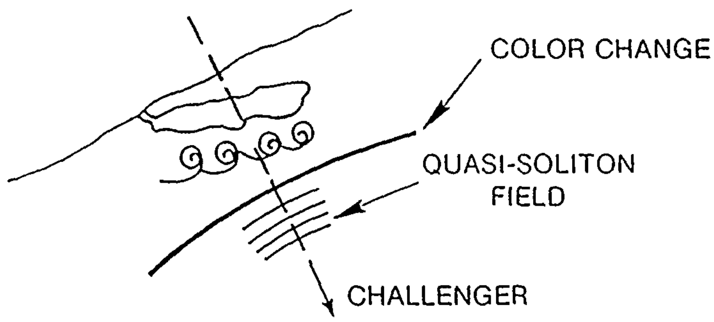
Rev #65. Southern shore of Central Mediterranean off the Egyptian Coast, close to the Egyptian-Libyan border, Dave Leestma captured on film a series of spirals. I was on the non-glint side and did not see them. However, this put me in a good position to look at the Red Sea in high color. It was very clear but no dynamics were seen. Also looked at the glint starting from Somalia all the way down to Mauritius—Nothing!!

Rev #66: Great sunglint along coast of Portugal—photo
Huelva front very visible—photo
Sunglint did not get over Isla de Alboran. Sunglint and dynamics in the Med—photo
Sunglint and dynamics along the coast of Morocco—photo
All photos taken with H(250) at f11/8.

Rev #67: Lunch

Rev #68: Press Conference

Rev #69. Right over Mystic, CT. cloud covered. Then over Long Island Sound and Long Island—cloud covered. Then clear over the Atlantic. As we headed southeast the first thing we saw was a long line of spiral eddies off the eastern shore of Long Island. Then smooth ocean. Then a series of long (approx. 100 mi.) slicks which looked like quasi-solitons. There were a group of about four. Then it became obvious that these were aligned with a color change in the ocean—the north wall of the Gulf Stream. The quasi-soliton field was aligned parallel to the north wall of the Gulf Stream and (I think) further toward the southeast.



Note that the quasi-solitons were seen before the Gulf Stream boundary. They drew my attention to the color change.

Rev #70: Miami/Florida Keys. A little structure in the Atlantic—not much, no photo.
Lake Maracaibo—some structure in the sunglint—one photo H(250).

Rev #71: Oceanography T.V. opportunity—flight deck.

Just prior to this (which was down the middle of California), Dave Leestma and I saw in southern Sumatra what looked like a spectacular lava flow approx. 35 mi. in diameter. You could even see the rivers of lava as a spider web throughout the flowing area. Also, around the edge was glowing brighter. [Note: We looked again a couple of days later. We now think it was the lights of Singapore.]

One comment which should be made in general is the amount of cloud covering the earth, both land and water. It is incredible. However, each day the clouds seem to be, in total, *less* around the world.

Rev #72: Tried for the Falklands. Went right over but almost dark and completely cloud covered.

Rev #73: Great sunglint/dynamics (slicks, fronts, spirals and internal waves) along the eastern shore of the Kamchatka Peninsula.

During the sleep period, on Rev #77, Kathy was on the flight deck and saw packets of solitons off the Australian Coast both north and south of the headland near Bundaberg. They were the diffuse type of solitons that Hoot Gibson photographed off the northwest Australian coast on STS-11.

Flight Day #6

Rev #80: Spiral storm: 57.0° N, 20.0° W. Photographed on H(100).
Kharg Island, Persian Gulf: Polarizing pair H(250), f11.
Lights of cities at night.
Interconnected thunderstorms/lightning.

Auroras.

N.B. "Best" opportunity in the oceanographic MET list appears to coincide with the ground track immediately over a given area. However, the *best* opportunity is when the *sunglint* is over the given area.

Rev #81: Spirals in channel between Ireland and England.
Central Mediterranean socked in.
Mozambique Channel no structure.
Did a sun angle/sunglint test. See recorder for results.

Rev #82: EVA prep. (prebreathing on flight deck).

Crip took se.eral photos of the Strait of Gibraltar in the sunglint. From my position at the mid-deck hatch window looking north (non-sunglint direction) I saw a color front at right angles to the coastline near Algiers (no photo). It was about 80 nmi. long.

As you orbit down over Africa there is a dramatic change in the color as the Sahara (reddy-brown sand) gives way to a dark, dull, green (vegetation) as soon as you reach the river system and central Africa.

Also, I was able to observe the entire transect of the Mozambique Channel (looking north) i.e., color only. There was scattered cumulus but you could easily see the water. No apparent dynamics at all.

Rev #83: Some structure around the Canaries and off the African Coast—some photos.

Good circular impact crater in Sahara with internal concentric rings.

A little structure in the water off Equatorial Guinea, but angle too oblique to photograph (Challenger in bad attitude due to SIR-B TDRS dump). Looked for Rogue waves off tip of Africa, right at Port Elizabeth, but it was too cloudy—but the surf was up at Port Elizabeth!

Rev #84. Tried out the polarizing filter by hand. The effects are dramatic—in the sunglint you can really see through the glint. But the most dramatic effect is coastal effects—high color dynamics which are subtle to the naked eye are intensified and made higher contrast by the filter. Hence the dynamic boundaries which were subtle now jump out at you. The one drawback is the overhead windows. These produce polarizing color bands in the view. However, the aft windows and the cockpit windows do not. This correlates with the observation made earlier that the overhead windows produce a greenish-yellowish tinge to the ocean color.

On the night pass to this rev., we looked at cities by night—they look great. Also the horizon looks much closer than during the day. The atmospheric thickness can easily be seen as a thick brownish translucent band with a few stars shining through it. AND moon glitter does work—I saw a front in the ocean in moon glitter.

Rev #85. Right over New York City, but it was socked in. Then went to awkward attitude for a SIR-B TDRS dump.

Rev #86. Gulf of Mexico—see tape recorder notes. When going over New Orleans, I looked north at the tropical storm Josephine sitting off Cape Canaveral. It is extremely large, but not all wound up. It has a sharp linear edge running parallel to the coast and approx. 150 nmi. offshore.

Note. You just can't get over the fact that you are actually 120 mi. up. The view is so clear and detailed, it is as if you could reach out and touch it. Only when you realize the total breadth of the vista, does it come home to you that you must be way up there.

Rev #87. Galapagos in the sunglint. Wakes behind the islands with banded linear diffuse internal waves between the islands—3 photos, H(250).

Rev #88. East Pacific—South Equatorial current and counter current seen. See taped notes for details (photos).

Falkland Islands. Just the tip showing from beneath the clouds in low sun angle—1 photo.

Rev #89: Dinner

Big Jon shot a spiral eddy northeast of the Hawaiian Islands Roll #34, Frame #56 on H(100).

Flight Day #7

Rev #95: H(250) of southwest tip of Australia, south of Perth.

Rev #96: Black Sea: sunglint: usual slicks and small spiral eddies—no photos

Persian Gulf. right down the middle, overhead windows, H(250), f9.5. Photos of burning oil wells in top of Gulf, Kharg Island, and shores of Bahrain. Looking vertical at the waters of the Gulf you would swear that you could see the black oil subsurface throughout the Gulf. Point against. the waters near all shorelines appeared clean, point for. the edges of the "oil" appeared as dynamic flow patterns rather than as abrupt changes in bottom topography.

Diego Garcia: 2 photos H(250), f9.5—directly underneath.

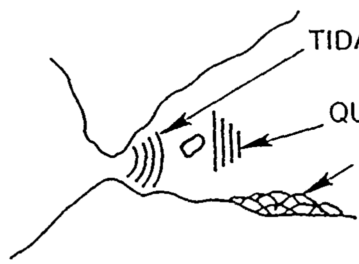
Rev #97. English Channel. clear for the first time; clouds over both land masses. Saw the now "typical" slicks and spirals (photo).

Mediterranean: great wave train behind a small island, possibly Malta (photo); "typical" slicks and spirals off the Libyan coast.

No sign of the Somali Current.

Mauritius not in sunglint but high color. Hence, no wake. However, Reunion alongside it was in sunglint and a great wake was present. Photos of it by Kathy. Quite extensive notes of this rev. are on tape.

Rev #98: Just THE most spectacular Gibraltar pass, all in sunglint. In one frame: tidal pulsing through the strait *plus* linear quasi-solitons off the Isla de Alboran, *plus* internal waves off the Moroccan coast. Detailed notes are on tape.



Also, may have seen the Agulhas current off Mozambique as two linear slicks approx. 100 mi. long, 20 mi. apart, parallel, marking the boundaries of the current. Again, detailed notes on tape.

Rev #99: Dust storm off Morocco, 100 mi. out to sea. Detailed notes on tape.

May have seen a set of Rogue waves southwest of Port Elizabeth at southern tip of Africa. Again see tape for detailed notes.

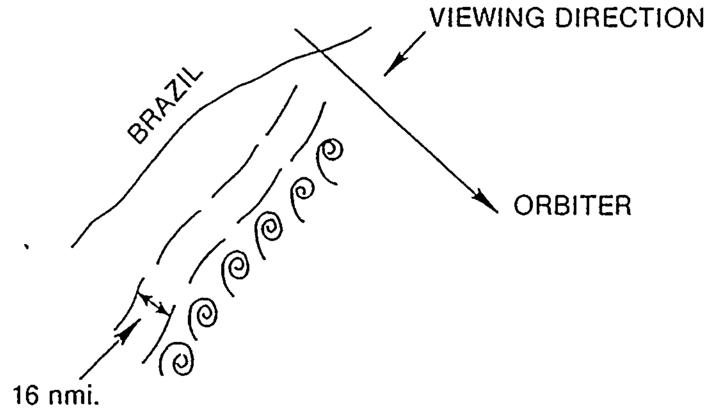
Rev #100: Start of EVA. Played around with the polarizing lens in the cockpit windows. If the plane of the lens is at a sharp angle to the plane of the window, i.e., a long way from parallel, then you get the classic polarizing colored lines in the picture.

Rev #101: During EVA—orbiter nose toward the earth. Snow on mountains in Alaska is melted in the valleys and the vista reminds one of pictures of fractals. The snow patterns are multi-faceted "petal" patterns on each mountain.

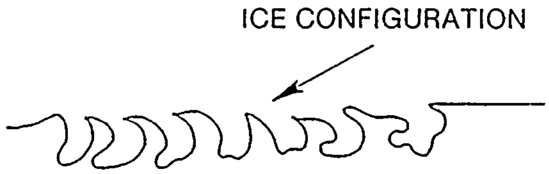
Rev #102: EVA still in progress. Connector cable IFM on flight deck for Ku antenna work-around. Observed entire Gulf of Mexico to southwest of track. Detailed description is on end of side A of tape, although hard to hear because of background noise due to EVA activities. Basically, puffball cumulus covered the Gulf, and there was no sign of the loop current or the eddy either in the sunglint or the color. I continuously scanned the whole Gulf but to no avail.

We then crossed into the Caribbean. This had much denser cloud and nothing was seen except a little near-shore dynamics along the south coast of Cuba.

On crossing the eastern coast of South America in the southeast corner of Brazil, the orbiter was in a very awkward attitude and I only got an angled view of the coastline out of the corner of window one. But the dynamics were impressive. Near shore was smooth in the sun glitter, but offshore there were two straight line slick/fronts which I timed to be 16 nmi. apart (just like the ones previously reported). And they were approx. 50 mi. long. Then I was able to look down the line of the fronts and saw they were part of a larger pattern of similar slicks which stopped and started. On the seaward side of these fronts were a whole line of spiral eddies.



At the bottom of the orbit, I saw ice, just like the photos from STS-9.



Rev #103: Assisting in EVA ingress on mid-deck.
Time MET for EVA end (hatch close) 06:08:02

Rev #104: Falkland Islands—Low light, 3/4 cloud covered. 1 photo H(100), f5.6.

Rev #105. Saw circular cloud structure in mid-ocean which may indicate a cold core eddy. Took a photo. SPOC gave a position of 7.4° S, 130.8° W.

N B SPOC changes approx. 1.7 degrees of Lat at each update in tropics and mid-latitudes.

Also mention that just before bed last night we orbited over the Persian Gulf at night. The number of oil well fires was amazing. At least 28 in the vicinity of Kharg Island. The atmospherics were very clear.

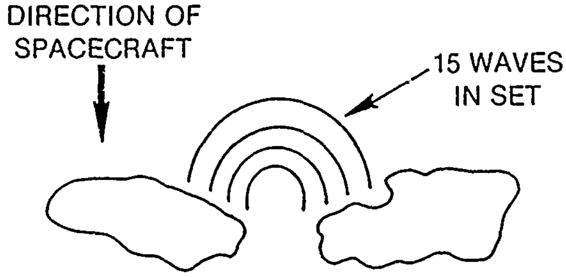
Some notes. During Rev #105 (I think) we saw a cloud wake embedded in solid cloud.

Could this be the tip of an island volcano reaching up into the cloud deck? Took photo for interpretation. This was the photo in which the film magazine on the Hassalblad jammed Also, during this rev (I think) I took a photo of the orbiter through the rear window. The orbiter was in the tail down attitude and the photo got the whole of the vertical stabilizer, the two OMS pods, and the ocean below. Just the photo for "Oceanography from Space."

During Sleep Period

Rev #109: Saw Great Barrier Reef, Curtis Island and Fraser Island, etc. "Turquoise gems in a turquoise ocean." Other than coastal color, no ocean dynamics noted.

Rev #110. The best tidal pulsing I've seen—through the Indonesian Islands. Counted 15 waves in the pulse—see diagram. Kathy remarked on the biggest refraction grating of all time



This orbit then went down the middle of Australia. The most striking thing is the color—ochre. Albert Namatjira got it right. It is strikingly different from any other country from space. The deserts are yellow/orange, the continents are brown/green, but central Australia is red/brown. We exited over Spencer's Gulf, Kangaroo Island, etc.

Flight Day #8

Rev #113. Over English Channel—bad attitude, could only look north, partially clouded, nothing significant—took 1 photo.

Central Mediterranean: socked in.

Note. Tried 100mm and 250mm sighting through the viewfinder. At an altitude of 120 nmi. the scale of things on the earth through the 100mm lens is *exactly* the same as that seen with the mark #1 eyeball.

Wake behind the northern tip of Madagascar heading due west.

Note: When in the gondola position in -ZLV, the center of the cockpit windows view approx. 120 nmi. left or right of the ground track, at an altitude of 120 nmi.

Looked for Somali Current to no avail.

Mauritius not in sunglint.

Reunion in sunglint—same wake structure as yesterday.

Rev #114: MET: 07:01:01 (approx.)

Gibraltar Pass—ORS transfer in progress. Dave reported great sunglint and tidal pulses through Gibraltar "bowing right out", also internal waves. Crip took a series of photos with H(100) and Big Jon took a couple of Linhoff's.

Agulhas region: ORS transfer in progress—also bad attitude. Kathy was unable to view the area properly. Saw no dramatic dynamics in what she could see.

Rev #115: Dust storms still 100 mi. at sea off Morocco
Usual coastal dynamics off Morocco
Orbiter in unusual altitude due to FCS system checkout before entry
No Rogue waves seen off Cape Town

Rev #116: Watched the Atlantic from top to bottom. Cloud cover ranged from scattered to total. Saw no indication of super-T or the mid-Atlantic ridge.

Rev #117: Presidential phone call from train in Dayton, Ohio.

Atlantic coastline of the U.S. was cloud covered with just a few gaps—no joy.

Went right over the tropical storm Josephine in the western North Atlantic. IMAX shot the whole thing including the eye. Also Hasselblad and Linhoff shots. Saw a classic cold core eddy in the eastern Caribbean (about 30 nmi. diameter) in the sunglint, but no cameras available on the flight deck.

Usual internal waves off the coast of South America, Caribbean side, together with a few well-defined fronts about 80-100 nmi. long, parallel to the shoreline.

Rev #118: Gulf of Mexico: cloud varied from scattered cumulus to solid cover. No dynamics were seen either in the sunglint, or color, except several linear slicks, about 100 nmi long, approx. 2 nmi. apart in a group of 3 or 4. This group was situated approx. 300 nmi. from the coast of Cuba (i.e., in mid-Gulf) and was oriented parallel to the coastline of Cuba. I saw these fronts in the sun glint. By the time I got my hands on a camera (the Linhoff) the sunglint was gone, but I took the photo anyway. There may be something in the color. The Caribbean was all socked in, including the northern coast of South America. Also, the southeastern coast of South America was socked in. At the bottom of the orbit, we saw the Antarctic Ice pack (the edge of it) where it was breaking up. We tried to get photos of it.

Also, a really giant aurora, with vertical columns in it, was seen after we passed into darkness.

Rev #119: Galapagos: went right over them. Good sunglint taken by Dave. Also IMAX got the whole run over the Galapagos. I was in the window looking north.

Brazil-Falkland Confluence: Looked north as instructed in today's teletyped messages. Looked near-field and far-field but saw no pattern in the clouds and no color change However, Dave Leestma, looking south in the sunglint, reported great glint and took photos, and Crip at the overhead windows reported a color change and took photos. Also, saw the start of the pack ice at the terminator.

Rev #120: Equatorial East Pacific: saw a "current" just south of the equator delineated by a 50 nmi. wide clear strip in the clouds. It had a wavy edge with wavelength approx. 500 nmi. (no photo). About mid-latitudes, saw another "current" delineated by rings of clouds about 60 nmi. diameter. They were lined up in a line. Took several photos. I was looking into the glint and in both cases the "currents" were lined up exactly east-west. Detailed notes can be found on tape.

Got the tip of the Falklands in best light yet—most of them were cloud covered. Shot H(100) and H(250)

Thought: Are we seeing slicks and spirals only for a certain range of sun angles? Look back through the results and correlate.

Entry Morning. Flight Day #9

The morning Persian Gulf orbit.

Looking south into the sunglint in the Gulf of Oman saw a huge approx. 200 nmi. diameter eddy. We all saw it by the linear slicks which had curvature to them. By looking very obliquely through the overhead window, I could just make out 1/2 the eddy and it was perfectly circular. The slicks were all banded and perfectly formed.

DISCUSSION

a) Ascent

From my point of view, the ascent was a more benign experience than I had expected, except for the last portion before main engine cutoff where the effects of the 3-g's were stronger than I had anticipated. The reason for this is twofold: 1) they last for several minutes and (2) the pressure is downward on your chest as compared with the g's you pull in a plane like the T-38 where they are vertical through your body and, although much higher, only last for several seconds.

b) Postinsertion Adaptation

I didn't have any problem adapting to the zero-g, but I was aware of two sensations. One is that, although I've done a fair bit of KC-135 zero-g work, the zero-g feeling to me in space was different from that on the KC-135, but I can't quantify it. Just to me, it was different. And the other sensation I had is that I was immediately aware of the fluid shift, which surprised me. I thought that would be far more gradual. And they were my two sensations having gone into orbit.

c) Use of Orbiter Facilities

The training with the WCS and the galley was quite adequate. I personally found the WCS easier to operate as a user than some of the stories I've heard. That was a pleasant surprise. In terms of smoothness of operations, it's certainly true, looking back, that one of the key things that was done that made the operation of this crew smooth was the CDR setting guidelines to us, all preflight, in terms of "When this operation is going on, we want you, you, and you on the flight deck and you people on the mid deck," and vice versa depending on the operations. That set of guidelines was very valuable.

d) Access to Workspace and Equipment

For someone like me, whose job on orbit is to take photographs, I think, in hindsight, we can make two points. One is that, given the situation that we had where I was just using the standard crew equipment, then I think it's essential that, for someone like me being added, we add an extra total Hasselblad complement. In other words, that's a camera bag with a camera and all the lenses. Secondly, some more film, somewhere between five and eight extra magazines of film. And in my case, that would mean with data backs. Because there were several occasions when I felt that my requirements were conflicting with the rest of the crew's requirements to take photographs. Because my job was, in fact, an overlay on the normal requirements to take photography. So I think that with a PS added whose job is to take photographs, that's what we should do in the future.

e) On-Orbit Integration

I think one of the observations that I made during this flight highlights a generic issue that I think should be put on the table. And that is by adding PS's to flightcrews, it is very easy for their work to impinge upon the regular crew's work in the sense of, although on paper, it looks like they can do everything themselves in the particular timeline they've given, when you're actually on orbit, the PS's find out that they can't achieve their objectives as laid down preflight. And therefore, they've got one of two things that can happen. Either they badly underdo or underachieve what they set out to do or they place increasing requirements on the regular crew, especially the MS's, which I don't think is fair to the MS's.

f) Deorbit PREP and Entry

In terms of the entry timeline for PREP, it was certainly adequate. I don't think I'd want to reduce it at all because, for the PS's, there's not all that much to do other than get yourself reconfigured. But you've also got to make sure that you allow other people to do what's required. In terms of the medical DSO's on entry, I volunteered for two. I think that's one too many. I think you should only do one medical DSO on entry because it is a new experience, and by the time you configure yourself with two sets of electrodes, which have to be plugged in two different ways with two different PREP's, I think that's too much, given that, if it wasn't your first flight, maybe it's not too much. But for a first flight experience, I think two medical DSO's on entry is one too many; it should only be one.

The entry was far more benign than I expected. And having landed, my experience was similar to that which you have when you've been at sea for 1 or 2 months, and you step ashore and the dock seems to be oscillating a little bit. I had that feeling for maybe 20 minutes, half an hour. It wasn't unpleasant. I've been through that set of experiences before, and after half an hour, it was fine.

OCEANOGRAPHIC LESSONS LEARNED

Apart from the oceanographic data and results, which are reported in the next section, there are a number of points and lessons learned in regard to the oceanographic onboard operations. These are listed below and can be used as a check list for future flights of oceanographers or other earth scientists.

a) Dedicated Observer

Although it may seem trite in retrospect, the most important lesson learned was the value of the dedicated observer. I would not have believed how busy the regular crew are on orbit. This means that photographs taken by regular crewmembers are by their very nature one-off, as-time-available, etc., etc. But the value of a human observer is that he/she can integrate data and images. Hence a dedicated observer has time to look out the windows for hours at a time, determine whether he is looking at an isolated (oceanographic) event or a continuum, and assess how wide spread a particular phenomenon is in the world's oceans. The advantages gained by having someone who has the time to focus on a particular aspect (in this case oceanography) throughout the flight cannot be underestimated.

b) Dedicated Equipment

Once you add a dedicated observer whose job it is to take photographs, you have automatically overloaded the regular use/requirements for the standard complement of cameras and film regularly carried. This therefore impacts the normal crew use of cameras and film. Future dedicated observers should be manifested with an additional Hasselblad camera complete with 100mm and 250mm lenses and between five and eight extra magazines of film, each with data backs.

c) Tape Recorder

Copious notes and voice recordings are crucial in reconstruction of the data. The tape recorder is the most essential piece of equipment after the cameras. Although used extensively, I would recommend its use almost continuously for ocean observers. Hence more cassette tapes (two to three more) should be carried with a dedicated observer. Although it seems dumb when you first start to use it, you soon get into the swing of it. Practice in using the tape recorder for long periods during the simulations should also be included.

d) Viewing Windows

On orbit, it soon became clear that by far the most information on ocean dynamics and features can be obtained from the sun glitter. This is an important point, the more so because all our previous experience, although indicating this as the best method, did not prepare me for the overwhelming advantage of using sunglint over the other viewing conditions. This in turn impacts on which windows to use. Since the sun angle is rarely near nadir, it means that the specular point of the sun and the glitter pattern is almost always some distance to the side of the sub-orbital ground track. Thus looking at the sun glitter is quite difficult if you're looking out the overhead windows. By far the best windows to use are the cockpit windows. Windows 1 and 2 (port side) or windows 5 and 6 (starboard) are the ones to use (the head-up displays in windows 3 and 4 make them hard to use). You choose the side of the cockpit commensurate with tracking the sun glitter pattern. The best orbiter attitude is -ZLV, i.e., payload bay pointing to the earth. In this configuration, the slanted cockpit windows are at an angle such that you tend to look normal to the plane of glass (thus minimizing refraction effects) when you're looking off track into the sun glitter. The best viewing position is therefore what I term the gondola position—it's just like looking out from a gondola on an airship. This consists in floating upside down (relative to the cockpit) and "hanging" there, looking out the appropriate cockpit window with the orbiter in the -ZLV position. It has the added advantage that you can also (a) see the whole panorama and (b) see what's coming up. Obviously the orbiter nose-forward position is the best, but I was surprised to find that the tail-forward position was also quite good due to the gondola effect.

The overhead windows, apart from the difficulty mentioned above, have the further disadvantage that the ocean color appears different through the overhead windows relative to any other windows. The reason is, apparently, that there is a thin wafer of different material between the "sandwich" of the panes of glass in the overhead windows;

you can see this wafer in particular lighting conditions. You can also see it easily if you look through a polarizing filter. This has the effect of imparting a greenish-yellow tinge to the color of the ocean that is not real.

e) Sun Glitter

The available range of useful sun glitter angles is far greater than we had expected preflight. Indeed, the range of useful sunglint observation and photography extends from a directly overhead sun angle down to a sun elevation of about 15 degrees. Of course, lower than about 25 degrees the sun glitter patch elongates dramatically, but this too has its advantages. For as the glint patch elongates, you become increasingly aware of how the ocean dynamics is indeed interconnected for hundreds of miles and is not simply a series of isolated features.

f) Viewing Conditions

Again the available range of viewing/lighting conditions was far greater than expected. Useful viewing can be made terminator to terminator, although the low light level near the terminator makes photography most difficult. But it can be done.

g) Visual Acuity

This brings us to the topic of space vision. For many years astronauts and cosmonauts have reported on space vision, in which their visual acuity appears to significantly increase with time on orbit. The classic description has been (using New Zealand as an example) that on the first pass over—"yes, there's New Zealand"; on the second pass over—"yes, there're two islands", on the third pass over—"yes, I can see Cook Strait," etc., etc. I believe that space vision as defined is largely a myth. What is true is that viewing performance, like any task, improves with practice. In the case of looking at the earth from orbit, the learning time on-orbit can be shrunk to near zero by the proper preflight training This consists of (in this case) looking at thousands of photographs of the earth and the oceans from space in which the scale of the features in each photograph is known. In this way, the observer is well attuned to the scale of view from low earth orbit before he flies, and does not have to overcome "scale shock" once he gets on orbit.

h) Visual Resolution

By conducting a simple experiment on-orbit, I concluded that the resolving power of a single human eye is exactly that of a Hasselblad with a 100mm lens. But—in real life you are looking with two eyes, i.e., in stereo, and the image is backed up by the adaptive processor called the brain. There is no question that you are looking at a three-dimensional view from low earth orbit. The net result is that you are able to resolve/discriminate about equal to a Hasselblad with a 250mm lens. In addition, the mark #1 eyeball is superb in being able to distinguish extremely subtle changes in both color and texture Hence, many times, what you are able to perceive and verbally record cannot be seen on film, even using the 250mm lens. When developed, the film just does not show the detail you see. A good example of this is the soliton doublets (double crested solitons) that I observed and photographed in the Red Sea. The photograph, which is reproduced in this report, does show the soliton packet, but the double crested nature of each wave did not show on the film, even the master copy.

i) Binoculars

Obviously, the binoculars do improve your ability to see small details. But there is a cost involved, and that is the large increase in the time it takes to scan a given area. Again by conducting a simple test, I convinced myself that you would not miss any signficant ocean feature by scanning an area by eyeball as compared to using binoculars. Once you have scanned a large area quickly by eyeball and have seen some oceanographic feature, then it helps to look at it through binoculars for added resolution. For example, you can eyeball (in the sunglint) any reasonable ocean swell; and using the binoculars you can determine the direction in which the swell is moving.

j) Oceanographic MET List

This list, Figure 2, is invaluable for conducting oceanographic operations. However. it can be improved considerably. Its structure is very good, listing what should be accomplished as it follows sequentially, orbit by orbit, through the flight. The only comment on the layout is that it should be designed so that it fits easily into a flight suit pocket as you tend to carry it around with you all the time and constantly refer to it. I had to fold it in four to carry it around, so you find yourself folding and unfolding the list. The content of the list is what should be improved. First the f-stops. It became clear to me very early in the flight that the f-stops given for each site in the list were incorrect, namely that they were all out by at least a whole f-stop in the direction that, if followed, they would have produced overexposed film. This is a terminal fatality in that underexposed film can be processed on the ground to bring out the required information, but with overexposed film you have lost it. Fortunately our experience in training previous crews saved the day, since we had developed rules of thumb, based on experience, for best f-stops in given situations. We already knew that using the light meter was not the way to go—it is too time-consuming and you miss taking the photo at the correct time, and, moreover, the light meter readings do not produce the best results. Furthermore, you don't have the time to keep referring back to the MET list to check on f-stops. What you need is a simple rule which you can memorize to make the necessary adjustments in f-stops. Reduced to its simplest form, the rule is:

f-stops

normal glint	f11
normal color	f8

Then for variations beyond the normal, you change by a half f-stop. Thus the complete matrix becomes:

f-stops

bright glint	f11/16
normal glint	f11
high sun, color	f8/11
normal color	f8
low sun, color	f5.6/8

Once you have done this, you can then remove the f-stop information from the MET list, thus simplifying it.

The site name, feature to be photographed, and special viewing comments are all good, and should be left in. However, the list for 41-G was prepared in such a way that the orbit number and MET was calculated for each site based on the sub-orbital ground track, i.e., for looking straight down. Obviously for sun glitter sites this is just plain wrong (see subsection d on viewing windows). Thus soon after getting on orbit, I had to redo the MET list for sun glitter sites based on the fact that the best time to capture a site in the sunglint may be one or two orbits removed from the orbit for which the site is immediately below on the sub-orbital ground track. Thus the MET list should be constructed preflight using information such as given in Figure 3 for all sunglint sites. For color sites, on the other hand, the ground track approach is still the way to go.

k) Slider Map/SPOC/Orbital Chart/Atlas

All of these are standard equipment. All are useful to a greater or lesser degree. The slider map was not used as much as expected since SPOC provided most of the answers. However, the slider map was great to resolve precise positioning. You would update the map with the ascending node information (from SPOC) and then position yourself on each particular orbit from that. The best place to keep the slider map on orbit was found to be on Velcro between the CDR seat and the center console.

The atlas was also not used as frequently as expected. The best place to stow it for easy access was found to be on Velcro between the PLT seat and the center console.

The SPOC was a great help. One of its best features for oceanography was its Code L capability. This means that when passing over a feature of interest you could punch in a Code L and then later interrogate SPOC for the position at the time Code L was punched This gives your position (Lat and Long) to within 1½ degrees.

The orbital chart was used constantly, and carried around with the MET list. This means that, just like the MET list, it should be organized preflight to be capable of being carried easily in your flightsuit pocket. Moreover, if you can carry a version of the orbital chart which already has plotted the location of the specific sites of interest, then that would be most helpful.

l) Perceptions

One overall point to make is that, in zero-g, simple operations take almost twice as long to perform as on the ground. This is because you must constantly remind yourself to slow down, since a small movement, a simple push against the side, can send you rocketing across the orbiter to your own and the rest of the crew's consternation.

You also get conflicting feelings on looking at the earth; oblique views, including the horizon, shows you how really big the earth really is; vertical views on the other hand were so clear that you feel that you are so close to the earth that you could almost reach out and touch it. My personal explanation for this is that when you're looking straight down, you're looking normal (in the mathematical sense) to the atmosphere which is, after all, a horizontally stratified fluid. Thus, you are minimizing the effects of attenuation and refraction compared to looking the same distance obliquely through the atmosphere.

Finally, going to space for oceanography can be compared directly with going to sea for oceanographic cruises. Both involve much prior preparation and a constrained environment. And in either case you must bring along everything that you need! Oceanographic at-sea cruises are therefore great training for a space oceanographer.

OCEANOGRAPHIC DATA AND RESULTS

The preflight oceanographic observation plan delineated 12 specific ocean sites for which there were 66 observational opportunities spread over 43 orbits. Of this number, 7 observational opportunities encompassing 5 orbits were precluded due to concurrent operational requirements of the orbiter/crew making them unavailable. However, each of the 12 sites were covered a multiplicity of times and no significant site data were lost.

In addition, significant ocean data were obtained on a further 24 orbits which were not specified in the observation plan. Indeed some of the most important oceanographic discoveries on this flight were made in ocean areas and on orbits which were not called out in the preflight plan. This highlights the advantages of having man in the loop who can quickly assess the situation and reorder the priorities once on-orbit.

During the mission, about 1700 earth-looking views (land and ocean) were photographed by the crew, of which approximately 25% showed significant ocean dynamics. In addition, visible and color infrared photographs were taken by the large format camera in the payload bay, visible and thermal infrared images were collected by orbiting satellites, *in-situ* data were obtained by ships and aircraft at several sites, and some synthetic aperture radar data were obtained onboard and transmitted via TDRSS back to earth. All of the data collected (with the exception of SAR) are tabulated and discussed in NUSC Technical Document 7609, which is the companion volume to this report. The SAR data are the subject of a separate report to be issued by the Jet Propulsion Laboratory.

The major oceanographic results and discoveries from Mission 41-G involved the following ocean phenomena:

COMPLEX SUBMESOSCALE DYNAMICS
SHEAR CURRENTS
SPIRAL EDDIES
SOLITONS
INTERNAL WAVES
QUASI SOLITONS
SHIP WAKES
EQUATORIAL CURRENTS
FRONTS
ISLAND WAKES

COMPLEX SUBMESOSCALE DYNAMICS

Far and away the most impressive discovery resulting from this flight is the realization that the submesoscale ocean (length scales less than 100 km.) is far more complex dynamically than ever imagined in even the least conservative estimates. Moreover, this complexity was seen to extend all the way down (in range) to length scales of 100 meters, yet, on the other hand, patterns of this complexity could be seen to be interconnected for hundreds and hundreds of kilometers. Not all the oceanographic research ships in the world could collectively piece together such a pattern, and no remote sensor yet designed would be able to capture any but a small part of the overall structure. One can begin to gain a realization for the complexity involved by examining Figure 5.

This is a photograph of the Mediterranean just south of the Greek Isles taken looking into the sun's reflection on the sea surface. It is near the beginning of a series of sequentially overlapping photographs starting at Greece and crossing over the Central Mediterranean all the way to the Egyptian/Libyan border. All show the same pattern of dynamics. Moreover, lest one think this is an isolated example, let me assure you that it was chosen almost at random from the dozens and dozens of photographs of the entire Mediterranean, all of which show similar dynamics. Indeed, for the eight days we were on orbit, we passed over the Mediterranean three times a day (although not the same place) and each time the sun's glitter pattern would reveal a similar pattern of dynamics (see onboard written and taped notes).

The first thing that strikes one about all of the photographs is that the relatively bright lines in the center of the image are continuous into the relatively dark lines toward the edge. Since we are photographing into the sun's reflection, the center of the image is the specular point, and the darker area surrounding it is the subspecular annulus. Thus, since the pattern itself must be caused by a local change in the surface texture of the ocean, the change from high intensity lines in the specular area to low intensity lines in the subspecular annulus indicates that these features must represent places where the local roughness of the sea surface is **smoother** than the surrounding area. This could be caused by local changes in the dynamics of the ocean along the lines or the presence of surface surfactants at these places, or both.

In order to interpret such photographs one must first come to grips with the scale involved. Obviously since most photographs of the sun's glitter pattern are taken obliquely, i.e., at some angle away from nadir, there is a stretching of the geometry in the cross-track direction relative to the along-track direction. Since many of the ocean views on this flight were taken at an altitude near 120 nmi. (220 km.) using a 250mm lens, the following table based on these values is provided to assist in their interpretation.

$\phi = 0°$	A = 48,	R = 48
$\phi = 30°$	A = 56,	R = 68
$\phi = 45°$	A = 70,	R = 104

where ϕ is the look angle in degrees from the vertical
R is the Range (cross-track) ground coverage in km.
A is the Azimuth (along-track) ground coverage in km.

This photograph (Figure 5) therefore scales out to have a ground coverage of about 85 km. on a side. The bright lines have a thickness of the order of 100 meters, and the distance between lines is of the order of 1 km.

SHEAR CURRENTS

We now turn to a consideration of the bright lines themselves. For this we use Figure 6 which is also from the Mediterranean, but at a different time and in a different location from the previous photograph. Again we see the same pattern of ocean dynamics represented. But in this case, the photograph has been chosen to include not only the submesoscale dynamics but also ships and ship wakes.

The most obvious ship wake is that running horizontally across the middle of the image. Closer inspection however, reveals a number of ships and the turbulent stern wake behind them. In those cases where the ship is visible, the wake extends in a straight line behind the ship But in the case of the wake running across the entire image, several break points can be seen as the wake crosses the bright lines. This indicates that the bright lines represent horizontal shears in the ocean.

The ship making this long wake is well out of the image to the left. This is known since we have overlapping photographs of this area. Hence the wake is several hours old at the points where it is seen to be sheared, in contrast to the straight line wakes behind the ships that can be seen in the photographs. Several calculations on this image and several others from the flight, using reasonable estimates of the age of the ship wakes, indicate that the differential currents across the shears is of the order of 0.1 to 0.15 m/s.

This estimate of the magnitude of horizontal shear processes in the ocean is supported by the work of Scott, et al., 1985. As part of the SIR-B experiment on this flight, they laid an artificial slick consisting of a thin surface layer of oleyl alcohol in the North Atlantic in deep water west of the Bay of Biscay. The oil film was approximately 150 m. wide by 2.5 km. long. Not only was the slick imaged by the SIR-B radar, but it was seen to undergo a "break" about half way along. The *in-situ* data indicated that there was indeed a shear at the surface with a mean relative horizontal shear current of 0.15 m/s. In addition, the simultaneous towed thermistor chain data showed clear evidence of the shear extending down in the water column to a depth of at least 80 m.

We can now calculate the magnitude of the horizontal surface velocity shear values represented in these photographs. Taking the estimate of the differential current as 0.1 ms^{-1} and the width of the shear as 100 m., as previously noted, gives a value for the horizontal shear of 10^{-3} s^{-1}. This is in excellent agreement with that of Sheres et al. (1985) who measured similar shears over the northern California continental shelf having exactly the same magnitude and extending down to a depth of at least 90 meters.

This returns us to the question as to whether the shears delineated in the sun's reflection in the Mediterranean are made so highly visible by the effect of the local dynamics alone, or by the action of the dynamics in concentrating any surfactants, natural or man-made, on the sea surface.

The first thing that strikes you in looking at these shears in the sun's reflection is their mirror-like appearance. This indicates that the local ocean surface wave spectrum within the shear lines is devoid of any high curvature capillary waves. Now it is well known that surfactants reduce capillary and short gravity wave amplitudes and would thereby alter the visible forward scattering properties of the sea surface. Hydrodynamic shears, on the other hand, also modify the local surface wave field but in the sense so as to decrease the local visible brightness in the specular area and increase it in the subspecular annulus.

Secondly, there is always a sharp transition in the brightness characteristics along any shear as the geometry changes from specular to subspecular. This is not the case for the non-shear areas, where there is a far more gradual change in surface reflectivity and scattering as the geometry changes across the scene. This would again indicate that there are surfactant concentrations along the shear lines.

And thirdly, the brightness contrast present in all cases between the shear lines and the surrounding water, for both the specular and subspecular cases, would appear to be far greater than can be ascribed simply to hydrodynamic wave modulation by the shears themselves. A reasonable case therefore can be made to support the contention that the dynamics of the shear zones tend to concentrate the surfactants along those zones.

Analysis of the ships' wakes, moreover, provides almost overwhelming evidence to support such a conclusion. Again we return to Figure 6. Careful study of the long wake running horizontally across the image shows that not only is its brightness far less than that of the shears within the specular region but that there is also a marked edge effect along the entire wake on **both** sides, in which a very bright (surfactant) signature is seen continuously along each edge. Moreover, the wake maintains this appearance regardless of whether it is cutting through shear or non-shear regions of the ocean. This distinct difference between the visual properties of turbulent stern wakes and ocean shears almost certainly confirms the surfactant hypothesis.

And finally, the temporal persistence of the wakes for several hours, as demonstrated by the known age of the wakes, is an independent indicator of the presence of surfactants, since it is a measure of the time required for the surface interface to relax to a random state due to small scale turbulence.

The accumulation of surfactants along the shears also has some implications for the dynamics of those shears, for it indicates that these are regions of convergence at the surface, together with a concomitant downward motion of the surface water along the shear zones. This interpretation is at least partly substantiated by the work of Scott et al. (1985, op. cit.) in which their thermistor data clearly showed such downwelling through a shear.

The surfactants have wider implications as well. Since they are considered to be mainly of biogenic origin and only occasionally from pollution, the widespread occurrence of such regions in many areas of the world's oceans as observed during Mission 41-G would indicate that the concentration of such material is therefore much higher worldwide than previously thought. This in turn has implications for life cycles in the ocean.

Furthermore, high concentrations of surfactants on the ocean's surface could have significant effects on other types of remotely sensed ocean data. In particular, since the local thermal emissivity will be lowered, passive microwave and infrared imagery could well be affected. For active systems, the alteration to the capillary wave structure may change the wind speed values recorded with a scatterometer, particularly for light winds, and will certainly modify the radar backscattering image from a synthetic aperture radar.

SPIRAL EDDIES

Big whorls have little whorls
That feed on their velocity,
And little whorls have lesser whorls,
And so on, to viscosity.

Lewis F. Richardson

As is readily apparent from Figures 5 and 6, the horizontal surface velocity shears often roll up into spiral eddies to form a continuous and interconnected pattern. This is characteristic of the submesoscale dynamics seen in many areas of the world's oceans during Mission 41-G and is by no means the exception. Indeed, spiral eddies were observed in all the following locations:

Black Sea
Brazil Current
California Current
English Channel
Gulf Stream
Northeast of Hawaii
Irish Sea
Kamchatka Peninsula
Mediterranean Sea
Gulf of Mexico
Off Morocco
Gulf of Oman
Persian Gulf

Occasional examples of such features (although not called spiral eddies) were noted on the early Gemini and Apollo flights (Soules, 1970) and subsequently in the Skylab, Apollo-Soyuz and early space shuttle photographs. But they were thought to be isolated peculiarities and not of importance to basic ocean dynamics. Their almost ubiquitous occurrence during 41-G however, whenever submesoscale dynamics was revealed in the sun glitter, indicates that they are perhaps **the** most fundamental entity in ocean dynamics at this scale. The difficulty is in explaining their structure.

Figure 7 is another photograph taken over the Mediterranean just off the coast from the Egyptian/Libyan border. The geometry is similar to that of the previous two photographs and displays the usual complex field of submesoscale shear currents. However, the spirals depicted are atypical in that they are aligned in a straight line and are not randomly positioned throughout the field as is normally the case. This alignment in a spiral street is thought to be due to their having just been generated, possibly in conjunction with the lineated shears on the one side of the street (which is again atypical), and have not had time to have been advected into a more random pattern. This photograph is perhaps the best therefore to begin to elucidate the structure within the spirals.

The most obvious thing to notice is that the sense of rotation of the spirals in the street is always counterclockwise and that there are no corresponding spirals at all on the other side of the lineated shears. Thus, this phenomenon cannot be a von Karman vortex street (which consists of two parallel rows of vortex pairs) and hence probably rules out the possibility that such features are generated by isolated bottom topographic peaks.

Further investigation of the inner structure of the spirals shows that the shears have the appearance of a rolled up vortex sheet rather than that of the "bathtub vortex" characteristic of dust devils, tornadoes or hurricanes (see for example Sibulkin, 1983). Indeed, the structure in the spirals is very similar to that obtained by Rosenhead (1931) who calculated the evolving shape of a vortex sheet, with no density difference across it, after it had been given a small sinusoidal displacement. By including the non-linear terms, he showed that the sheet rolled up into a spiral form due to the interaction of the various parts of the vortex sheet and the distortion of the waveform by the mean flow. The point to note is that the oceanic shears are continuous within the spiral, much like a series of vortex sheets, and do not seem to form a singularity at the center of the spiral. Of course, it should be kept in mind that this is a two-dimensional analogy, and the strong baroclinicity of the spirals should not be overlooked.

The structure is also similar to that obtained in stratified flows when a density interface becomes unstable. In this case, a Kelvin-Helmholtz instability forms and grows on the interface, and the resulting pattern, in its initial stages, looks remarkably like the spiral street seen in Figure 6 (see Thorpe, 1971). Indeed Roshko (1976) showed, in a superb series of experiments on turbulent shear flows, that there is a fundamental deterministic structure to the turbulence. This structure, especially for low Reynolds number, has many of the characteristics exhibited by the spiral eddies.

But again there are some signficant differences. The turbulent shear flows in Roshko's mixing layer are still fundamentally two-dimensional, in contrast to the ocean spirals for which all evidence points to their being sharply baroclinic. These ocean spirals would have to be essentially barotropic for there to be a similarity in the basic dynamics. Moreover, vortices in the turbulent shear flow are seen to grow in size downstream, in sharp contrast to the ocean spirals which all have approximately the same linear dimensions. Furthermore, the nature of turbulent shear flow in a mixing layer, with its basic mean vorticity all of one sign, is such as to inhibit the formation of three-dimensional structures; for such structures usually require the existence of a double row of vortices of opposite signs so that it becomes possible to form vortex loops or rings. Hence the dynamics inherent in ocean spiral eddies is probably of an entirely different origin.

We turn now to a consideration of other spiral eddies seen on Mission 41-G. Figure 8 shows a series of spiral eddies inboard of the Gulf Stream off Long Island, i.e., between the north wall of the Gulf Stream (seen as a sharp color boundary in the top left-hand corner) and the coast. Again the geometry (altitude, sun-angle) is similar to the previous photographs taken over the Mediterranean.

At first glance, the spiral field appears to be more complex and to have much smaller characteristic length scales. But this is an artifact of the camera, this photograph was taken with a 100mm lens in contrast with the others which were taken with a 250mm lens. In real life it appears essentially the same as that in the Mediterranean with the same generic pattern of complex shear currents and interconnected spiral eddies. A feel for this similarity can be obtained by enlarging this photograph by a factor of 2½ before comparison. Note moreover that all the spirals in this photo are again of the same sign, having a counter-clockwise sense of rotation, and when allowance is made for the camera, they are of the same linear dimensions as those in the Mediterranean.

The next photograph, Figure 9, was taken just a few seconds before the previous one, and is an excellent example of the interconnectivity of the spiral dynamics. Because it is a high oblique photograph, the field of view stretches from Long Island all the way south to Cape Hatteras, a distance of approximately 365 nautical miles. Note that the shear currents and their associated spiral eddies can be seen over this entire length.

This same generic pattern repeated itself wherever spiral eddies were seen throughout the mission. Individual spirals had a remarkably uniform size of 12 to 15 km. in diameter and were interconnected by their constituent shear currents for distances of hundreds of kilometers. The only significant difference in these eddies worldwide is that they rotate in the opposite direction in the southern hemisphere.

This preferential predilection for a rotation direction is always in the sense of cyclonic motion, being counter-clockwise in the northern hemisphere and clockwise in the southern hemisphere. Indeed all spiral eddies ever seen, either from this mission or from earlier or subsequent missions, have been cyclonic in nature. This becomes all the more remarkable when a compilation of spiral eddies is made from many shuttle flights. Figure 10 shows the locations of such spirals from the first sixteen shuttle missions, and it should be regarded as a very conservative estimate since not all photos which show spiral formations have been so identified in the computer data base.

Furthermore, this preference for cyclonic motion would tend to indicate that earth rotation effects are important, although the scale length of the eddies involved is at the low end of the range of oceanic values for the Rossby internal radius of deformation, the natural internal length scale in an inviscid rotating stratified fluid. Thus, although earth rotation effects are probably important, other effects could well be of equal magnitude and must therefore be considered.

In summary:

SUBMESOSCALE SPIRAL EDDIES

- First realized to be of importance to ocean dynamics by their frequent observation on Flight 41-G
- Occur in all regions of strong ocean dynamics
  - — Eastern and western boundary currents
  - — Confined seas (e.g., Mediterranean, Persian Gulf)
- Always cyclonic sense of rotation (counter-clockwise in the northern hemisphere, clockwise in the southern hemisphere)
- Uniform size (12-15 km diameter)
- Often interconnected for hundreds of kilometers
- Are embedded in complex fields of shear currents
- Totally different from larger scale circular eddies and rings
- Detectable by remote sensing, due to accumulation of surfactants (both natural and man-made) along boundaries of shears

Finally, it should not be overlooked that if the presence of surfactants is necessary in order that spiral eddies be visible in the sun's glitter pattern, then it is quite possible that such dynamics are far more ubiquitous in the world's oceans than currently recognized.

One way to determine this is to use satellites, which have the advantage of wide area repetitive coverage. The question is therefore, are there any sensors aboard the meteorological satellites currently flying that can remotely detect spiral eddies? In order to examine this, Bob Whritner of the Scripps Institution of Oceanography Satellite Facility has processed a considerable amount of high resolution infrared data from NOAA 7 taken over the Mediterranean throughout the time of the 41-G flight. A typical example is given in Figure 11.

This image of the western Mediterranean has been processed using the usual convention of white/cold, dark/warm. The general circulation features of cold water entering the Mediterranean through the Strait of Gibraltar, flowing clockwise to form the well-known Alboran Gyre and then bifurcating to give a flow of cold water along the Algerian coast can clearly be seen. But beyond th general circulation, the submesoscale dynamics can also be distinguished. Just like the visual, it depicts a very complicated structure in which, indeed, cyclonic spiral eddies are embedded. This is most noticeable in the upper right part of the image in the general area of the Balearic Islands. Since this image is state-of-the-art, it means that it is just now becoming possible to consider a satellite infrared study of spiral eddies, now that we know what to look for.

SOLITONS

In August 1834, J. Scott-Russell observed a large pulse of water travel without distortion for several miles down a river near Cambridge. This was the first instance of the recorded observation of a soliton and was long considered a rather unimportant curiosity. However, in the past twenty years the study of solitons has exploded and they have found application in many diverse fields ranging from quantum theory to the Great Red Spot of Jupiter. In fact, they are now thought to be a common feature of nature, spanning 22 orders of magnitude in size.

Fundamentally they are non-linear localized travelling waves that maintain their shape and integrity through a balance between the non-linear and dispersive wave effects. In the ocean, they manifest themselves as large internal (or subsurface) waves having only a small surface expression. They were first seen from space by Vance Brand on Apollo-Soyuz in 1975, and have been called V-Brand waves in the astronaut office ever since then.

In the open ocean, they typically come in groups of between 6 and 10 with the leading wave being the most intense. The interspatial wavelength is usually several kilometers and the crest lengths are often found to be in excess of 100 km. The subsurface amplitude of these waves can reach as high as 100 meters, and the whole packet moves with a speed of several knots. Seen from low earth orbit, they appear as long parallel bands of roughened water on the surface of the ocean, interspaced with alternate bands of calm water. An excellent study of these features is given by Apel et al. (1985).

A dramatic example of ocean solitons was seen on several occasions during this flight just inside the Strait of Gibraltar in the Alboran Sea. A typical example is shown in Figure 12. To get an idea of scale, Gibraltar can just be seen at the top of the photograph, and Ceuta on the tip of Morocco is some 30 km to the south. This well defined soliton packet is triggered by a tidal impulse over the sill in the entrance to the Strait, and extensive ground truth at this site was obtained throughout the flight by a group from the Naval Ocean Research and Development Activity (see LaViolette, 1984).

Each tidal cycle in the Strait initiates its own soliton packet that then propagates eastward into the Mediterranean. Up to three such packets, each separated by a distance of about 60 km., could be seen across the Alboran Sea on those days when the viewing conditions were good (Figure 13). Indeed, the extensive shuttle photographs, satellite data and *in-situ* ground truth gathered throughout the mission have led to a number of papers either published or in press (see for example, LaViolette and Arnone, 1985, Armi and Farmer, 1985).

Not all solitons show up this distinctly, however. A good example of this is the solitons seen in the Red Sea (Figure 14). I was able to visibly see and count 10 distinct waves in this packet, each one of which had a double crest, i.e., each crest could be resolved into a double band or pair of crests quite close together. Although not easily seen, this doublet structure could be distinguished with the naked eye without the use of binoculars. However, when the film was processed, not only was the doublet nature of each soliton not apparent, but also the total number of waves shown in the packet was less than that counted from on-orbit. This graphically illustrates the ability of the human observer in space to distinguish extremely subtle variations in both color and texture.

INTERNAL WAVES

These are the more common linear subsurface waves in the ocean and both their existence and observation from space have been widely known for years (see for example Garrett and Munk, 1979). Their spatial and velocity scales are of the order of 2 to 5 times smaller than those characteristic of solitons, and they are often found in coastal areas as intersecting packets with marked wavefront curvature where they have become refracted by the underlying bottom topography. Although not remarkable in themselves (and hence no photograph is reproduced here), what was remarkable throughout the flight was that these linear internal waves were observed along every coastline that could be viewed in the sun's reflection. A marvelous demonstration of the ubiquity of internal waves in the ocean.

QUASI-SOLITONS

These features were certainly the most subtle phenomena seen in the ocean from the shuttle on this flight; indeed they were so subtle that, although seen on many occasions, they did not even once show up on the developed film.

First to define what is meant by a quasi-soliton, which is merely the short hand notation that I developed on-orbit to describe these features. Simply put, they are intermediate in size between the normal internal waves and the normal solitons that you see from orbit. What makes them so hard to distinguish however, is that the crests that define their banded structure are very diffuse. They show up almost like shadows on the sea surface, and are easily differentiated from the rather more sharply defined internal wave or soliton packets.

These quasi-solitons do have a structure however. They tend to come in groups ranging anywhere between 4 and 40 (sometimes far more than is found in internal waves or soliton packets) and typically have crest lengths of about 50 to 100 km. with an interwave spacing of 2 to 3 km. In essence, they look like a scaled down and diffuse version of solitons, but with a characteristically smaller wavelength. Hence the name.

The intriguing thing about quasi-solitons, however, is that their observation was not an uncommon event; rather they were often seen in regions in which there was a spiral eddy field. Indeed, they would be seen to be laid right across the spiral structure. Could quasi-solitons be the "missing link" then, the key to unravel the dynamics of spirals? I believe that it might just be so.

Perhaps, therefore, the quasi-solitons as viewed from space are the surface expression of near-inertial internal waves. These waves could then interact with the horizontal shears, which as we have already seen, are quite widespread, in such a way as to amplify and trap that energy. The result of this could then be the formation of the spiral eddies. Since this interaction would be an intermittent process, it would go a long way to explaining the rather uniform size of the spirals seen in the ocean.

SHIP WAKES

We have already discussed ship wakes to some extent in terms of their interaction with the shear currents in the ocean. Seen from space, the long turbulent stern wake is highly visible when viewed in the sun's glitter pattern. By following this specular area as it tracks across the ocean in concert with the spacecraft, ship wakes extending 150 nautical miles behind the vessel would routinely be seen. This persistence of the wake may be due entirely to hydrodynamic effects, but is more likely the result of its interaction with the natural surface surfactants.

A typical group of ship wakes, in this case all on parallel tracks, can be seen running across the picture in Figure 15. Note, in passing, the bending of these wakes as they cross the ocean front. The much brighter wake in the center of the group is not nearly as common and indeed was rather puzzling at first.

These bright wakes, of course, jump right out at you, and several instances of them were seen in different parts of the world. Having looked in some detail at these bright wakes, of which Figure 16 is a good example, it is now relatively certain that these signatures are characteristic of a ship that is either leaking oil or pumping its bilges. The oil becomes trapped in the stern wake, and its appearance from space is then rather similar to that of the shear currents. Indeed, as the geometry changes from specular to subspecular, the oil wake undergoes a sharp reversal in its brightness characteristics just as in the case of the shear currents.

More intriguing though were the Kelvin wave bow wakes which showed up best in the subspecular annulus, just beyond the edge of the sun's glitter pattern, and especially if that region was an area of light winds and therefore a smooth sea surface (see Figure 17 for instance).

Well over a century ago, Lord Kelvin published his now famous theory on ship wakes, in which he showed that a ship would generate a pattern of divergent and transverse waves which would form a line of caustics at 19.5° off the centerline on each side of the ship. Moreover, this V-wake angle would be invariant regardless of the type of ship or its speed.

It was surprising then, when, in 1978, ship wakes imaged by the synthetic aperture radar aboard the SEASAT Satellite showed Kelvin wakes which had an uncharacteristically small V-angle. This caused a flurry of theoretical interest and it was finally resolved that the SAR, which sees backscattering from Bragg resonant surface waves, was selecting out those waves in the wake which had a particular **wavenumber** and direction that would satisfy the Bragg condition. Hence by imaging only those waves, the SAR would show Kelvin wakes which had a narrow-V appearance.

It was even more surprising then to see Kelvin wakes in the visible from 41-G which also had a narrow-V appearance. Moreover, many of these wakes had a series of V's within the outer V, all meeting back at the apex with increasingly smaller opening angles. Now it could well be argued that visible light in forward scattering off wakes which lie just outside the sun's glitter area would select out those surface waves in the wake which had a particular slope and direction that would satisfy the specular reflection condition. However, although this might explain the existence of a narrow-V Kelvin wake, it is hard to see how it also accounts for the multiple-V structure.

EQUATORIAL CURRENTS

As previously seen there was extensive cloud cover during this flight. Hence, when long cloud-free bands appear, stretching for hundreds of miles in an east-west direction, they get your attention. Two such bands, each about 50 miles in width, were seen in the eastern South Pacific Ocean, both on the same orbit. They were located at 8.2° south and 23.2° south respectively. The first probably coincided with the South Equatorial Current, but the second is somewhat of a mystery. However, the rather sharp boundaries to these cloud-free streets probably indicate that they were caused by a temperature anomaly in the ocean, rather than by purely meteorological effects.

FRONTS

Oceanic fronts can easily be seen from low earth orbit, both in the sunglint and by their color contrast. They are most prevalent off headlands, indeed, the observation of fronts extending 20 to 40 km. off coastal headlands is the rule rather than the exception.

Fronts in the open ocean are equally visible, but there can be traps for the unwary. Note Figure 18. This photograph, taken with a 250mm lens over the Ionian Sea, shows what appears to be a strong front in the ocean. Figure 19, however, shows the same scene at the same time, but was taken with a 50mm lens. Note the dark banded structure with the puffball cumulus rows aligned directly above them. This indicates a purely meteorological effect.

Subsequent satellite data analysis indeed shows a significant atmospheric frontal wave near Albania. In addition, enhancement of the satellite data show instability waves southwest of the main Greek Islands in both the visible and the infrared bands. They have been interpreted as gravity wave ripples on a low level inversion layer. Hence the apparent ocean front is almost certainly a change in the ocean's textural characteristics caused solely by the atmospheric front. Moreover, the long ship's wake, extending right across the image in Figure 18, is seen to cross this front without any shearing, thus further confirming this interpretation.

ISLAND WAKES

When islands are situated in regions of strong current, they trail behind them broad wakes which are easily visible from space, both in the sun's glitter pattern and quite often purely from colo, discontinuities. Indeed, changes in the direction of island wakes, and hence the prevailing current, due to the effects of El Nino have been noted by satellite data and by space shuttle photography.

The effects of currents behind islands is to produce strong upwelling and vertical mixing, thereby transporting deep cold nutrient-rich waters into the surface layers. This increases the phytoplankton concentration, which in turn ultimately affects the higher trophic levels.

Good island wakes were observed behind the Azores, Galapagos and Reunion Islands as well as Malta and Madagascar. A typical example is seen in Figure 20, which shows the islands of Isabela and San Salvador in the Galapagos. Note the strong wake behind San Salvador and the inter-island wave train which is probably a purely hydrodynamic effect

OCEANOGRAPHIC PUBLICATIONS USING DATA FROM FLIGHT 41-G

L. Armi and D.M. Farmer, "Surface Manifestations of Internal Hydraulics of Gibraltar Straits," Eos, *Trans. Am. Geophys. Un.*, 66, 1267-1268, 1985

M.T. Bagg, et al., "A Study of Internal Wave Imaging in the Northeast Atlantic Using the SIR-B System," SIR-B Science Workshop, Jet Propulsion Laboratory, Pasadena, CA, 14-16 May 1985

D.M. Farmer & L. Armi, "Maximal Two-Layer Exchange over a Sill and Through the Combination of a Sill & Contraction with Barotropic Flow," *J. Fluid Mech.* (In Press)

G. Feldman, "Satellite Observations of Phytoplankton Variability in the Eastern Equatorial Pacific," PhD Dissertation, State University of New York at Stony Brook, 217 pp, Dec. 1985

G. Feldman, "Patterns of Production around the Galapagos Islands," *Tidal Mixing and Plankton Dynamics*, Bowman, Yentsch and Peterson—Eds., Springer-Verlag (In Press)

R.W. Fett, "Space Shuttle and Landsat Views of Environmental Phenomena Related to Meteosat and Polar-Orbiting Satellite Imagery," Meteosat Users Conference, Rome, Italy, May 1985

M.G. Fischer, "Oceanographic Analysis of Sunglint Images from Space Shuttle Mission 41-G," Naval Postgraduate School Thesis, March 1986

E.O. Hartwig and F.L. Herr, "Chemistry and Biology of the Sea-Surface Interface Relationships to Remote Sensing," Office of Naval Research Workshop Report, 2 April 1985

J.G. Hughes, J.J. Gallagher and P. Scully-Power, "Navy Oceanographer Shuttle Observations, STS 41-G, Data Catalog," NUSC Tech. Document 7609, 26 March, 1986

P.E. LaViolette and R.A. Arnone, "Regional Circulation in the Area of the Strait of Gibraltar as Defined by Space Shuttle Photographs," Eos, *Trans. Am. Geophys. Un.*, 66, 287, 1985

P.E. LaViolette and R.A. Arnone, "Preliminary Study of a Standing Wave in the Western Approaches to the Strait of Gibraltar," Proceedings of the Commission International Pour Exploration Scientifique de la Mediterranne, 24th Congress, Lucerne, Switzerland, 1985

P.E. LaViolette, T.H. Kinder and D.W. Green III, "Measurements of Internal Waves in the Strait of Gibraltar Using a Shore-Based Radar," NORDA Report 118, January, 1986

P.E. LaViolette and H. Lacombe, "Tidal Induced Pulses and Flow in the Strait of Gibraltar," submitted to *Oceanologica Acta*

M.H. Schultz and D. Lee, eds., *Computational Ocean Acoustics*, Pergamon Press, New York, NY, 1985

J.C. Scott, "The Future of Sunglint Imaging as a Spaceborne Oceanographic Observation Tool," Admiralty Research Establishment Technical Memorandum TM (UJO) 86105, February 1986

J.C. Scott, M.T. Bagg and N.M. Lane, "Evidence for Horizontal Shear Processes in the Ocean, Derived from SIR-B Imagery," submitted to *Science*

P. Scully-Power, J. Hughes and W.T. Aldinger, "Navy Oceanographer Shuttle Observations, STS 41-G, Quicklook Report," NUSC Tech. Document 7379, 28 February 1985

P. Scully-Power, "Ocean Dynamics: Views from Space," Eos, *Trans. Am. Geophys. Un.*, 66, 234, 1985

P. Scully-Power, "Oceanography from Space Shuttle," Invited Paper, 19th Annual Congress of the Canadian Meteorological and Oceanographic Society, Montreal, Quebec, 12-14 June 1985

P. Scully-Power, "Oceans from Challenger Exhibit Anomalous New Structures," Invited Paper, Oceans '85, San Diego, CA, 12-14 November 1985

Figure 5: Complex Submesoscale Dynamics

S17-35-083

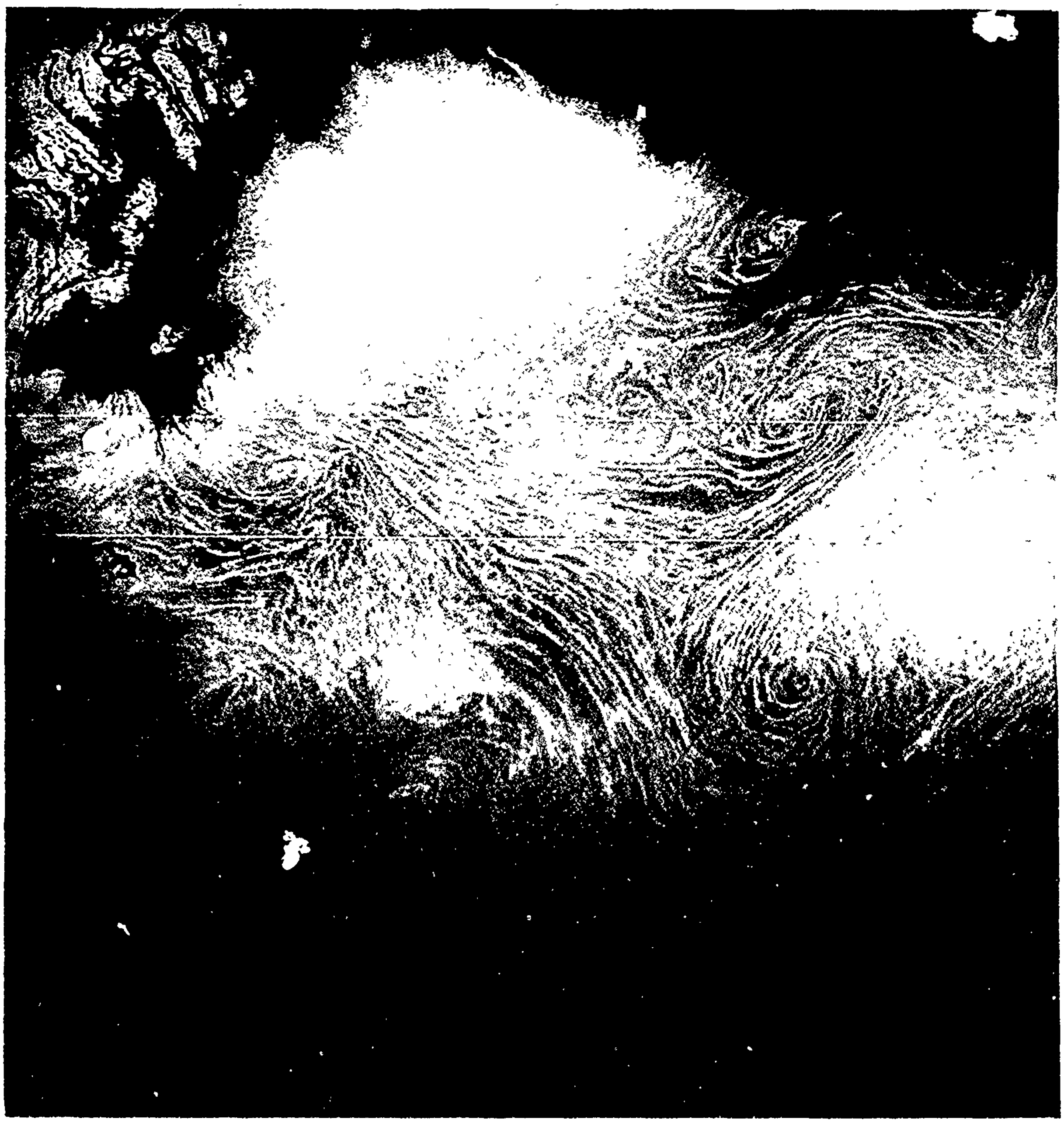


Figure 6: Shear Currents

S17-38-060

Figure 7: Spiral Eddy Street, Mediterranean

S17-35-094

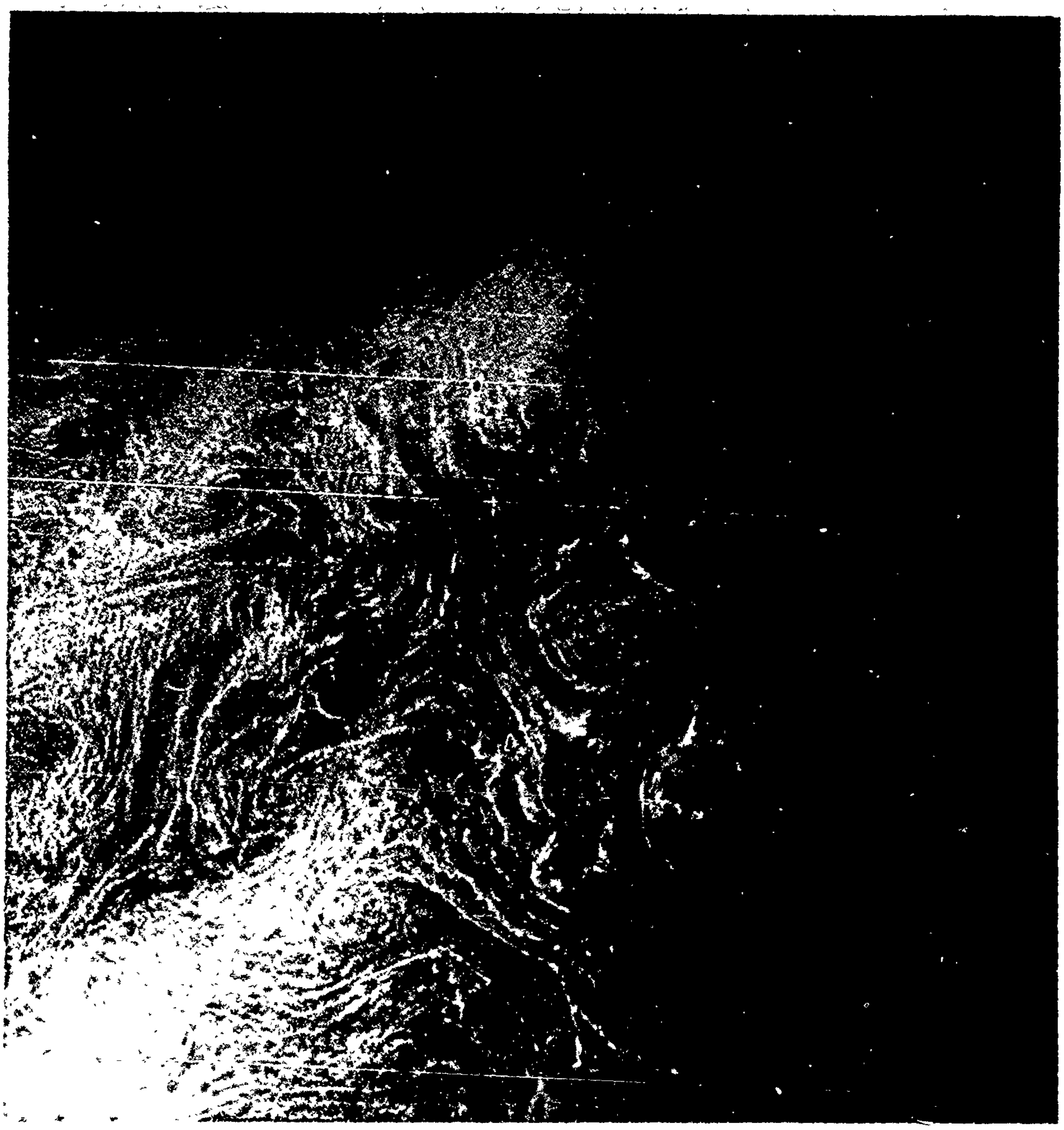
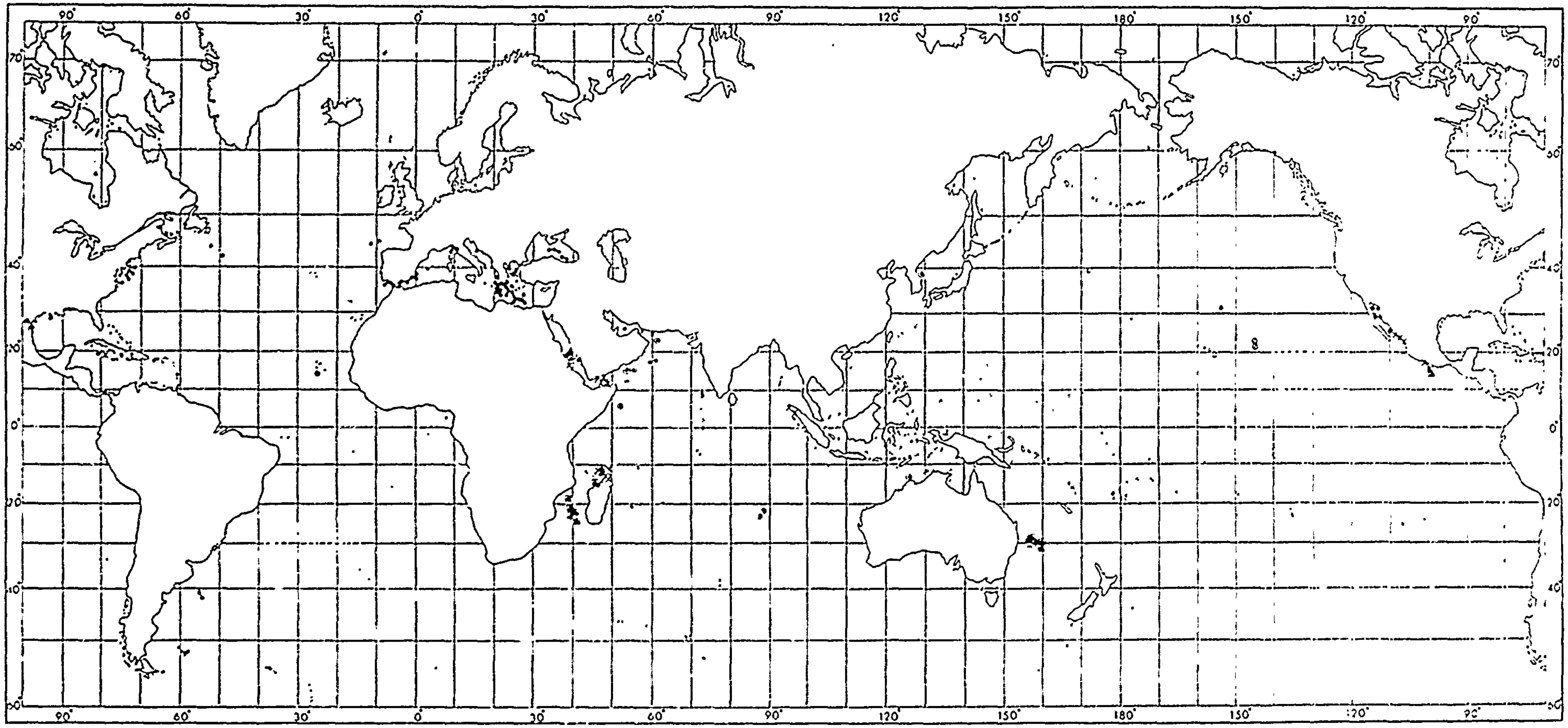


Figure 8: Spiral Eddies, Gulf Stream (low oblique)

S17-41-046

Figure 9: Spiral Eddies, Gulf Stream (high oblique)

S17-41-042



LOCATION OF HANDHELD SHUTTLE PHOTOGRAPHY
FROM THE FIRST SIXTEEN MISSIONS SHOWING
SUB-MESOSCALE SPIRAL EDDIES

KEY
- o WINTER (DEC-MAR)
- ▴ SPRING (MAR-JUN)
- ▲ SUMMER (JUN-SEP)
- • FALL (SEP-DEC)
- x (STS 51A) (STS 5)

MISSIONS

STS 5	11 NOV-16 NOV 82
STS 6	4 APR-6 APR 83
STS 7	18 JUN-24 JUN 83
STS 8	29 AUG-5 SEP 83
STS 41B	3 FEB-11 FEB 84
STS 41C	6 APR-13 APR 84
STS 41G	5 OCT-13 OCT 84
STS 51A	8 NOV-16 NOV 84
STS 51D	12 APR-19 APR 85
STS 51B	29 APR-5 MAY 85

Figure 10. Location of Spiral Eddies from Shuttle Flights

Figure 11: High Resolution Infrared Satellite Image, Mediterranean

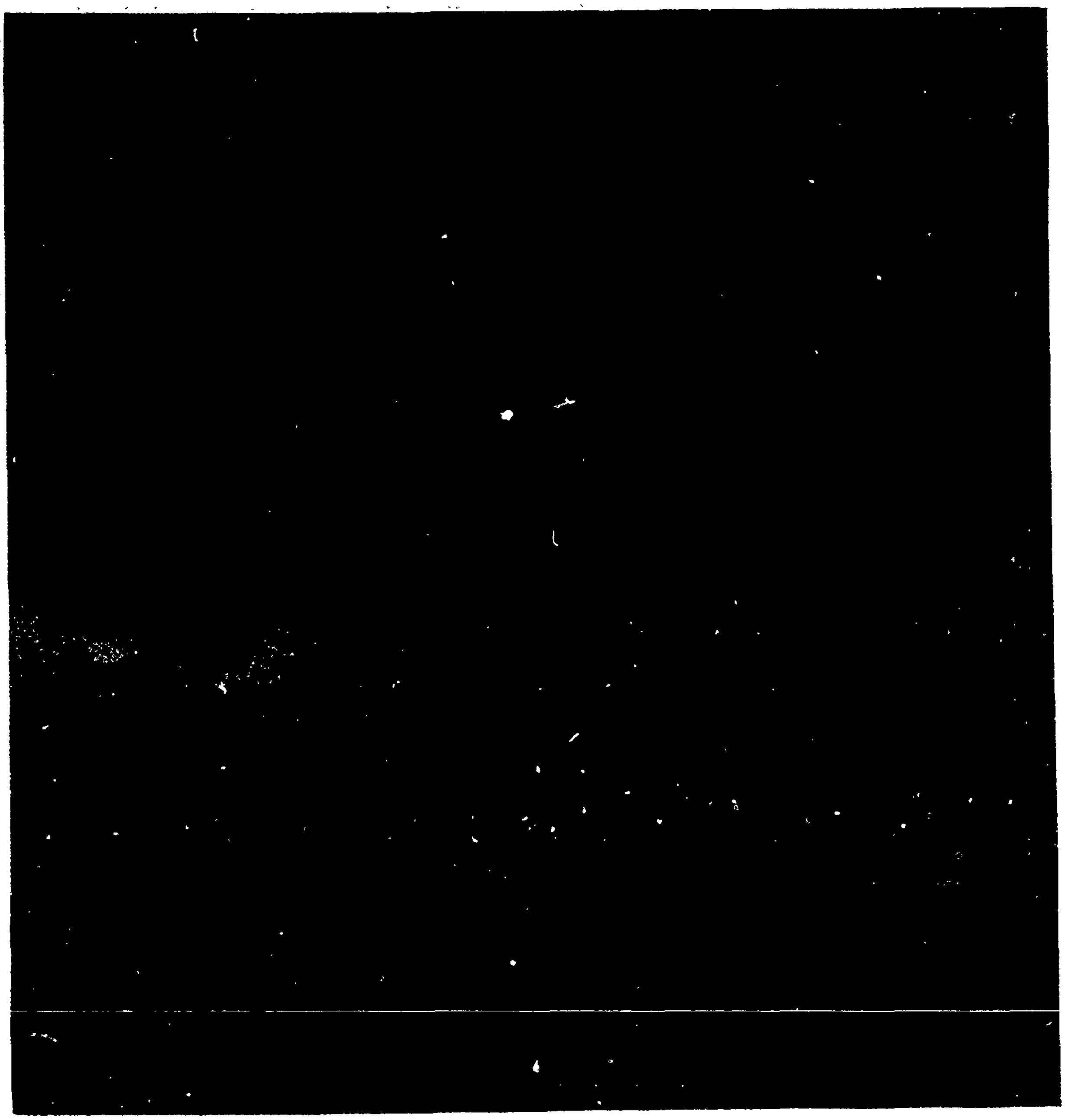


Figure 12: Soliton Packet, Strait of Gibraltar (250mm lens)

S17-34-098

Figure 13: Soliton Packets, Strait of Gibraltar (100mm lens)

S17-34-079

Figure 14: Soliton Packet, Red Sea

S17-36-034

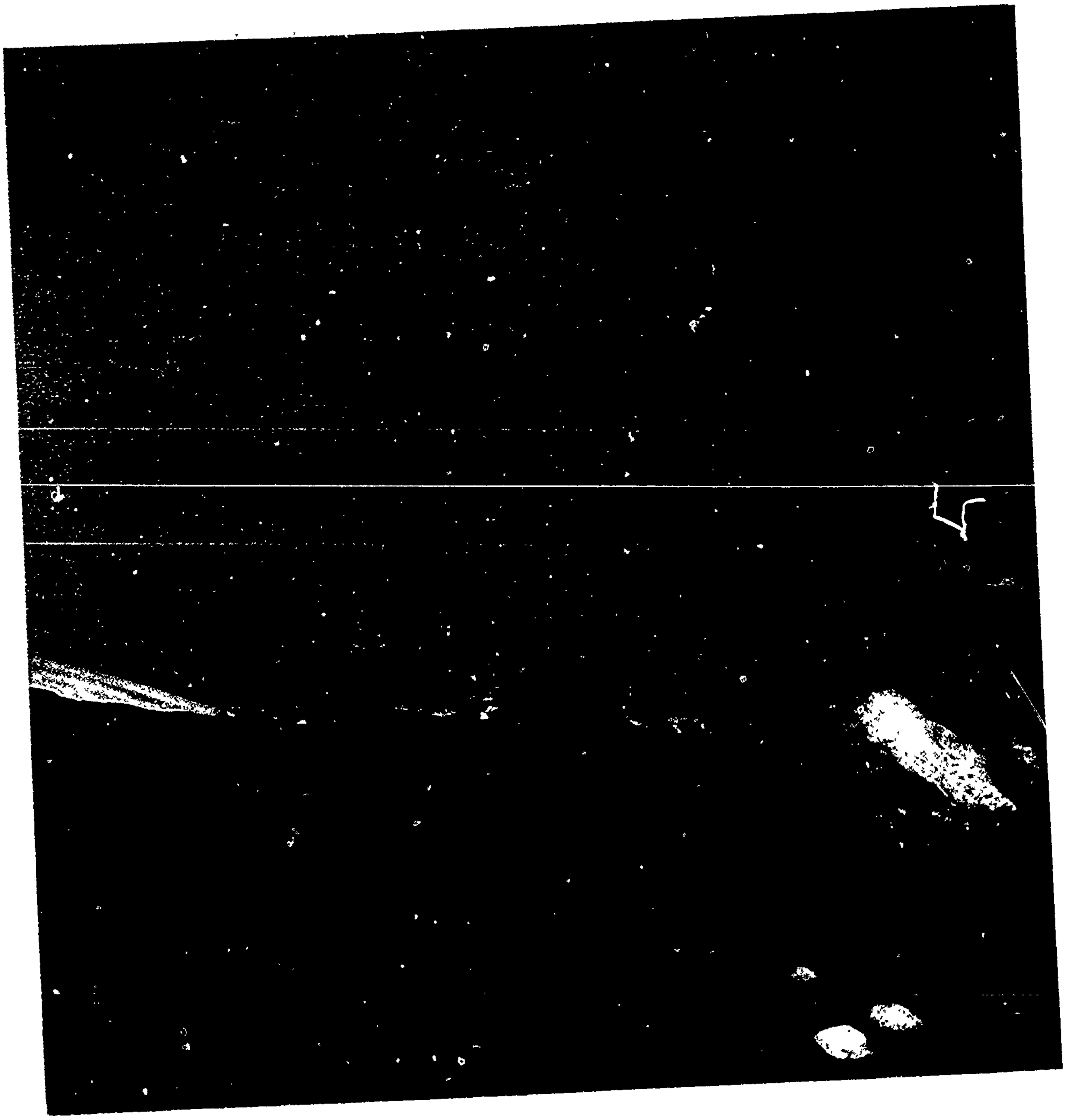


Figure 15: Group of Ship Wakes

S17-38-080

Figure 16: Oil-Contaminated Ship Wake

S17-38-063

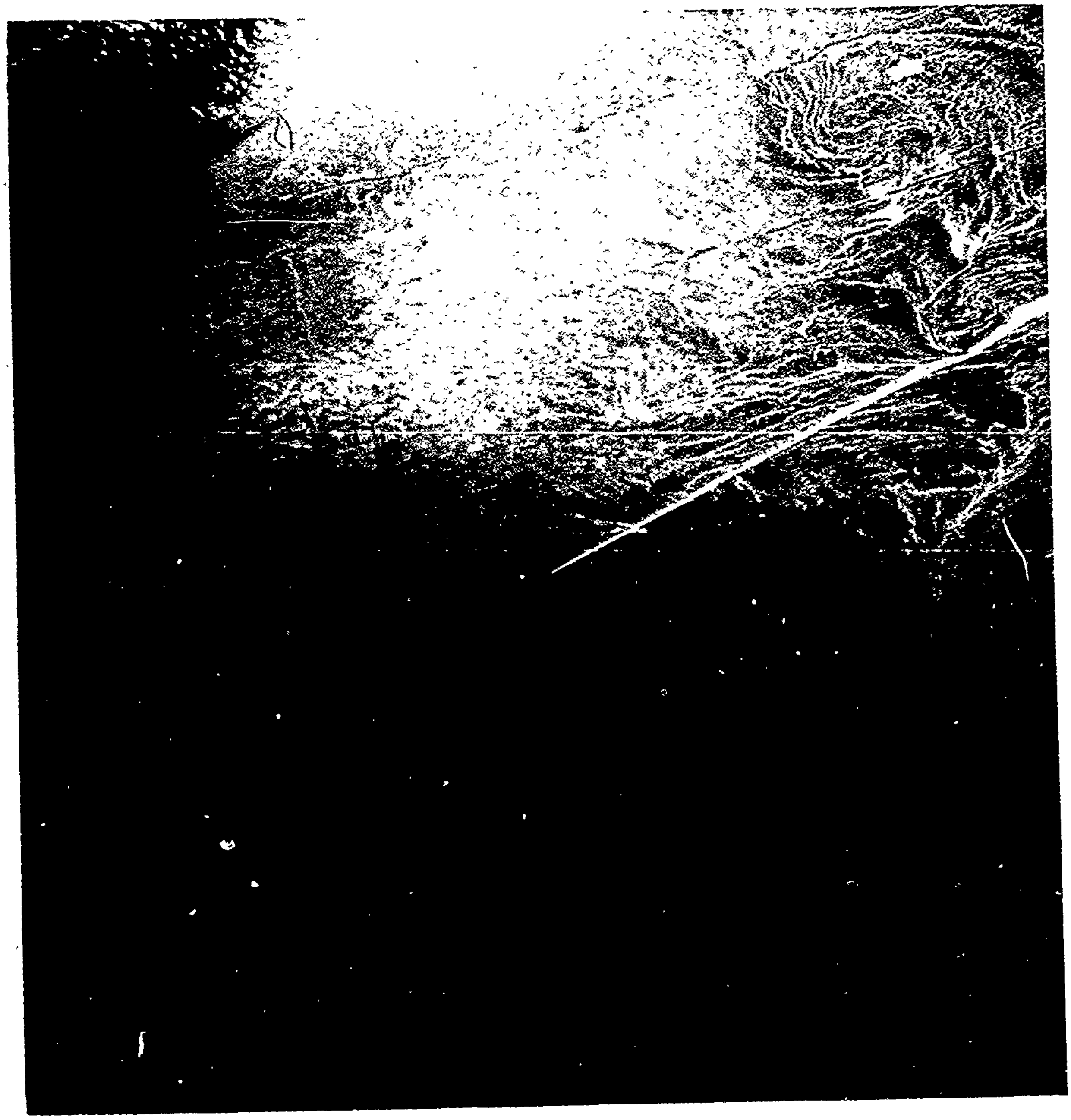


Figure 17: Kelvin Bow Wake

S17-38-061

Figure 18: Wind Front, Ionian Sea (250mm lens)

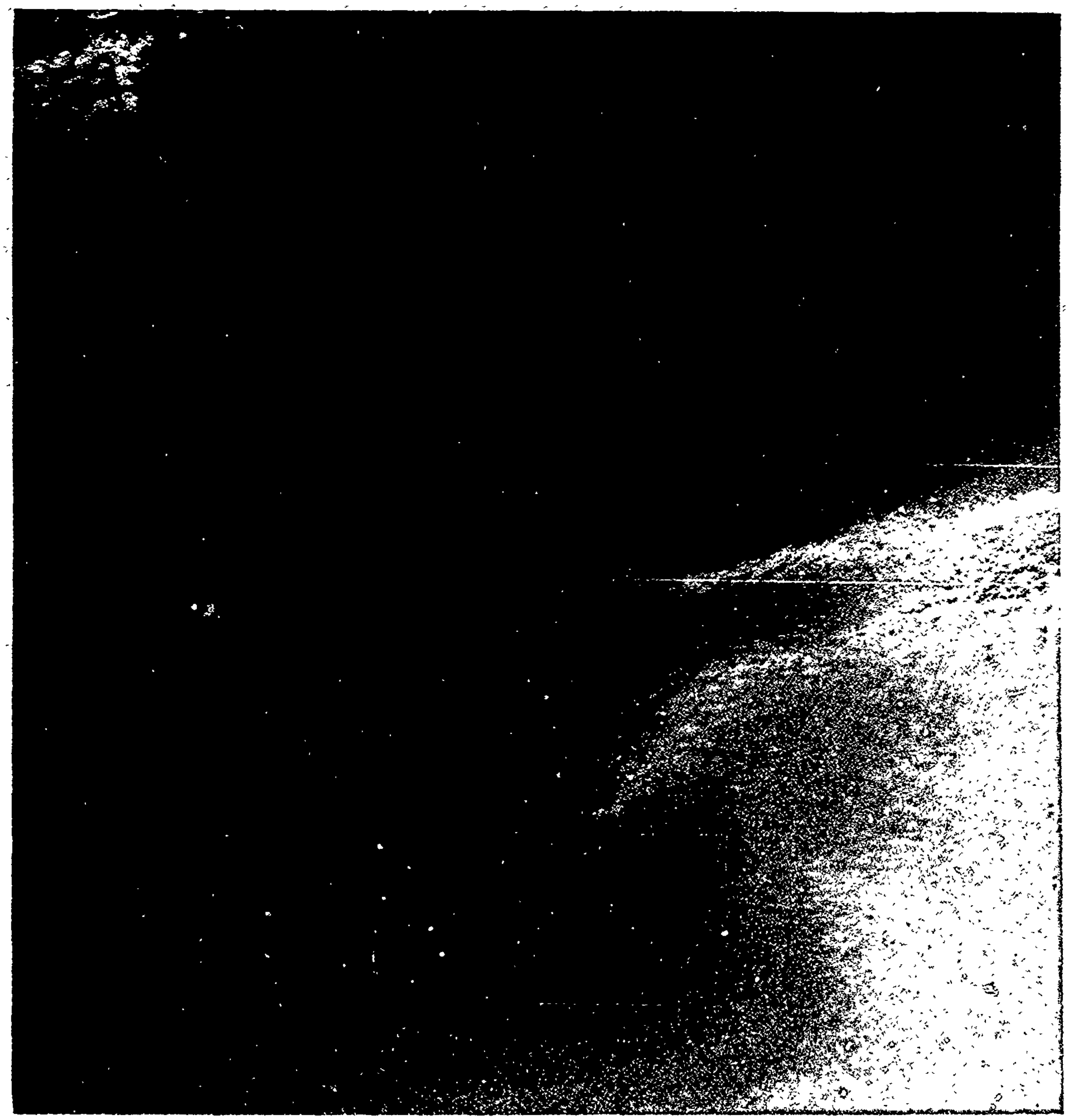
S17-38-055

Figure 19: Wind Front, Ionian Sea (50mm lens)

S17-42-047

Figure 20: Island Wake, Galapagos

S17-43-021



POSTFLIGHT

It was the best of times.
It was the worst of times . . .

Charles Dickens
A Tale of Two Cities

The postflight phase is the one part for which you are not prepared. After the formal requirements of a crew debriefing to the Flight Crew Operations Directorate and a postflight physical have been met, you are then subject to the whims, requests, vicissitudes and entreaties of the world at large. There are no guidelines, other than your own inner desire to give back to the space program some small measure of what it has given you.

In essence, the demands on your time take two forms: scientific/technical and public relations. I will briefly outline each in turn.

Since many scientists were involved in the flight, each has his/her specific requirements for a subset of the total oceanographic data taken on-orbit. All such requests were met, and a tabulation of the types and amounts involved has been included to give a feel for the order of magnitude.

In addition, these scientists, the professional societies to which they belong, and high ranking officials all want you to make technical presentations. And rightly so, for it is the scientific and technical community who is the ultimate beneficiary of any new understanding of the physics of nature that might result from the flight. Again, to give some indication of the wide range of technical presentations made, a listing is included which covers the major ones to the end of calendar year 1985.

On the other hand there is the public relations side. Requests for speeches/interviews range over the whole gamut of human endeavor: newspapers, radio and TV stations, banks, hospitals, libraries, schools and colleges, social clubs, fraternity clubs, service clubs, churches, seaports and aquariums . . . from small towns to foreign countries. All want to know first hand of the experiences of space, to be a part, even though it be a vicarious part, of the space program.

And then there is the mail! It literally comes in by the thousands of pieces, from every conceivable part of the world, and written in a multitude of languages. And they all want something! An autograph, a signed photo, all the way to a full written treatise on your experiences.

But then there are the best of times—the twelve year old who tentatively puts his hand up to ask a question, digests the answer and then, ah! insight! It is a good feeling.

DISTRIBUTION OF PHOTOGRAPHS FROM FLIGHT 41-G

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Dr. J. Apel	APL/JHU	20	20	20 PT*
Dr. L. Armi	SIO		9	
Mr. M. Bagg	ARE Portland	3	13	3 PT
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Dr. O. Brown	U of Miami	8	8	8 PT
Mr. D. Browning	NUSC	6	6	6 PT
Mr. J. Bruce	NAVOCEANO	14	14	14 PT
Dr. H. Bryden	WHOI	34		
CDR Callahan	SWO School Npt	8		
Mr. R. Cember	Lamont		3	
Mr. R. Cheney	NOAA	6	6	6 PT
Dr. D. Conlon	ONR	6	6	6 PT
CAPT Dalton	CTF 66		1	
Dr. G. Feldman	Goddard SFC	24	24	4 PT
Mr. R. Fett	NEPRF	22	46	22 PT
Mr. J. Gallagher	NUSC	6	6	6 PT
Dr. C. Gautier	SIO	6	6	6 PT
Dr. L. Goodman	NUSC	4	6	
Dr. R. Goodman	SACLANTCEN	12	12	12 PT
Dr. A. Gordon	Lamont	8	8	8 PT
Dr. D. Halpern	U of Wash	4	4	4 PT
Dr. M. Hendershott	SIO	1	1	1 PT
Dr. F. Herr	ONR		20	
Dr. R. Hoglund	ORI	18	18	18 PT
Dr. R. Houghton	Lamont		8	
LCDR S. Howard	NOCD Naples		1	
CDR J. Hughes	NUSC	11	14	
CDR J. Jensen	NAVWARCOL Npt	20		
CAPT J. Jensen	NOCC Rota	3		1 LG‡
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Dr. R. Kennedy	NUSC	10		
CDR F. Kline	NOCC Rota	41		
Dr. E. Levine	NUSC		7	
Dr. P. Lobel	WHOI	1	1	
Dr. J. Luyten	WHOI	8	8	8 PT
Dr. K. Melville	MIT	39	5	5 PT

* 70mm positive transparency
‡ Large print

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Dr. E. Mollo-Christensen	Goddard SFC	6	6	6 PT
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Dr. J. Price	WHOI	15	15	15 PT
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Dr. J. Spiesberger	WHOI	8	8	8 PT
Dr. R. Spindel	WHOI	2	2	
Dr. W. Von Winkle	NUSC	10		
Dr. C. Yentsch	Bigelow Lab	20	20	20 PT
	TOTALS	462	353	226

TECHNICAL PRESENTATIONS (TO THE END OF 1985)

Hon. M. Paisley, ASN (RE&S), 1 Nov 1984, Washington, DC
URI Marine Advisory Council, 6 Dec 1984, Narragansett, RI
Hon. John Lehman, SECNAV, 17 Dec 1984, Washington, DC
ADM James Watkins, CNO, 18 Dec 1984, Washington, DC
VADM A. Baciocco, OP-098, 8 Jan 1985, Washington, DC
AMS Annual Meeting, 9 Jan 1985, Los Angeles, CA
SIO, 10 Jan 1985, La Jolla, CA
RADM R. Rich, COMASWWINGPAC, 10 Jan 1985, San Diego, CA
AFCEA, 16 Jan 1985, Newport, RI
Dr. George Keyworth, President's Science Advisor, 31 Jan 1985, Washington, DC
SIO Workshop, 12-13 Feb 1985, La Jolla, CA
Scripps Aquarium, 13 Feb 1985, La Jolla, CA
NOSC, 14 Feb 1985, San Diego, CA
USNA, 19 Feb 1985, Annapolis, MD
NRL, 19 Feb 1985, Washington, DC
NAVSPACOM, 20 Feb 1985, Dahlgren, VA
PSAG, 22 Feb 1985, Washington, DC
AFCEA, 28 Feb 1985, New London, CT
Naval Space Symposium, 22 May 1985, Monterey, CA
National Research Council of Canada, 14 Jun 1985, Ottawa, Canada
Naval War College "Global 85," 23 July 1985, Newport, RI
National Association of State Universities, 10 Sept 1985, Washington, DC
VADM N. Thunman, OP-02, 10 Sept 1985, Washington, DC
WHOI Workshop, 16-17 Sept 1985, Woods Hole, MA
RADM R. Morris, Hydrographer RN, 3 Oct 1985, London, England
Oxford University, 4 Oct 1985, Oxford, England
ARE, 7 Oct 1985, Portland, England
IOS, 8 Oct 1985, Wormley, England
Man-in-Space Symposium, 15 Oct 1985, Langley, VA
Schmidt Lecture, USNA, 22 Oct 1985, Annapolis, MD
Los Alamos National Laboratory, 29 Oct 1985, Los Alamos, NM
U.S. Space Command, 30 Oct 1985, Colorado Springs, CO
Newcomen Lecture, USCGA, 1 Nov 1985, New London, CT
ASA Annual Meeting, 6 Nov 1985, Nashville, TN
LDGO, 22 Nov 1985, Palisades, NY

RECOMMENDATIONS

Behold the tortoise
Who only makes progress
When he sticks his neck out

Anon.

It has become increasingly obvious since the flight that any plans or recommendations for the future must take into account, and be governed by, a careful consideration of the pros and cons, the strengths and weaknesses of the two modes of conducting space oceanography: manned spacecraft and unmanned satellites. Unfortunately the two are often misinterpreted and misapplied. It is time to refocus them.

A careful delineation of the attributes of these two methods of obtaining remotely sensed ocean data from space show that they are mutually orthogonal and, if used wisely, complement each other in a synergistic way, with a payoff that far transcends the results to be obtained from either system operating on its own.

The following table highlights their characteristics:

MANNED SPACECRAFT	UNMANNED SATELLITE
SHORT DURATION	LONG DURATION
VARIABLE MISSION	FIXED MISSION
NEW, EXPERIMENTAL SENSORS	PROVED RELIABLE SENSORS
SHORT LEAD TIMES	LONG LEAD TIMES
FLEXIBLE ONBOARD REPROGRAMMING	LIMITED GROUNDBASED REPROGRAMMING
PANORAMA SENSING	CONSTRAINED GROUND SWATH
LIMITED SITE REVISIT	REPETITIVE SITE REVISIT
AZIMUTHAL SITE TRACKING	LIMITED SITE TRACKING
HUMAN INTERACTIVE	COMPUTER CONTROLLED
DATA SELECTION AND COMPRESSION	UNCRITICAL DATA LOGGING
QUICK REACTION TO UNEXPECTED	SLOW REACTION TO UNEXPECTED
ONBOARD INTERPRETIVE	SUBSEQUENT INTERPRETATION
SUBTLE DISCRIMINATIONS	SENSOR RESOLUTION
ONBOARD REPAIR AND ADJUSTMENT	LIMITED BACKUP SYSTEMS
DISCOVERY (R&D) MODE	*OPERATIONAL MODE*

Keeping these firmly in mind, there are a number of recommendations that naturally follow, based on the experiences gained to date.

1. *Continue the program.* Flight 41-G proved to be highly successful for the oceanographic community.

2. *Fly other qualified oceanographers.* We are still in the discovery mode and can look forward to further new revelations in ocean dynamics. The advent of polar missions for the space shuttle can only help to enhance these possibilities. Consideration should also be given to flying two oceanographers on the same flight.

3. *Focus and quantify the science.* To the current discovery role should be added, progressively, a survey role for ocean phenomena already known to exist, and a quantification and hypothesis testing role for specific oceanic processes. This will inherently mean a multi-platform, multi-spectral approach utilizing ships, aircraft, satellites and the space shuttle, with a wide diversity of sensors and instrumentation.

4. *Try new sensors and techniques.* The space shuttle, in its role as a laboratory in space, can be used as a test-bed for experimental sensors to evaluate their usefulness before committing them to satellites. Various techniques including stereo, polarization, low light level cameras, TV's, flight-deck controlled payload bay instrumentation, and onboard image processing could be tried, to name but a few.

5. *Prepare for space station.* Carefully considered, step by step building upon the foundations already established will, over the next decade, provide an expertise in space oceanography that will allow the full utilization and exploitation of the unique capabilities of the space station when it comes on-line.

ACRONYMS

AERO LINHOFF — Aerial Reconaissance Camera
ASC — Ascent
ASTP — Apollo-Soyuz Test Program
AXBT — Airborne Experimental Bathythermograph
B-57 — High Altitude Aircraft
CAP — Crew Activity Plan
CDR — Flight Commander
CEIT — Crew Equipment Interface Test
DMSP — Defense Meteorological Satellite Program
DSO — Detailed Secondary Objective
EAFB — Edwards Air Force Base
ERBS — Earth Radiation Budget Satellite
EVA — Extra Vehicular Activity
FB — Fixed Base (Simulator)
FCS — Flight Control System
FD — Flight Director
FDF — Flight Data File
1G — One-G Trainer
G-SUIT — Anti-Gravity Suit
H(100) — Hasselblad Camera (100mm Lens)
H(250) — Hasselblad Camera (250mm Lens)
IFM — In-Flight Maintenance
IMAX — Large Format Movie Camera
INT SIM — Integrated Simulation
I.W. — Internal Wave
JSC — Johnson Space Center
KC-135 — Militarized 707 Aircraft
KSC — Kennedy Space Center
LCC — Launch Control Center
LEH — Launch and Entry Helmet
LFC — Large Format Camera
MB — Motion Base (Simulator)
MCC — Mission Control Center
MET — Mission Elapsed Time
MOCR — Mission Operations Control Room
MS — Mission Specialist
O/H — Overhead
OMS-2 — Orbital Maneuvering System (Burn #2)
OMS PODS — Orbital Maneuvering System Pods
ONR — Office of Naval Research
OPF — Orbiter Processing Facility
OPS — Operations
ORS — Orbital Refueling System
PAD (39A, 39B) — Launch Pad 39A & 39B
PAX RIVER — Patuxent River
PI/DO PREP — Post Insertion/Deorbit Preparation
PLT — Flight Pilot
PS — Payload Specialist
SAR — Synthetic Aperture Radar
SASSE — Space Adaptation Syndrome Studies and Experiments
SCRIPPS — Scripps Institution of Oceanography
SIM — Simulation
SIR-A — Shuttle Imaging Radar (Flight 1)
SIR-B — Shuttle Imaging Radar (Flight 2)
SLF — Shuttle Landing Facility
SMS — Shuttle Mission Simulator
SPOC — Shuttle Programmable Onboard Computer
SRB — Solid Rocket Booster
STA — Shuttle Training Aircraft
STS-41G — Space Transportation System Mission 41G
T-38 — High Performance Jet Trainer
TCDT — Terminal Countdown Demonstration Test
TDRSS — Tracking and Data Relay Satellite System
T/L — Time Line
UAR — United Arab Republic
WCS — Waste Control System
ZERO-G — Zero Gravity
-ZLV — Minus Z Local Vertical

REFERENCES

"Catalog of Space Shuttle Earth Observations Hand-Held Photography, STS 41-G," JSC Publication JSC-20639, July 1985

"Flight Data File, Crew Activity Plan, STS 41-G," JSC Publication JSC-19965, September 3, 1984

"Navy Oceanographer Shuttle Observation Plan, STS 41-G," Navy Space Oceanography Committee, September 14, 1984

"STS 41-G Technical Crew Debriefing," JSC Publication JSC-20135, November 1984

J.R. Apel, J.R. Holbrook, A.K. Liu and J.J. Tsai, "The Sulu Sea Internal Soliton Experiment," *J. Phys. Oceanogr.*, 15, 1625-1651, 1985

C. Garrett and W. Munk, "Internal Waves in the Ocean," *Ann. Rev. Fluid Mech.*, 11, 339-369, 1979

P. LaViolette, "A Prospectus for NORDA Oceanographic Participation in the Seventeenth Flight of the Shuttle (STS 41-G)," NORDA Special Publication SP 42:84:320, August 1984

L. Rosenhead, "The Formation of Vortices from a Surface of Discontinuity," *Proc. Roy. Soc.*, A 134, 170-192, 1931

A. Roshko, "Structure of Turbulent Shear Flows: A New Look," *AIAA Journal*, 14, 1349-1357, 1976

D. Sheres, K.E. Kenyon, R.L. Bernstein and R.C. Beardsley, "Large Horizontal Surface Velocity Shears in the Ocean Obtained from Images of Refracting Swell and In-Situ Moored Current Data," *J. Geophys. Res.*, 90, 4943-4950, 1985

M. Sibulkin, "A Note on the Bathtub Vortex and the Earth's Rotation," *Am. Sci.*, 71, 352-353, 1983

S.D. Soules, "Sun Glitter Viewed from Space," *Deep-Sea Res.*, 17, 191-195, 1970

S.A. Thorpe, "Experiments on the Instability of Stratified Shear Flows: Miscible Fluids," *J. Fluid Mech.*, 46, 299-319, 1971

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Mel Paisley, who blessed it,
Jim Fanseen, who negotiated it,
Jim Beggs, who approved it,
Bill Von Winkle, who inspired it,
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Bob Crippen, who led it,
John Kaltenbach, who studied it,
John Hughes, who wrote it,
Jon Malay, who staffed it,
Ty Aldinger, who juggled it, and finally
Bob Stevenson, who fathered it all.

But above all others:

Fran, my wife

and,

Adam, Lincoln, Holly, Victoria, William and Tara,

our children.

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