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COPE

Coastal Ocean Probe Experiment
Northern Oregon Coast
14-16 September 1995

Test Operations Report
Summary of LLNL Activities

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ABSTRACT

Operations involving Lawrence Livermore National Laboratory (LLNL) assets associated with a field experiment named COPE (Coastal Ocean Probe Experiment) are described. The lead organization responsible for the planning and conduct of COPE is NOAA/ETL headquartered in Boulder, Colorado. This experiment was conducted off the coast of Northern Oregon during September-October 1995. The primary measurements involve radars and other imaging microwave sensors imaging surface effects associated with natural internal waves which are abundant off the Oregon coast in the late summer and early fall. In-water, surface, and above-water environmental sensors were fielded by ETL and their contractors on the FLIP platform moored 13 miles offshore and elsewhere to characterize the environmental conditions and help interpret various features in the imagery.

LLNL's Imaging and Detection Program has taken advantage of this unique site and suite of ground-truth measurements to collect radar image data over a three-day period (14-16 September 1995) with our Airborne Experimental Test Bed (AETB) and its X-band, HH-polarization synthetic aperture radar (SAR) as a piggyback to the primary COPE data collection.

This report documents test operations during this three-day data collection involving the AETB/SAR from a LLNL perspective. A total of 42 SAR images were collected at grazing angles of 8°, 20°, and 45°. From all indications during data collection, data quality appears good for about 75 percent of the passes. Strong internal waves were observed each day in calm to light wind conditions. ETL's hillside dual-polarization X-band and Ka-band real aperture radars recorded data simultaneous with the AETB SAR. The presence of other airborne platforms and low cloud cover limited the AETB aircraft's ability to operate at low altitude. Limited sea-truth data was collected onboard FLIP.

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LLNL participants in COPE were Dave Mantrom (LLNL experiment leader, based at COPE hillside radar site, near Cannon Beach, Oregon), and Mark Miller and Mel Wieting (radar systems onboard LLNL/Hughes AETB aircraft, based at Naval Air Station Whidbey Island, Washington). Rod Kiefer contributed to test planning.

Hughes Aircraft Co. participants under contract to LLNL were Ray Nagele and Gerard Robottom (radar systems), Dennis Stock (ground support and logistics coordination at NAS Whidbey Island), and Ron Woltman and Mike Glenn (aircraft pilot and flight engineer, respectively).

Bob Kropfli and Jay Palmer were our ETL contacts during test planning and data collection. John Gaynor was the sponsor's representative on-site during LLNL's data collection.

1. Introduction

COPE is the acronym for the Coastal Ocean Probe Experiment, conducted by NOAA/ETL off the northern Oregon coast in September-October 1995. In general terms, ETL collected data with various types of microwave sensors including radar on internal wave-induced modulations to the ocean surface, and collected substantial subsurface, surface, and above-water environmental data to characterize the imagery and help explain certain features visible in the imagery. This test site (general location highlighted on the map of Oregon in Figure 1) was chosen because strong surface effects associated with internal gravity waves have been regularly observed there and the presence of a coastal mountain range would allow a large land-based radar to be situated high enough to image these internal wave effects at a reasonable low grazing angle.

In COPE, ETL fielded a broad suite of microwave sensors, and a variety of sea-truth and atmospheric-truth instruments. These included land-based, high power, X- and Ka-band real aperture radars (RAR) located at 2410 ft elevation on the side of a coastal mountain, and various water column, surface wave, air-sea interface, and atmospheric sensors on the FLIP measurement platform moored approximately 13 miles offshore. The hillside radar site and FLIP mooring locations are shown on the chart in Figure 2. In addition, various active and passive microwave devices onboard a blimp, two ground-based CODARs that measure large-scale surface currents, various wind profilers, and others were fielded in COPE.

General aspects of COPE including test objectives, rationale, and instrument systems are described in ETL's test plan (Palmer, 1995).

Lawrence Livermore National Laboratory's Imaging and Detection Program took advantage of this unique site and opportunity to collect imagery with our radar that was supposed to be well ground-truthed with subsurface, surface, and above-water environmental data and be compared to radar image data collected simultaneously with ETL's hillside radars. Specifically, we conducted a short data collection with our Airborne Experimental Test Bed (AETB) jet aircraft-based X-band, HH-polarization synthetic aperture radar (SAR) as a piggyback to the planned COPE operation. This was the second significant ocean image data collection with the AETB; it had been successfully flown during Project Overview at AUTEC in July 1995 (Mantrom, 1995a).

LLNL's objective for the COPE experiment is as follows, quoted directly from LLNL's test plan document (Mantrom, 1995b):

Collect SAR image data with the AETB XHH SAR containing natural internal wave-induced features over a range of grazing angles and look directions re: internal wave, sea, and wind directions, and characterize the internal wave-induced modulations and ambient clutter statistics as a function of these radar parameters and environmental conditions (which will vary naturally over the data collection period).

Our data collection occurred on 14, 15, and 16 September 1995. We had a contingency plan to stay up to 19 September (up to three additional days) if there were problems with prohibitively bad weather or mechanical problems with the AETB/SAR. The operations that took place are described in the next section. We will formally request COPE data collected by ETL to characterize and support interpretation of our data after the completion of the experiment.

2. LLNL Operations in COPE

2.1 Planned Operations

We planned to fly three identical missions as illustrated in Figure 3 on three consecutive days. We desired to image different surface effects associated with internal waves under different subsurface, surface, and above-water conditions. The hope was that there would be significant natural variability over the three day period for this purpose. We planned for all flights to be conducted during daylight hours, with planned and actual on-station times as follows:

Flight	Date	Planned On-Station Time	Actual On-Station Time
1	14 September	1500 - 1800 (local)	1625 - 1930 (local)
2	15 September	1200 - 1500	1215 - 1545
3	16 September	0900 - 1200	1030 - 1315

The reason for flying at different times of day is that if there were any diurnal pattern to environmental conditions (e.g., tidal cycle; calmer winds in the morning, picking up in the afternoon), our data collection would cover that range of conditions.

In each flight, we planned on flying at three different altitudes to provide three different grazing angles. As shown in Figure 3, at each of the three altitudes we planned to fly up to eight (8) straight and level passes, each about 20 km in length. Six of the passes were to be centered on the FLIP instrumentation platform moored offshore. These six passes were to be in an asterisk pattern; the six passes courses 60 degrees apart. We flew headings of North, 60°, 120°, ... 300° in the order shown in the figure. The remaining two passes were parallel to the coast where long-crested internal waves whose wavefronts are roughly parallel to the coast had been observed visually prior to COPE. The three grazing angles we desired were 5°, 20°, and 45°; we ended up doing 8°, 20°, and 45° for reasons explained in the following subsection. The design altitudes for the planned grazing angles were 500 ft, 5600 ft, and 23,000 ft which were the same altitudes for these grazing angles flown in Project Overview at AUTECH. We flew the 8° grazing angle data collection at 3000 ft. We denote the images as Flight Number (1, 2, or 3), 8°, 20°, or 45° grazing angle, and Pass number (1 to 8).

2.2 Operations Actually Conducted

The aircraft left Van Nuys Airport on the morning of 14 September. It refueled at McClellan AFB, Sacramento, en route to the COPE site. After fixing a data acquisition system problem, the aircraft departed McClellan and arrived at the COPE site, whereupon it performed the first day's data collection. Upon completion of the data collection, the aircraft flew to Naval Air Station Whidbey Island, Washington which would be its base for the remainder of the experiment. After the third day's data collection, the aircraft returned to NAS Whidbey Island to refuel, and then returned to Van Nuys.

A summary of the passes made by the aircraft along with wind, swell, and tide conditions are presented in the tables below. Wind and swell conditions were reported from FLIP approximately 30 minutes before scheduled on-station times. Tides were obtained from local tide tables. A complete table of start/stop times and comments logged by the radar crew onboard the AETB for each pass is included in the appendix.

Table 1. Number of AETB passes in COPE.

Passes	14 September	15 September	16 September	Total
23000 ft (45°)				
Over FLIP	6	6		12
Coastline	2	1		3
Total 23000 ft	8	7		15
5600 ft (20°)				
Over FLIP	4	6	6	16
Coastline	1	2		3
Total 5600 ft	5	8	6	19
3000 ft (8°)				
Over FLIP			6	6
Coastline			2	2
Total 3000 ft			8	8
Total	13	15	14	42

Table 2. Daily environmental conditions and tides in COPE.

14 September	15 September	16 September
Flight 1 1630 - 1930 local	Flight 2 1215 - 1545 local	Flight 3 1030 - 1315 local
Wind: 3 kt from 310°	Wind: 4 kt from 170°	Wind: 5 kt from 200°
Swell: 2-4' from 300°	Swell: 2-4' from 315°	Swell: 3-5' from 300°
Tide: High at 1619; +7.6'	Tide: Low at 1107; +2.3'	Tide: High at 0642; +5.7'
Tide: Low at 2320; +0.4'	Tide: High at 1700; +7.3'	Tide: Low at 1201; +2.7'

It was discovered near the end of our data collections that the SAR data for passes 5 and 6 over FLIP, for all flights at all altitudes, may be irreversibly contaminated. A total of 10 passes were affected; however, internal waves were visible in the processed SAR imagery on these passes. We will look into this further in the near future.

An example image from COPE is shown in Figure 4.. This image corresponds to Serial 3, Pass 1, a 20° grazing angle image over FLIP collected with the aircraft at 5600 ft altitude on a nominal course of 060°. (Ground) range is the vertical coordinate (increasing range from top to bottom of the page), and the horizontal (azimuth) coordinate increases in the opposite direction of flight (which was right-to-left in this coordinate system). The radar looked to port, so "down" in the figure corresponds to a look direction of approximately 330°. FLIP is the bright feature in this image at range 4200 m and azimuth 4800 m. A subset of this image in the vicinity of FLIP is shown in Figure 5, plotted so the range and azimuth scales are equal. The ocean structures seen in this image are believed to be swells, reported from FLIP to be 3 - 5 ft from 300° (directly into look direction on this pass).

Another example is shown in Figures 6 and 7. These correspond to a "coastal" pass with the aircraft on a north course, Serial 3, Pass 13. The grazing angle is 8 degrees. Figure 6 is the entire image and Figure 7 is the subset from approximate azimuth 6.5 to 12 km. These images clearly show that the radar had sufficient power to image the ocean at low grazing angle, even under light (5 kt) wind conditions. The long linear features prominent in this image are perpendicular to the reported swell direction. Their separations (approximately 500 m) are rather long compared to typical ocean swells; these will be compared to sea height data measured from FLIP.

3. Summary

COPE operations involving the LLNL AETB aircraft SAR can be described as follows:

Things that went well:

- For the most part, the aircraft flew well and the radar systems worked well; we were on station all 3 days nearly on schedule (approximately 1 hour late twice due to system problems and weather delays).
- Internal waves were conspicuously visible all three days, both on the displays on the aircraft and at the hillside radars.
- 42 XHH SAR images were collected (32 believed to be good quality) at 23,000 ft altitude (45° grazing angle), 5600 ft (20°) and 3000 ft (8°).

Things that didn't go well:

- There was limited sea-truth data collected on board FLIP. All systems were not up on FLIP (most importantly, surface wave height). There was poor coordination with FLIP scientists regarding LLNL aircraft operations.
- SAR data was only collected to a grazing angle of 8° (the aircraft did not fly below 3000 ft). Backscatter was weak on Flight 1 due to very calm seas. A blimp was in the air at 1000 ft altitude on Flight 2 and while airborne, was not monitoring the assigned aircraft radio frequency and thus could not respond to communications attempted by our aircraft who needed to verify the blimp's position in order to fly IFR at a low altitude. There were thicker clouds on Flight 3 and the air traffic center would not let our aircraft fly below 1600 ft; our aircraft elected to fly above clouds at 3000 ft.
- There were relatively low winds all three days, not giving us much variation in wind speed in this data set.
- There were 10 passes over FLIP (60° and 240° course passes) that may have degraded SAR data.
- There was military restricted airspace west of FLIP that was active during Flight 2 which caused an interruption in our data collection.

4. References

Mantrom, D.D. (1995a) "Project Overview Radar Ocean Imaging Experiment, AUTECH, 11-17 July 1995, Test Operations Description, US Activities," LLNL Report CLY-95-0018, August. (SECRET)

Mantrom, D.D. (1995b) "LLNL Data Collection During NOAA/ETL COPE Experiment, Test Plan," LLNL Report UCRL-121682, September.

Palmer, J., ed. (1995) "Coastal Ocean Probe (COPE) Experimental Plan," Draft, NOAA/ETL Report, May.

APPENDIX

COPE Data Summary

Type	Track	Gr Angle	Alt. (m)	Sl Range (m)	Time (PDT)			Comments
					Start	Stop	Elapsed	
Run-1	1	45	7200	9298	16:35:35	16:37:18	0:01:43	Ant. drove off to other side of target @.15 min to complete. No FLIP
Run-2	2	45	7200	9298	16:45:29	16:47:06	0:01:37	RF=0 /ff= 14 (start ~14 changed to 0/14)
Run-3	3	45	7200	9298	17:00:16	17:02:14	0:01:58	No FLIP. Internal waves seen near end of run
Run-4	4	45	7200	9298	17:13:18	17:16:20	0:03:02	No FLIP/strong returns near end of run
Run-5	5	45	7200	9298	17:27:34	17:29:54	0:02:20	Saw FLIP, no az stabilization
Run-6	6	45	7200	9298	17:38:52	17:40:39	0:01:47	Saw FLIP, no Az stabilization
Run-7	7	45	7200	9298	17:53:12	17:55:07	0:01:55	Antenna glitch @ .5 EOT, Internal Waves south of Tgt.
Run-8	8	45	7200	9298	18:06:48	18:09:31	0:02:43	Internal waves south of target
Run-9	1	20	1700	4197	18:40:03	18:42:54	0:02:51	Smaller returns seen
Run-10	2	20	1700	4197	18:48:21	18:50:20	0:01:59	Antenna drifted other side, prior to FLIP, corrected just prior to FLIP
Run-11	3	20	1700	4197	19:00:02	19:03:21	0:03:19	
Run-12	4	20	1700	4197	19:10:44	19:13:14	0:02:30	
Run-13	7	20	1700	4197	19:20:01	19:23:33	0:03:32	Antenna drifted briefly @ 1.5 EOT

Record Type	Track	Gr Angle	Alt. (m)	Sl Range (m)	Time (PDT)			Comments
					Start	Stop	Elapsed	
Run-1	1	20	1700	4197	12:20:40	12:22:40	0:02:00	Antenna stabilization went wild 1/2 through run
Run-2	2	20	1700	4197	12:29:06	12:31:01	0:01:55	
Run-3	3	20	1700	4197	12:41:36	12:44:15	0:02:39	
Run-4	4	20	1700	4197	13:14:05	13:16:26	0:02:21	
Run-5	5	20	1700	4197	13:45:28	13:47:28	0:02:00	
Run-6	6	20	1700	4197	13:59:10	14:01:11	0:02:01	no Az stabilization
Run-7	7	20	1700	4197	14:10:13	14:13:23	0:03:10	0/0dB @ start 5/0 dB towards end of run
Run-8	8	20	1700	4197	14:21:40	14:24:55	0:03:15	
Run-9	1	45	7200	9298	14:42:40	14:44:23	0:01:43	
Run-10	2	45	7200	9298	14:50:59	14:52:39	0:01:40	
Run-11	3	45	7200	9298	15:03:01	15:05:14	0:02:13	Didn't see FLIP
Run-12	4	45	7200	9298	15:13:40	15:15:39	0:01:59	
Run-13	5	45	7200	9298	15:24:15	15:25:58	0:01:43	No stabilization on most of run, last 1/2 min ok
Run-14	6	45	7200	9298	15:33:30	15:35:11	0:01:41	Stabilization OK. Sercom mgr. blew at end of run
Run-15	7	45	7200	9298	15:42:55	15:45:16	0:02:21	

Record Type	Track	Gr Angle	Alt. (m)	Sl Range (m)	Time (PDT)			Comments
					Start	Stop	Elapsed	
Run-1	1	20	1700	3434	10:46:26	10:48:31	0:02:05	
Run-2	2	20	1700	3434	10:55:44	10:57:48	0:02:04	
Run-3	3	20	1700	3434	11:09:06	11:11:34	0:02:28	0/12dB changed to 0/20dB @ 2.1 EOT
Run-4	4	20	1700	3434	11:19:27	11:21:55	0:02:28	
Run-5	5	20	1700	3434	11:30:31	11:32:22	0:01:51	No Az Stabilization ~290knots
Run-6	6	20	1700	3434	11:38:58	11:40:49	0:01:51	
Run-7	1	8	900	4930	11:58:28	12:00:35	0:02:07	Multiple scatter as seen near FLIP
Run-8	2	8	900	4930	12:08:22	12:10:34	0:02:12	No Stabilization
Run-9	3	8	900	4930	12:19:53	12:22:38	0:02:45	0/6 then 0/9dB changed Atten. at beginning Didn't see FLIP
Run-10	4	8	900	4930	12:30:37	12:33:21	0:02:44	Didn't see FLIP
Run-11	5	8	900	4930	12:41:29	12:43:29	0:02:00	
Run-12	6	8	900	4930	12:50:33	12:52:39	0:02:06	0/6 ?
Run-13	7	8	900	4930	12:59:17	13:02:12	0:02:55	
Run-14	8	8	900	4930	13:09:28	13:12:22	0:02:54	0/6dB then changed to 0/3dB at beginning then 0/0dB later on

9/14/95

Figure 1. COPE site on Northern Oregon Coast.

Figure 2. Chart showing locations of FLIP and NOAA/ETL hillside radar.

Coastal Ocean Probing Experiment (COPE) Proposed AETB Flight Profiles

SAR Imaging Swath
1-6—From different directions over FLIP
A & B: Coastline imaging

Grazing Angle	A/C Alt.	Coastline Imaging A & B	Flip 1-6
5°	500'	2 passes	6 passes
20°	5600'	2	6
45°	23,000'	2	6
Note: Each pass is approximately 10 miles (16 km) and 3 min. of data collection			

Figure 3. AETB SAR used in COPE.

Figure 4. XHH SAR image taken by LLNL/Hughes AETB at COPE site with FLIP in scene; Serial 3, Pass 4.

Figure 5. Close-up of region around FLIP of SAR image presented in Figure 4.

Figure 6. COPE SAR image, data collected parallel to coastline; Serial 3, Pass 13.

Figure 7. Close-up of subset of Figure 6.