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PROJECT LEWEX: AN INTERNATIONAL READING OF OCEAN WAVES

In March 1987, experimenters from eight participating nations met for the first time to begin work on the Labrador Sea Extreme Waves Experiment (LEWEX). Their goal was to determine whether satellite radar estimates of waves could improve the accuracy of existing predictions. Since I could not cover the story directly from both ship and shore, I recount my experience with the LEWEX experiment from the shoreside perspective.

INTRODUCTION

The year 1987 saw an unusually bitter late winter in St. John's, Newfoundland, as researchers assembled in early March to conduct LEWEX, the Labrador Sea Extreme Waves Experiment. Sometimes the capricious weather produced blinding sun on snowbanks that had accumulated several feet high, and at other times a gray sky dumped more snow, as cold wind sliced a tunnel down the long main street. The two research ships and two instrumented aircraft for the project arrived from Canada, the United States, and the Netherlands through heavy seas and high winds. The researchers themselves arrived from those countries and from Norway, England, France, West Germany, and Spain.

We could cope with harsh weather on land, but what of life at sea, and in the air, where the work would be taking place? The Canadian research vessel *Quest* arrived in St. John's (Fig. 1) from Halifax, Nova Scotia, with its deck crusted in ice and the crew weary from a battering passage. (Figure 1 and all subsequent photographs in this article were provided by the author.) Two days earlier a huge wave among 30-foot seas had rolled the ship some 40 degrees—a phenomenal tilt for a ship—tumbling unsecured objects into heaps. At least it was obvious that this was the place and time of year to measure large ocean waves.

On hand to greet the ship were two of the three principals of the LEWEX experiment: the science coordinator, Robert C. Beal of The Johns Hopkins University Applied Physics Laboratory, and the ship sensor coordinator, Susan L. Bales of the David Taylor Naval Ship

Figure 1. The sheltered harbor of St. John's, Newfoundland, is entered only through the Narrows, beyond which can often be seen floating ice or the whitecaps of heavy seas.

Research and Development Center. The third principal, Nelson G. Freeman of the Canada Centre for Remote Sensing (CCRS), would join the group later in Gander.

The LEWEX was named for the site of operations in the storm-prone waters off Labrador, the northern extension of Canada's Newfoundland Province. The planning stage had taken more than a year. A final commitment had come out of discussions at an international symposium, "Measuring Ocean Waves from Space," held in April 1986 at JHU/APL. (Three years later, the LEWEX experimenters assembled at APL to present and share the results of the project; in early 1990 an entire issue of the *Technical Digest* will be dedicated to the scientific results of LEWEX.)

The 1986 symposium provided the occasion for many people involved in advanced radar techniques and ocean wave research to meet and exchange ideas. Their discussions led to the decision to organize an international effort to better understand and predict wind-generated ocean waves associated with severe storms. The LEWEX scientists at the meeting each agreed to seek funding in their own countries and to assemble their various ships and aircraft. The data from their individual experiments would further their own research and would also help to answer a larger set of questions concerning the prediction of ocean waves.

Beal, Bales, and Freeman had worked together to organize the resources, which included the 295-ft (90-m) Dutch research ship *Tydeman*, the 230-ft (70-m) Canadian research ship *Quest*, and two research aircraft, a Canadian CV-580 and a U.S. P-3 provided by NASA. They planned the experiment to operate in conjunction with APL's GEOSAT spacecraft, which would pass almost over the site every third day in the late morning. The data from wave sensors on all the units, simultaneously measuring the same sea conditions, could at those times also be compared with estimates of wave height from the spacecraft. Further, the winds estimated from GEOSAT would provide a check on the more conventional wind forecasts that drive the wave prediction models.

BACKGROUND

The LEWEX had two major scientific objectives: to assess the performance of wave predictions from recently developed wind-wave models and to compare that performance with results from earlier, more primitive versions. To do this, accurate measurements of the wave spectra from buoys were vital. The experiment also had a major technical objective: to assess the relative merits of several remote techniques for monitoring the wave spectrum. For this, the radar instruments aboard the two aircraft were essential. The fundamental question underlying these objectives was whether satellite radar estimates of waves could substantially improve the accuracy of existing forecasts.

The experiment compared information from three levels and sources: (1) data taken at or near sea level through the readings of several state-of-the-art directional buoys and ship-mounted radars; (2) data from aircraft equipped with several radar wave-measuring instruments; and (3) data from the GEOSAT spacecraft, orbiting 800 km above the Earth, which used a radar altimeter to measure wave height. With all three directed simultaneously at the same sea states, each set served to verify the estimates of the others.

Robert Beal observes that although the severity of an ocean storm is usually considered in terms of its maximum winds or wave heights, this is a gross simplification of the actual state of the sea surface. The effect of storm waves on ships, beaches, and off-shore towers can better be predicted when the sea is characterized by its period and direction, and also by whether it consists of both wind-sea and swell. In fact, storm waves typically contain a whole spectrum of wave periods or frequencies traveling simultaneously in several directions. Only by being able to predict this whole spectrum for several days into the future over an entire ocean can mariners choose an optimum route. For cargo ships, the optimum route will be the shortest one that does not damage its cargo. For military ships, weapons accuracy can be strongly influenced by excessive ship motions. If the mariner has an accurate idea of the wave spectrum likely to be encountered, he can always choose an optimum heading and speed. The problem is that there are no sufficiently accurate spectral ocean-wave forecasts available today.

Beal adds that the solution will require the application of radar-instrumented satellites to measure wave spectra over global scales. But how many satellites, in what orbit, and with what instruments? How accurate must the satellite measurements be? Can they be combined with operational wave forecast models and with other satellite measurements of wind, which will become available in the 1990s? For that matter, how good are existing wave forecast models? Do they need to be improved before they can take advantage of satellite measurements?

LAYING THE GROUNDWORK

The success of an experiment with complicated logistics depends on the quality of the nuts-and-bolts preparation. Since the experiment measured sea-state conditions from several points simultaneously, the project required coordination of personnel on land, at sea, and in the air, so that the instruments from the ships, planes, and spacecraft would all gather data on the same events.

Monday, 9 March. The experimenters from the participating nations gathered for the first time at St. John's, Newfoundland (Fig. 2). The site was the Marine Dynamics Laboratory of Memorial University, a new facility that includes one of the largest towing tanks in the world.

Bob Beal passed out the LEWEX science plan and discussed it in outline. Susan Bales reported that rough seas like those experienced by the *Quest*, now in port, had not caused any damage to the *Tydeman*, which had left Europe the week before. The Dutch ship had been slowed by packed ice off the Newfoundland coast, but would be arriving within another day. Several experimenters expressed concern for the safety of their instrumented buoys stored in the hold of the *Tydeman*.

Figure 2. Susan Bales, left, ship sensor coordinator for project LEWEX, confers with members of the experiment teams during an organizational meeting in St. John's. Standing, left to right: Peter Gerritzen (Holland), Robert Bachman (United States), and Peter Vermeij (Holland). Seated, left to right: Ove Sandvin, Peter Kjeldsen, and Birger Eilertsen (all of Norway).

The participants, many of them colleagues who had been in touch with each other for years, renewed or established acquaintances and settled in. Some had tales to tell since they had last met. Said Peter Kjeldsen of Martinek in Trondheim, Norway, whose large moored buoy (Fig. 3) would provide key wave data: "We spent more time on funding and other paperwork than in preparing our experiment." He added wryly "We have to negotiate with administrators who [do] not know about ships."

Donald Murphy of the International Ice Patrol gave a report on ice conditions off the Newfoundland/Labrador coasts where the research ships would deploy. The ice, as expected in early spring, formed a 40-kilometer barrier along the coast (see Fig. 4). The Canadians had recently been monitoring the ice more closely than ever before to protect oil drilling rigs. Murphy said that he expected winds to be northeasterly throughout much of the week, with water temperatures between 4°C and 6°C. The northerly winds would create choppy to rough open water in the deployment area of the *Tydeman* in the southern Labrador Sea at 50° N, 45° W. The same conditions might result in icing on the deck of the *Quest*, which would be positioned at 50° N, 47.5° W, closer to the coastal ice pack.

Beal outlined a projected schedule for the duration of the experiment. The two research aircraft would be stationed in Gander, at the international airport 130 air miles northwest of St. John's. As part of the operations plan, daily communications between the operations center in Gander and the ships at sea would begin each morning at 4:00 to get an early report of local sea conditions on which to base plans for the rest of the day.

Four in the morning? There were less-than-enthusiastic expressions from those who would have to make the shipboard reports, but everyone agreed reluctantly that the predawn exchange would be necessary to meet the daily timetable.

The shore-based team, including pilots and experimenters, would then gather at 5 AM for a briefing by

Figure 3. Large Norwegian moored buoy being prepared for loading aboard the *Tydeman* on the quay in St. John's Harbor.

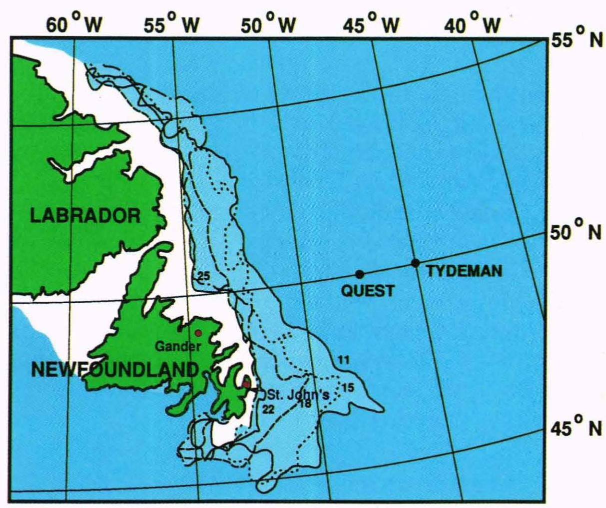

Figure 4. A map of the Newfoundland/Labrador coasts showing the LEWEX ship locations and the ice edge (light blue area) on the dates in March 1987 indicated by the numbers.

the meteorologists at the Gander airport. The decision to fly would rest with the pilots. (Early March in the North Atlantic can be rough for planes and ships alike, but the potential of high seas was the very reason for the timing of the experiment.) The *Quest* could safely deploy and recover its buoys only until seas reached 12 feet; the *Tydeman* could deploy in 25-foot seas and recover in 15-foot seas. This placed an automatic limit on the weather under which the experiment could operate.

If seas were reported manageable and atmospheric conditions permitted safe flying, the shore team would notify the ships by 6 AM. This would give the ships time to deploy their buoys, some of which needed to be moored and others set adrift (Figs. 5 and 6). The planes would take off at 7 AM for an hour and a half flight to the ships. The team agreed that the buoys should be operational in the water by the time the planes took off, so that they could begin a three-hour instrument record of sea conditions. When the planes reached the ships at 8:30 AM, they would make a 45-minute overflight between the *Quest* and *Tydeman* and then a reverse overflight, landing in Gander about four and a half hours after taking off.

A daily late afternoon conference in Gander would be held to review the data of the morning's flight. Beal would then talk to the two ships at 8 PM to discuss time and plan for the next day. There would also be a ship-to-shore protocol at a set time each day, to be used only for such emergency messages as a dramatic change in the sea state or the loss of a buoy.

Tuesday, 10 March. The *Tydeman* passed between the icy mountains of St. John's Harbor at 6 PM. After mooring, there followed a friendly visit in the wardroom. (Unlike American ships, the Dutch research vessel had a bar with good Dutch beverages.) The next morning Beal, Bales, and other members of the project met on board the *Tydeman* with its officers to discuss the mission, logistics, and communications of the coming experiment.

The ships needed to maintain a constant course during the time of the air overflights. What of fishing vessels, which might unknowingly set their gear in conflict with the buoys? How much of the ship's time on its radar and unique data handling system—both integral to the project—could be devoted to the experiments?

The *Tydeman* radiomen discussed the placement of the buoys' antennas and receivers so that the ships' radios would not interfere with their transmissions. They presented a diagram of the ship to show the placement of their own antennas. Peter Vermeij, the Dutch advance liaison for the *Tydeman*, spread out a plan of cabins available on the ship and invited experimenters to sign up for their berthing spaces.

Beal and Bales outlined the schedule that the experimenters had discussed. Beal suggested allowing more time each morning to deploy the buoys. Bales contended that quick deployment presented no problem: The tedious part would be picking them up afterward. This led to the realization that some buoys might still be in the water after dark and that more information about each buoy was needed. Which had drift lights and strobes? Which were coated with anti-icing paint? There were also specific concerns such as that special care would be needed in throwing the French experimental buoy over the side so as not to damage its antenna.

Bales drafted a schedule for retrieving the buoys after the aircraft passes. Given the projected flight plan, retrieval could not begin until 1:30 PM. She suggested taking them back aboard in reverse order to their deployment, since the wave-riding buoys would drift faster than the small buoys dropped earlier.

Wednesday, 11 March. Beal and the shoreside team flew to the Gander airport, where the two instrumented planes were waiting. The team began preliminary work in a nearby operations office. Kenneth Asmus of the Canadian Atmospheric Environmental Service, who ran the operations center, supervised installation of the equipment. Also working from the center, collecting U.S. Navy wave forecast information to apply to flight decisions, were Thomas Gerling and Francis Monaldo of APL.

At a late afternoon briefing, the team discussed flight plans with the pilots of the two planes. Captain Al McDonald of the NASA P-3 told the group that air traffic control required air space clearance 48 hours in advance for their flights over the *Quest* and *Tydeman*. That meant it would be necessary to keep requesting clearance daily for the duration of the tests, regardless of daily flight conditions. McDonald explained that the requested air space should be kept as small as possible. He sketched a tight ellipse around the *Quest* and *Tydeman* that encompassed the approximately 100 miles between the ships and added only turnaround room beyond the

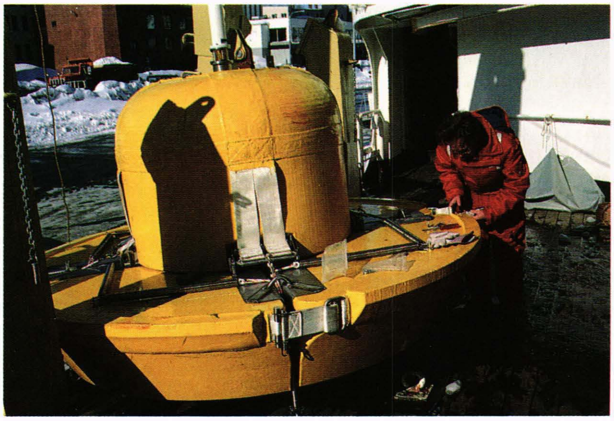

Figure 5. Peter Gerritzen of the Netherlands tapes protective material around the sensors of the moored buoy in his charge, preparing it for sea. The buoy was carried on the *Tydeman*.

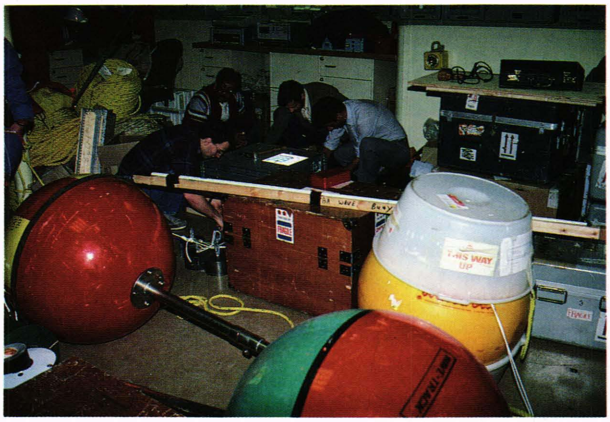

Figure 6. The LEWEX drift buoys in the cargo hold of the *Quest*. Experimenters check final details, surrounded by the ropes and other paraphernalia of such a seagoing project.

Tydeman. The NASA scientists from the Goddard Space Flight Center, Edward Walsh and Frederick Jackson, chose to fly from Gander to the test site at 22,000 feet to accommodate Jackson's instrument, and then descend to 5500 feet for the lower altitude needed to accommodate Walsh's instrument on the return leg.

A problem about the planes themselves had arisen at the airport. There would be an unanticipated charge for hangar space. Who would pay for it? Beal, Walsh, and Jackson weighed the cost of a hangar against the cost of de-icing. They each agreed to chip in something from their budgets for hangar space, given the weather. In the end, however, the space never materialized and the two aircraft remained on the tarmac.

Thursday–Friday, 12–13 March. The research ships put to sea from St. John's. The ocean outside the Narrows started pitching the well-battened ships at once. But after a few hours, they were sheltered by light coastal ice, which kept the sea relatively calm on their initial journey down the coast and around the ice pack. On the following two days, however, as the ships approached their designated positions, the roughest weather of the entire experiment passed through the region. Thirty-five-knot northeasterly winds accompanied by 15-foot waves threatened severe delays to the morning operations, especially on the smaller *Quest*.

Susan Bales, coordinator of sea operations, rode aboard the *Tydeman* along with Peter Kjeldsen (Norway), Georges David (France), Robert Bachman (United States), and Peter Gerritzen (the Netherlands), who were in charge of the directional sensors. Aboard the *Quest*, the scientific coordinator was Warren Nethercote of the Canadian Defence Research Establishment Atlantic in Dartmouth, Nova Scotia. Nethercote (later assisted by André Bolduc of the Canadian Marine Environmental Data Service) and Edward Foley from the David Taylor Naval Ship Research and Development Center each utilized separate types of wave buoys. Shipboard navigation radars were used to monitor sea-wave properties on board both the *Tydeman* and the *Quest*.

While waiting for the ships to reach position, the shoreside team in Gander spent the next day installing and checking out cameras and other equipment on both planes. The Canadian CV-580 also made an initial abbreviated flight to test and calibrate its synthetic aperture radar (SAR).

GATHERING DATA

Saturday, 14 March. Despite rough weather at sea, the two ships reported themselves in position and ready to begin operations. The day for the shoreside team began with a 4 AM wake-up and a trip to the airport meteorological office. A sharp wind blew streamers of snow from high snowbanks along the road. It seemed potentially a good day to find measurable waves at sea. The airport itself was deserted except for a lone person behind a ticket counter, but activities appeared ready to start. Various announcements noted cancellation of a commercial flight to St. John's (the St. John's morning fogs are legendary) but departure in an hour of the scheduled flight to Halifax. Soon a few passengers appeared, stomping snow from their boots and shaking water from parkas.

Upstairs in the brightly lit weather station, a dozen people from the LEWEX project nursed coffee and tried to look alert (Fig. 7). The officer in charge explained from his reports that the day's flight ceiling would rise no higher than 600 feet. At sea he predicted sleet and waves of 10 to 15 feet. Given prevailing local conditions, the pilots of the NASA P-3 and the Canadian CV-580 deemed this acceptable flying weather. Beal hurried to the operations center on the other side of the airport to notify the ships. The first day of the actual tests was beginning.

After a quick breakfast at the airport cafeteria, the crew and experimenters walked to the planes through deep slush (Fig. 8). Inside the big NASA P-3 the air was cold. The roomy interior had space for seats and also for banks of instrument consoles, with ample walk space remaining. As the plane warmed up, the experimenters started their equipment. Ed Walsh of NASA reported that he was satisfied with the signals received from the surface contour radar (SCR), but Fred Jackson announced

Figure 7. Early morning meteorological briefing at the Gander airport for pilots and LEWEX experimenters.

Figure 8. Gander. The LEWEX team picks a slushy course to the NASA P-3 plane.

a possible malfunction in his radar ocean-wave spectrometer (ROWS).

Given the spectrometer problem, it appeared necessary to request a two-hour flight delay from the scheduled 7 AM takeoff but, as the equipment warmed, Jackson associated the malfunction with temperature. A portable heater placed close to the high double console of his ROWS soon had the spectrometer signals functioning well enough for Jackson to give a go signal.

The plane finally took off at 7:50 AM. We climbed quickly through the clouds to fly over them and headed toward the *Quest* and *Tydeman*. It never really warmed inside the plane. The clouds opened and the wide sea stretched below us, etched with whitecaps that indicated rough water. Listening to the crew's routine passenger briefing on emergency procedures, the thought of a mere life jacket against this water seemed unattractive indeed.

By 8:30 on the NASA P-3 Beal had made contact with the two ships. They were located 96 nautical miles (178 kilometers) apart, which was the distance at this latitude of the planned 2.5° of longitude. At 9:10, with nothing visible below but gray rolling clouds, the plane's navigation equipment indicated a position directly over the *Tydeman*. Susan Bales, aboard the *Tydeman*, said the crew had been up all night preparing to deploy the buoys—this was the first time they were put over the side, which meant that they had to be unbattened after the sea voyage. She reported all buoys now in the water. Seas were about 4 meters high.

At 9:30 the NASA P-3 plane dropped to 5500 feet (still far above the clouds), and Ed Walsh began his SCR transmissions (Fig. 9). The vertical rectangular scope began to flicker with a series of waving lines. The lines were broken into small squares, light for the crests and dark for the troughs. The images were clear and precise enough that Walsh announced happily: "When the instruments work, there's nothing better." With the pass completed, the plane turned 90° and made a second pass at a right angle to the first. The trough/crest pattern on the SCR changed direction also but remained precise.

Figure 9. The LEWEX science coordinator Bob Beal of APL shares the pleasure of good surface contour radar signals with SCR experimenter Ed Walsh of NASA. The vertical scope shows a clearly readable pattern of sea state during a NASA P-3 flight over the research ships.

Fred Jackson monitored the signals from his ROWS with a headphone while data tapes rolled and the rotating antenna azimuth indicator blinked (Fig. 10). Clear signal, he acknowledged. He noted to Beal that his estimate of wave height differed substantially from that predicted earlier in the day back at the operations center.

By 10:45 AM the passes had been completed. The plane regained altitude and headed back to Gander. At the 5 PM briefing, the scientists from both planes were able to examine SAR wave imagery and to quote from ROWS and SCR data. Beal speculated that the day, begun as a possible abort, may have been more significant than any single flight during the NASA and APL scientists' 1984 Shuttle wave experiment off the coast of southern Chile. The aircraft had been able to rendezvous with the ships almost exactly as a storm center passed through the site. Both wind-sea and swell had been present simultaneously. The grueling work of the ships' crews all through the previous night had paid off handsomely.

A discussion ensued over whether to fly the next day. Seas were calming, so there might be nothing gained by additional measurements, given the day's success and the cost of each flight.

At 8 PM, Beal drove through steadily falling snow to the operations center at the airport to talk over the next day's plans by radio with Bales aboard the *Tydeman*. Reception was terrible. Ken Asmus, the operations center coordinator, repeated over and over again on the marine radio, "*Tydeman, Tydeman, Tydeman*, this is Gander, Gander, Gander. How do you read me? Over?"

Finally, Susan Bales' faint but clear voice from the Dutch ship said: "Gander, Gander, Gander, this is *Tyde-*

Figure 10. Fred Jackson operating the radar ocean-wave spectrometer experiment aboard the NASA P-3 plane.

man, Tydeman, Tydeman. We can hardly hear you." Reception remained so poor aboard the ship, in fact, that it took several minutes to persuade Bales to give her report when she could hear nothing back. Her voice, distorted by static, summarized, "Successful day . . . when you were over-flying, all buoys were in the water. Significant wave height was 3 to 4 meters. Everybody busy now. Just now recovering three drifting buoys. They drifted 13 miles. Virtually calm water. Will you fly tomorrow?"

Beal shouted into the microphone, "Negative, negative, negative."

Bales on the *Tydeman* said, "Can't hear you. Repeat."

After several repeats by Beal she asked, "Is that a negative?" Finally the message was understood.

Shore to ship communications were so difficult, in fact, that the plan made in St. John's to have detailed discussions at specified times was abandoned. All parties were forced to rely more for guidance on the daily chronology outlined in the science plan.

Sunday, 15 March. After a day of little activity beyond examining data, Beal reported at the 5 PM meeting that a long-term prognosis indicated a strong wave event likely to approach the LEWEX area from the south during the next three days. The following morning the seas remained so calm that it seemed nonproductive to fly. But the meteorologists expected a strong southerly swell with building easterly wind to begin around noon. The team decided to delay the flights by six hours.

In the operations office (where snow was piled high against the windows and wet boots were left in puddles of meltwater outside the door), team members examined the high-resolution imagery collected the day before from the SAR aboard the CV-580. Charles Livingstone of the Canadian Centre for Remote Sensing (CCRS), the coordinator of the SAR instrument, explained the content and location of the imagery to the other scientists (Fig. 11).

Meanwhile, a third research ship, the Canadian *Baffin*, instrumented to conduct an associated project called LIMEX (Labrador Ice Margin Experiment), reported itself stuck in ice. The *Baffin* was now stranded off Cape Race, 30 miles from its projected station in the Labrador ice pack, and too close to shore to obtain effective readings. Ashore, the LIMEX coordinator, Lynn McNutt of the CCRS, began to formulate an alternative plan for scheduling SAR flights for the CV-580.

The 8 PM attempt to reach the *Tydeman* produced little but heavy static on both ends. It took endless repeats to convey that there would be a flight the next day, but six hours later than the prearranged schedule.

Monday, 16 March. By 10:30 AM, at least the weather on land made it appear that there might be some waves at sea worth tracing. The CV-580 had been forced to cancel for the day because, with weather uncertain, it could not carry enough fuel for the closest alternative landing in Goose Bay, Labrador, if weather in Gander closed in. But the pilots of the larger NASA P-3 declared that they could still fly. That plane required a long de-

Figure 11. At the LEWEX operations center in Gander, Charles Livingstone of the Canadian Centre for Remote Sensing (CCRS) examines high-resolution imagery collected from synthetic aperture radar during a LEWEX flight. Left to right: Livingstone; Labrador Ice Experiment coordinator Lynn McNutt of the CCRS; and LEWEX science coordinator Bob Beal and Tom Gerling, both of APL.

icing procedure; men in oilskins, riding a cherry-picker crane, hosed a milky fluid over wings and body. It would have been a good day to have had the protection of a hangar. By the time the crew reached the tail of the plane, it was necessary to de-ice one of the wings again. The P-3 finally became airborne at 12:30 PM, more than an hour behind schedule.

En route, flying smoothly at 22,000 feet after a bumpy takeoff through bad weather on the ground, Beal made clear radio contact with Nethercote on the *Quest* and Bales on the *Tydeman*. It appeared that the wave forecast model had predicted higher seas than those being observed directly from the ships' decks. It indicated, as had Jackson's spectrometer readings two days before, that the conventional forecasts of wave conditions in the area were not always accurate, and that it indeed could be worth the effort to develop satellite-assisted forecasts.

At 2:30 PM, Jackson completed his spectrometer readings satisfactorily. For the unofficial record, he observed that he had filled with data about three miles of digital nine-track tape, one of the longest continuous wave records he had ever obtained. An unexpected delay occurred when the pilot requested routine clearance to descend to 5500 feet for surface countour radar (SCR) readings. Unfortunately, air control in Gander reported that the pilot of the Canadian plane, when he determined they were unable to fly, had canceled his request for air space that day, and the cancellation had been applied mistakenly to the U.S. plane also. Gander checked the air space and returned with permission.

The plane descended through thick clouds, all the way to 3500 feet. It was the first view of the ocean that day—an ocean with a heavily slanted horizon as the plane banked to assume its overflight course. A pale sun shone through the clouds. We could see the *Tydeman* as a small white object below—the first sight of her since we checked her gear in St. John's. From the deck below, Bales radioed that we were passing almost directly over the large Norwegian moored buoy. It confirmed the accuracy of the aircraft's precision navigation. Again, Walsh's SCR images of the ocean waves appeared on the screen with exceptional clarity.

The weather allowed a landing back in Gander at 4:42 PM through a dull white haze. The rain during the day had turned a foot of snow on the ground into deep slush. After dinner Beal led an 8:30 PM briefing. He reported, after having talked to Bales aboard the *Tydeman*, that the Dutch buoy used during the day's experiments had drifted off and was lost. In Gander, Richard Olsen, a visiting scientist at CCRS from Norway, obtained a satellite fix on the lost buoy by accessing the satellite's ground computer in Toulouse, France. The Dutch buoy had moved 13 miles to the west of the *Tydeman* in the direction of the *Quest*, but no one could rouse the *Tydeman* again that evening to tell them. Meanwhile, the *Baffin* was still reported stuck in ice, and a crewman aboard had injured his hand, further complicating the ship's predicament.

Most of the land-based team went to bed anticipating an early beginning the next day. In the motel room next to mine, though, a team of Russian pilots, on an overnight stop en route to Havana, decided to have a party.

Tuesday, 17 March. At the 5:30 AM weather briefing, the meteorologists reported that conditions would close down in Gander later in the day, with possible zero visibility by the afternoon; visibility was expected to be fair around the ships, however. Measurable swells were predicted, so the pilots of both planes decided to fly. I joined the Canadian scientists on their CV-580.

Out on the strip, the planes' wheel blocks were frozen to the tarmac and had to be banged loose. Team members pitched in, standing in three inches of slush, to help remove protective covers on the wings of the CV-580. It took off at 7:48 to fly at 12,000 feet, and the NASA P-3 followed at 22,000 feet. A half hour into the flight the clouds had cleared, and we saw the ocean below. Small whitecaps indicated a sea state of at least moderate proportions.

The CV-580 was far more cramped than the P-3 (Fig. 12). For one person to move about, another had to stay in his seat. Chuck Livingstone and Lawrence Gray of the CCRS operated the synthetic aperture radar (SAR), one of the most vital LEWEX sensors. Later the SAR would be used in the LIMEX project in conjunction with the *Baffin*, and would have been used already had the ship been free of the ice pack. Nelson Freeman and Lynn McNutt, both of the CCRS, were now beginning to plan the transition phase between LEWEX and LIMEX.

We expected to be passing over the *Quest* by 9:15, but the ship had slipped off station to the south. After a brief search, we found her beneath a light cloud cover.

Readings of the ocean indicated 2- to 3-meter swells. During the pass, the reading of swells rose to about 4 meters. When we passed over the *Tydeman*, we learned that they had found the missing buoy at around 9:30 the night before. Obviously, the practical aspects of the experiment were keeping the crew below busy beyond office hours. After making a second pass over the *Quest*, with flight time expiring, we returned to Gander for a safe landing in visibility that had lowered to 800 feet.

Figure 12. In cramped quarters aboard the Canadian CV-580, experimenters communicate with the *Quest* and *Tydeman* on the ocean below and take SAR readings. Left and right, Bruce Moir and SAR coordinator Charles Livingstone of the CCRS; center, Richard Olsen of Trondheim, Norway.

That evening the entire LEWEX/LIMEX shore-based team, consisting of some 30 people, enjoyed dinner together. This was their final opportunity, since much of the U.S. contingent would be leaving the following morning. A tight international camaraderie had developed during the last few days.

Later at the operations center we could not reach the *Tydeman*, but from discussions earlier that day we could assume they expected us the next morning. Lynn McNutt was able to contact the *Baffin* to learn that the ship had finally broken free of the ice, but before proceeding to station, it needed to deliver ashore the injured crewman for medical treatment. The LIMEX could then begin the following day.

ON TO THE NEXT PHASE

Wednesday, 18 March. Up at 4 AM. Massive stacks of luggage in the motel lobby attested to the approaching departure of the entire U.S. contingent of LEWEX. By 7:30 we were off aboard the NASA P-3. We took a final high-altitude data flight over the *Quest* and *Tydeman* with only the radar ocean-wave spectrometer activated. Then our plane veered southwest for the return to the States as the CV-580 completed the second half of its fourth flight and next-to-last LEWEX flight.

At sea, the *Tydeman* gathered its sensors back aboard—a full day's work, since this included moored buoys as well as those that were drifting. Early the next day, the *Tydeman* rendezvoused with the *Quest*, and both ships conducted readings using all of their sensors in conjunction with the Canadian airborne SAR for a final calibration in identical sea conditions.

On 20 March, the *Baffin* reached station and began the LIMEX project, observing the action of waves and currents on the slow but accelerating deterioration of the marginal ice pack. The CV-580 assisted with readings from its SAR.

A week later, on 27 March, most of the LEWEX experimenters reassembled in Halifax, Nova Scotia, when the two research ships returned to port. They reviewed the events of the last several days and established priorities for the analysis. The highest priority went to measurements collected on 14 and 17 March, when nearly all sensors had been operating and the seas were complex and most difficult to describe.

The execution phase of the LEWEX had been accomplished. The scientists who took part would now return to their home countries. Months of work lay ahead reducing, interpreting, and comparing the data they had gathered, before integrating the results and sharing them with their colleagues around the world.

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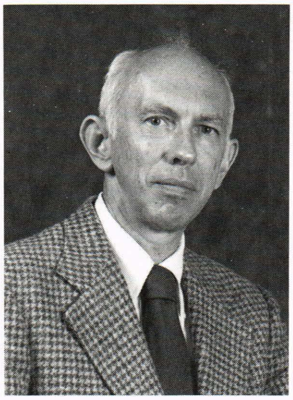
THE AUTHOR



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As a freelance writer/photographer, he has become increasingly identified with maritime issues, and his articles on those subjects have appeared in numerous publications including articles for the *Technical Digest*. Mr. McCloskey's novel, *Highliners*, was published by McGraw-Hill in 1979. His newest book, *Fish Decks*, will be published next spring.