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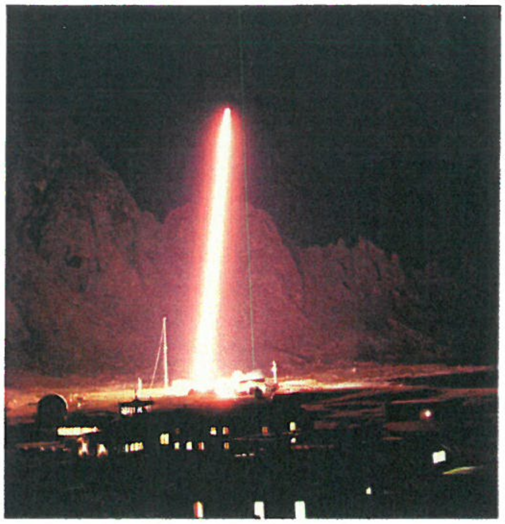
Cover: An X-ray image of the Chamaeleon molecular cloud complex, created by Jeff Mendenhall, graduate student in astronomy, and his adviser, associate professor David Burrows, from data provided by professor Eric Feigelson. This image delineates contour intervals that identify the molecular content of the cloud. Researchers at Penn State study X-ray absorption by such clouds to determine the distribution of hot gas in the Milky Way galaxy.

Mendenhall used this image to illustrate a project he presented at the 1992 Graduate Research Exhibition, and it was subsequently selected to be featured on the poster for the 1993 Exhibition, which will be held March 19-20 at University Park.



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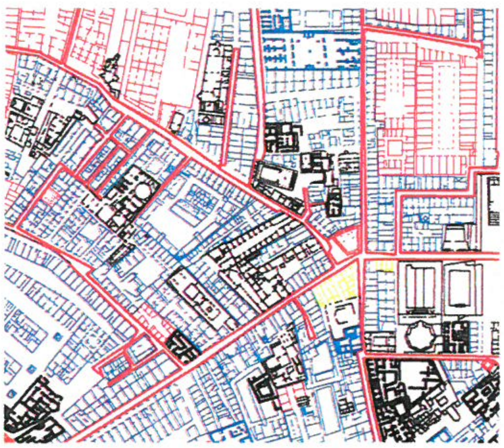

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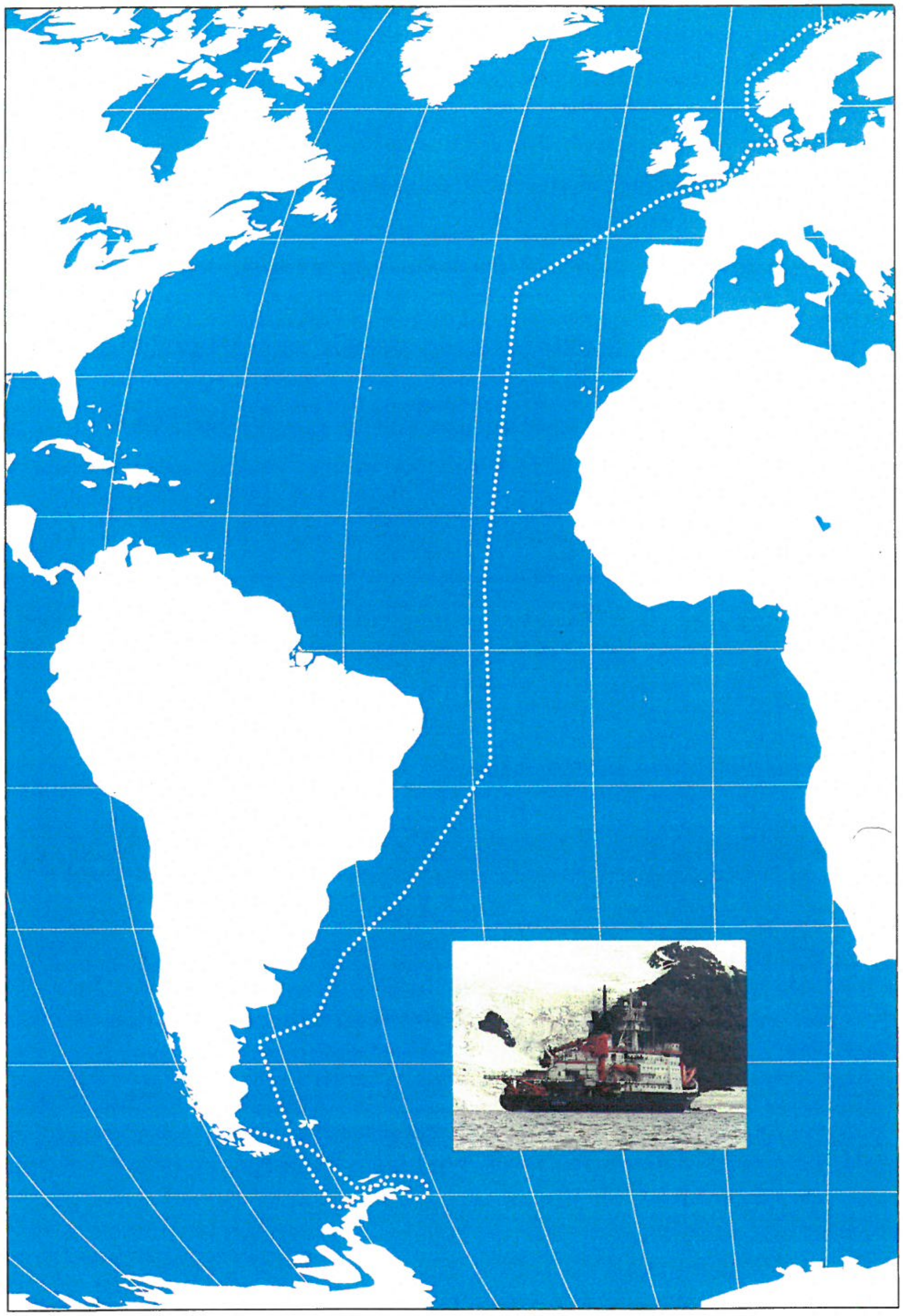
The Voyage of the Lidar



The sea is rough, some say the roughest the ship has seen. Here, in the North Atlantic, Tim Stevens and Paul Haris are on deck trying to set up the equipment that has led them thousands of miles from the comfort, and calm, of Penn State. The other researchers long ago abandoned them to their work and sought refuge below deck.

At last, the equipment is assembled, ready for testing. The sea calms a bit, but the sky remains unsettled — overcast, foggy, gloomy. Suddenly, a brilliant green beam of light pierces the early evening dreariness, illuminating the clouds before disappearing. Soon the other researchers on the ship, some noticeably seasick, all with necks straining upward, have come out to witness the entrancing light. Several snap photographs.

The green light is a ground-based laser system called lidar, an acronym for light detection and ranging. Last fall it and the two electrical engineering graduate students went on a four-month expedition from Norway to Antarctica on the German arctic-research vessel *RV Polarstern*, collecting data on the structure, dynamics, and chemistry of the middle atmosphere — data that had never been measured over such a wide range of latitudes.

Six months earlier, the whole expedition had been in doubt. "There are very few lidars in use because it's so new," Stevens says now, from behind a desk completely covered with schematics and mechanical drawings. "So it wasn't something we could just get the plans for and build. This one is different from any that has been built before, and we didn't know how some aspects of it were going to work."

A 250-pound Olympic weightlifting hopeful, Stevens would probably look more at home on Joe Paterno's offensive line than in a laser lab. But as he proudly describes the building and operation of the lidar, it's obvious he's where he wants to be. "It's sort of engineering at its finest, I think, because it includes everything," he says. "You get to study optics, materials science, statistics, the atmosphere, mechanics — it pulls everything together."

Lidar is a remote-sensing instrument, taking measurements up to 100 kilometers away. It works in much the same way as radar, except that it uses light waves instead of radio waves. A pulsed laser beam (20 pulses per second; 200 megawatts at peak power) is sent out; the light is scattered back by particles of dust, aerosols, and other molecules in the atmosphere and received by a telescope. Special filters that limit the telescope's field of view allow the lidar to take daylight measurements. A high-speed shutter wheel, designed by Stevens, provides the timing for the entire system and also keeps powerful low-altitude reflections from damaging the sensitive detectors which analyze the returning light. Most of the return signal will be at the same frequency as the transmitted beam, but a portion of it will be shifted in frequency depending on the different molecules encountered. Analysis of the scattered return beam can provide precise measurements of the density, temperature, molecular concentrations, and particle velocities in the atmosphere at altitudes too high for other ground-based measurements and too low for satellites.

LIDARS HAVE BEEN USED TO MONITOR EMISSIONS FROM INDUSTRIAL PLANTS, TO STUDY ANTARCTIC OZONE-LAYER DEPLETION, TO MONITOR WIND SPEED AND DIRECTION AT AIRPORTS, AND TO TRACK CLOUDS OF VOLCANIC ASH.

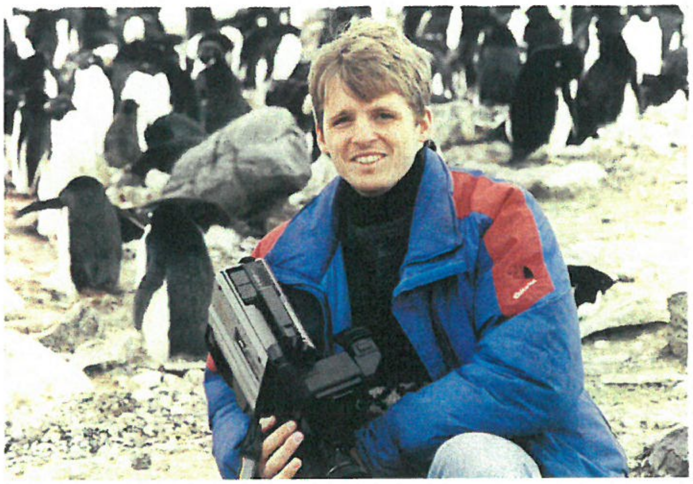
The thin green line of lidar and the fiery trail of an instrumented payload rocket light up the sky over the Andoya Rocket Range in Norway.

The team building the lidar, members of Penn State's electrical engineering department and Applied Research Laboratory (ARL), had been toiling with the system for more than a year. "Up until August, I didn't even think about the trip," recalls Stevens. "There wasn't any trip unless the system worked." Gradually, everything fell into place, and the lidar was successfully tested in early August. A little over a month later, Stevens and Haris left for Norway, along with professor Russell Philbrick, head of the lidar project, and ARL staff members Daniel B. Lysak and Don Upshaw, who managed the logistics.

The expedition began at the Andoya Rocket Range in Norway, at 69 degrees North latitude (for comparison, University Park is nearly 42 degrees N). There the team spent a week unpacking, setting up, and adjusting the equipment in a specially-modified shipping container. Soon, they were taking lidar measurements simultaneously with those of instruments aboard meteorological rockets, often under the glow of the Northern Lights. "The whole thing was to get the equipment working properly, to get everything tested there," says Stevens. "We worked constantly, taking data every night we could, and fixing things. Aligning the optical box, with its 60 optical components, was the toughest. It took eight to nine hours, all in the dark, to align it the first time."

At Andoya, they also met the University of Bonn students and faculty who would be operating another two lidar systems on the voyage. University of Bonn professor Ulf von Zahn and Philbrick, who have a 25-year friendship, had contacted the Alfred Wegener Institute together in 1990, while von Zahn was on a six-month sabbatical at Penn State, to inquire about the German arctic-research vessel. As a result, both received invitations to operate

LIDAR WORKS IN MUCH THE SAME WAY AS RADAR, EXCEPT THAT IT USES LIGHT WAVES INSTEAD OF RADIO WAVES.



Paul Haris in Antarctica

Tim Stevens in Chile

their instruments on the helicopter deck of the *Polarstern* during its 1991 resupply mission to scientific bases in Antarctica.

The three lidars and their operators (four from Penn State and four from Bonn) boarded the *Polarstern* in mid-October at Tromsø, Norway (70 degrees N), during the ship's return from a historic trip to the North Pole, and sailed to the German port of Bremmerhaven, attempting to take atmospheric data in the storm-tossed North Atlantic on the way. A four-week stay in Germany allowed time to make further adjustments to the lidar system, to verify data, and to install additional instruments. These included a microwave sounder to measure water-vapor concentrations between 30 and 80 kilometers and a digital ionosonde borrowed from Lowell University. The ionosonde would collect data on those layers in the ionosphere in which lidars had found sodium produced by meteors. Tom Collins, director of Penn State's engineering design services, and graduate student Joe Martone joined the voyage from Germany to Argentina.

The two-month voyage south began November 14. But all was not smooth sailing. Once underway, the lidar didn't work. "It was scary," says Stevens. "We had all this time in Germany to get ready for the real thing, and then the system didn't work." For the first few days aboard, no data were taken. The problem, laser alignment, was no sooner corrected then a second, more serious problem arose — the laser flash-lamp charger blew. "It scared us big time," Stevens says. "We faxed back and forth with Dr. Philbrick, trying to figure out what had caused the failure. Finally, since we had a spare laser with us, we just put in a new charger, and the system worked fine the rest of the trip." If the second charger had failed, the *Polarstern* might as well have been a cruise ship — the research would have been over.

A typical day found Stevens and Haris sleeping late while the other researchers, mostly marine biologists, took their measurements and samples during the ship's daily 12-hour stop. As the day wore on, the two would get ready to take data, beginning their work as the others were settling down for the evening in the pool, at the movie theatre, or just getting together below deck. "They'd see us running around late in the afternoon and think we were unsociable Americans," chuckles Stevens.

The lidar they used represents a third-generation system for Philbrick, who is not only an authority on lidars but a driving force behind lidar development in the United States. In the mid-1970s, he was responsible for the Atmospheric Measurement Program of the Air Force, a systematic attempt to analyze the structure and dynamics of the atmosphere. "I realized that we never were going to launch enough rockets to really make a thorough study on the small-scale variability and structure of the atmosphere. So I started at that point to build an advanced lidar." By the late 1970s, the technology had matured enough that reliable lasers were available, allowing less time to be spent on the lasers and more on their applications.

Lidars have been used to monitor emissions from industrial plants, to study Antarctic ozone-layer depletion, to monitor wind speed and direction at airports, and to track clouds of volcanic ash sent up by the eruptions of Mount St. Helens, El Chichon, and now, thanks in part to the Penn State expedition, Mount Pinatubo. "Near the equator, we kept seeing our return beam scattered, and whatever was scattering it was ruining our high-altitude measurements," says Stevens. The revelation that it was the ash cloud from the Philippine volcano caught Stevens and Haris by surprise, pleasantly: The ash-cloud profile they generated is proving valuable to researchers worldwide. "It turned out that we were able to monitor something no one else is going to have a lidar measurement of — a profile across all latitudes of the particle layer," says Stevens.

In addition to the data on the Pinatubo layer, the lidars generated a comprehensive profile of atmospheric density, temperature, cloud particles, gravity waves, and concentrations of water vapor and aerosols from 70 degrees North to 65 degrees South. "We were able to get quite a data set over a very wide range of atmospheric conditions," says Philbrick. "It's going to be very interesting to see what the data show us. That will take a year at least. I expect these results to be the basis of a dozen or more theses and dissertations."

The trip itself turned out to be rather calm, with more foggy and rainy nights than expected. But several incidents broke the routine. At one point, a Soviet battleship and cargo carrier headed straight for them, forcing the *Polarstern* to a complete stop. "We were radioing them, but they wouldn't talk to us," recalls Stevens. "We sat there for about 20 minutes until they went by. We were all wondering what was going on." After a moment of thought, he recalled that the encounter had occurred while the Soviet Union existed. "I remember the time we learned that the Soviet Union was gone. We were all shocked. These world events were happening, and we didn't realize it."

In Puerto Madryn, Argentina, on December 8, Philbrick joined the expedition and Collins returned to University Park for the holiday season. Summer was then in full swing, Philbrick recalls, the sun always near the horizon and dipping below it for only a few hours each day. After the "interesting" days crossing the Drake Passage (the turbulent water where the world's oceans circulate around the earth) the ship reached its first Antarctic ports in the Maxwell and Admirality Bays of King George Island (62 degrees S). (It was in Maxwell Bay that the *Polarstern* bumped into a smaller Argentine battleship one night, causing negligible damage to either vessel.) As they neared the frozen continent, the Penn State researchers were taken by the beauty of the region. The results of the biologists' work, in particular, impressed Philbrick. "I think the richness of the marine biology that exists in the region is truly astounding." The researchers saw icebergs, millions of penguins, and even the "green flash" — a phenomenon where, just before the sun dips below the horizon, a part of it turns green for an instant because of refraction of the sun's light. They also awoke on Christmas morning to a special present: the *Polarstern* was stopped in six- to nine-foot-thick ice. Usually, no one would think of such a predicament as a gift, but the occasion allowed the crew and researchers a unique opportunity to leave the ship and walk on the ice. Finally, just before the trip concluded in Punta Arenas, Chile (53 degrees S) on January 2, they saw the rare noctilucent clouds — clouds formed in the mesosphere at polar latitudes that are illuminated by sunlight long after the sun has dropped below the horizon.

Back in University Park after the expedition, Stevens and Philbrick see a strong future for lidar. "I think there's a tremendous potential for lidar," says Philbrick. "The next step is to make the system fully self-operating, self-calibrating, automated enough to turn on, take data, pre-process data, and send it out. That's right around the corner." Such a system may eventually replace cumbersome weather balloons.

"By the end of the decade," says Philbrick, "we shouldn't be relying on expendable hardware. Several hundred meteorological balloons are released each day, when the same data can be gathered with lidar and a few cents of electricity instead of a relatively expensive package that is lost each time." In addition, lidar takes measurements continuously, providing a complete record of atmospheric variations. This is a significant advantage, since balloons only provide data twice daily during a three-hour ascent of the balloon package, and meteorological rockets provide data sampled only during the descent of the instruments.

Eventually, a network of lidars could be set up across the country to continuously monitor the upper atmosphere, providing essential data for forecasters. Lidar will be particularly helpful for observing weather processes that last less than 12 hours, Philbrick notes, the time between balloon launches. The increase in the amount of information will limit assumptions, and forecasts will become more accurate.

While lidar-type measurements were made long before lasers (the earliest were done in the early 1950s with simple searchlights), the lidar on *Polarstern* represents the maturing of theory into application. "Lidar is not in widespread use because not many people really understand how to make full use of it," says Philbrick. "Most of the work that's been done on lidar to date has been completed in the lab, then written up and published. There's been very little effort to try to use it for routine measurements, and that's what we're trying to do now."

Stevens takes a broader view. "We saw so much, it was like living in an accelerated time frame. We did things that hadn't been done before. We demonstrated the equipment and saw it work successfully. And with the Pinatubo ash layer, we got lucky. This was a definite step towards making lidar more applications-oriented."

—Mike Hammond

C. Russell Philbrick, Ph.D., is professor of electrical engineering in the College of Engineering, 315 Engineering East Building, University Park, PA 16802; 814-865-2975. The LADIMAS measurements were sponsored by the National Science Foundation and by the U.S. Navy. In June 1992 Philbrick received an award from the Department of Energy's University Research Instrumentation Program to purchase and build a lidar and radar sounder (LARS) instrument for volume scanning of the atmosphere. Tim Stevens and Paul Haris are graduate students in electrical engineering. Stevens received his M.S. in August and Haris in December 1992; both are continuing for doctorates.

Mike Hammond received a B.S. in electrical engineering with a technical writing minor from Penn State in January 1992.