A LIDAR beam pierces the night sky at Poker Flat Research Range, Chatanika Valley, Alaska. *Photo courtesy of Richard Collins*

Lasers in the night

What impact does the upper atmosphere have here on the ground?

By Kim Morris

"Ah! The conditions are perfect," Richard Collins says as he surveys the February night sky, obviously relieved. We have just climbed up the metal stairs on the outside of the LiDAR Research Laboratory, Collins' professional domain. Located on a hill on the University of Alaska Fairbanks' Poker Flat Research Range (PFRR), in the Chatanika Valley about 35 miles northeast of town, the facility houses the hardware that makes his research possible. Standing on its roof, slightly out of breath, we admire the view. "Most people think the sky is clear if they can see the major stars," Collins continues, "but, for us, the minor stars have to be visible too."

The flat roof of the building appears to be littered with large packing crates – in fact, these are shafts into the roof covered with removable lids. Brooms and shovels in hand, we clear the snow from around the "boxes," then remove the heavy lids and maneuver them out of the way. The laser and telescope that comprise the most visible components of the Rayleigh Light Detection and Ranging (LiDAR) are now exposed to the sky. Tonight we will use this optical system to gather density and temperature data from miles up in the sky, information Collins uses to infer when and how the upper and lower atmosphere interacts and what the consequences might be for those of us on the ground.

Sky conditions are crucial to LiDAR observations – it must be both dark and cloud-free. As a conseequence, the LiDAR does not operate in the summer because interior Alaska does not experience astronomical darkness (sun 18° below the horizon) from late June to late August. Clouds increase the error in the measurements making them less reliable and harder to interpret. This means that Collins, a professor of atmospheric science at the Geophysical Institute, has no fixed winter data acquisition schedule – he is at the mercy of the weather. During the day, Collins must repeatedly visit the National Weather Service's website to check the weather forecast and look for incoming clouds on the updated satellite loop before committing to make observations that night.

By 5 p.m. he decides that conditions will probably be favorable. After a quick supper, we make the 40-minute drive out to PFRR. We buzz ourselves through the front gate to the range, sign in at the main office building, and head up the hill. Collins produces a second remote to open the garage door of the LiDAR building and we drive straight in. The building is pitch black inside except for the truck's headlights.

He heads straight for the laser room, turning on lights as he goes. "We need to get the laser started first. It takes 30 minutes to warm up," he says. "Then we can get the rest sorted out." He moves a refrigerated chiller unit into the adjacent, unheated room. This unit pumps cold tap water through a heat exchanger in the laser keeping the laser flashlamps and rods cool. Ironically, it produces a lot of heat and needs to be kept out of the laser lab. Next he flips a few switches on a second box and checks the power level on the laser.

Back inside after 15 minutes on the roof, Collins heads straight for the telescope room painted midnight blue to minimize light scattering. He uncovers, checks and cleans the 24-inch mirror that collects and directs returning laser photons to a counting device. In the control room, he boots up the computer, an old DELL from the mid 1990s, that initiates the laser firing sequence and integrates and stores the data. In order to get the computer ready, Collins has to go through a complicated go-around. The computer wasn't designed for this kind of application and has to be fooled into doing its job. Collins wings the complicated procedure from memory, talking himself through it. He requires his students to write down their own checklist but says, "I'm too old for that," and shrugs. Getting new computers would require a complete rewrite of the data acquisition and integration application. "A total overhaul of the code would be difficult and time consuming," he says. "I'm waiting for a student who's interested in doing that."

With the laser fully warmed up, Collins fiddles with the mirrors that direct the green laser into the sky. The alignment of the telescope and laser is critical for making accurate measurements. He searches for the optimal position. Like an optometrist fine-tuning a prescription, he adjusts the mirrors backwards and forwards, up and down. After each adjustment, we run a test and evaluate the results on the fly. He continues to reposition the mirror until the laser and telescope are properly aligned. This ensures that the maximum number of returning photons is captured and counted. The engineer in Collins clearly enjoys this process. He is a bit of a techno-geek. And with his broad, gap-toothed smile and male pattern baldness, he looks like a younger cousin of the human half of the famous


Richard Collins is a professor of atmospheric science at the University of Alaska Fairbanks. *Photo courtesy of Richard Collins*

gizmo-mad duo Wallace & Gromit. Finally everything meets his satisfaction. It's time to make some measurements.

Data acquisition amounts to pushing the F9 key over and over again. This initiates the laser shots. Each data set comprises 16 runs and takes about 16 minutes. Each run produces a line of data and an accompanying graph. Each run ends with a computer chirp. The sixteenth one ends with more of a screech reminding the operator to push F9 again. These data are automatically saved but Collins likes to record the first and eighth lines of data manually. It gives him and his students an at-a-glance record of the observations and warns them of possible problems with the equipment, such as instrument drift, which requires mirror adjustments, and the presence of clouds. When the return counts are particularly low, Collins throws on his black Carhartt coat, checks the sky for clouds and records his observations in one of his many notebooks. The nightly data integration creates a 12- to 14-hour average of the density/temperature structure in the upper atmosphere. Over the course of weeks and months, these profiles allow a glimpse into the movement of energy between the upper and lower atmosphere.

A Rayleigh LiDAR measures the Rayleigh scattering of light from molecules in the atmosphere to determine atmospheric density. Used to make stratospheric density measurements since 1951, this fully mature technology requires only routine maintenance. Making measurements with it is straightforward. The system is like a game of catch. The green laser shoots a thousand pulses of light particles or photons per minute straight up into the sky. This stream of photons collides with molecules in the atmosphere. These collisions force the photons off course and most of them do not return to their point of origin. The mirror of the telescope catches the returning photons and directs them to a high-speed counter. The counter relays its measurements to the computer for data storage – this is the raw data. The photons that arrive in the first fraction of a second after the pulse are from the atmosphere closest to the ground. Photons that arrive a few fractions of a second later are from higher up. In this way, a vertical profile of the atmosphere can be built up. The higher the laser penetrates into the atmosphere, the fewer photons return. Generally speaking, each 8-watt laser shot emits one quintillion (that's 1 followed by 19 zeros) photons – approximately 0.8 of them come back. The laser runs all night, the staccato tck, tck, tck, sounding like a perpetually free-spinning bicycle wheel.

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Richard Collins was born in the Republic of Ireland. Good at math and science in school, he decided to study engineering at the National University of Ireland – University College Dublin. “Engineering is harder to get into than science and its about doing things,” he says. Anyway, his father was an engineer. After graduation, he came to the United States and did graduate work at Case Western Reserve University in Cleveland, then the University of Illinois at Urbana-Champaign. He over-wintered at the South Pole Station in 1989-1990, launching radiosonde equipped weather balloons and probing the stratosphere with a LiDAR for his Ph.D. research. Coming to UAF was almost inevitable. Its engineering department has a strong remote sensing component – one of the few in the country. Collins arrived in Fairbanks in January 1994. He has been the primary user of the Rayleigh LiDAR installed at Poker Flat Research Range in 1997, one of only four in the Arctic. Over the years his interests broadened and he eventually moved to the Atmospheric Science Group to concentrate on science rather than engineering. Still his training as an engineer - and his experience as a foreign student - informs every aspect of his professional life.

Collins’ research centers on the Earth’s interactions between the lower and upper atmosphere. Our atmosphere consists of four layers, characterized by temperature profile, chemical composition, movement, and density. We live in the lower atmosphere, or troposphere, where all weather occurs. The stratosphere, directly above the troposphere, houses the ozone layer. Ozone is vital for the survival of life on Earth because it absorbs nearly all of the ultraviolet (UV) radiation coming from the Sun. If ozone did not filter out UV-B radiation, this biologically damaging energy – overexposure causes skin cancer and cataracts in people - would penetrate the atmosphere and reach the Earth's surface.

The most prominent feature of the middle atmosphere at high latitudes is the polar vortex. This low pressure, anticlockwise spinning structure forms in the Fall, when solar heating decreases at the pole, reaches its maximum during the long polar night, and begins to decay in the Spring, when light returns. Although it has no direct expression on the ground, it influences the location of the jet stream and recent observations suggest that the strength of the polar vortex has consequences for weather at the Earth’s surface. Ordinarily, the well-structured vortex acts like a big bowl restricting cold air to the polar-regions. However, in winters 2009-2010 and 2010-2011, the Arctic polar vortex was highly disturbed and many parts of the Northern Hemisphere experienced severe, in some cases record breaking, conditions as cold air spilled southward. Warm air replaces the cold air that moves south - this past winter was unusually warm in the Arctic itself.

The polar vortex also plays a key role in the distribution of trace gases, notably ozone, in the stratosphere. Ozone depletion occurs when it interacts with destructive chemicals, something that only happens when temperatures fall below -60°F in the stratosphere. Usually, about 25 percent of the Arctic ozone disappears during the winter. This year an unprecedented 40 percent of the column disappeared due to a longer cold period. People in Scandinavia, Greenland, Canada and Russia will be more vulnerable to UV-B rays until the stratosphere warms and the ozone layer repairs itself.

At Poker Flat, Collins and his students capture nightly snapshots of atmospheric changes as the polar vortex strengthens or weakens. A nightly temperature profile reflects the upper atmosphere's structure over a 12-14 hour period and gives them a general idea how cold the stratosphere is. Looking at shorter term averages in the data, say 15 minutes to two hours, allows them to investigate how the vortex interacts with waves and tides in the lower atmosphere that travel through the western Arctic. These waves and tides continually modify the vortex's structure, reinforcing or diminishing smaller scale features by transferring heat in the "surf zone" surrounding the vortex. They are one of the main avenues for interaction between the upper and lower atmosphere and documenting their frequency, location and duration is vital to understanding how these small-scale couplings work and what influence they have on our weather. This kind of detailed understanding of atmospheric processes is also important for computer modeling. Simulations yield very different results when these finer details are included.

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One o'clock rolls around and Collins puts a frozen pizza into the oven of the fully equipped kitchen. We quickly eat it and he settles into his seat, listening to Irish radio streaming over the Internet recounting the results of the national election. He stares off into the middle distance, his shoulders sagging. Suddenly, he explodes out of his chair. "Oh shit, oh shit," he shouts as he runs towards the kitchen, then wails, "ooooh noooooo!" I run to the kitchen to find out what's wrong. Water covers the floor. Collins left the faucet running intending to return a few minutes later. But that didn't happen. Now he spends half an hour using a wet shop vac and plenty of paper towels to clean up the mess while I man the F9 key on my own.

You might think the long nights at Poker Flat are a necessary evil for Collins. But according to his husband Patrick Marlow, "Richard is a night owl. If he wasn't working at Poker he would be up doing something else." Pulling all-nighters has been Collins' preferred method of work at least since his days as a graduate student. He often heads back to his office after dinner to write research papers, grant proposals or prepare lectures. He gets very little sleep.

Denise Thorsen, a fellow engineer and friend of more than 20 years, explains Collins' behavior this way, "Engineers are outcome oriented. They know what they want the final product to be and ask the question, 'How do I get there.' They look at all the resources available and find the most efficient pathway to the goal. Richard has a career path in mind, a very engineering thing, and is doing what he sees as necessary to get to his goal." Anupma Prakash, another collegue, concurs, seeing Collins as a pragmatic person who optimizes a situation and is willing to volunteer his ideas and take other people's ideas onboard when appropriate. "He thinks outside the box and doesn't hesitate to stretch out – an important factor for collaboration," she says. "He is enthusiastic about other people's science and doesn't want his students to be narrow-minded [about their work]," says his graduate student, Brita Irving. Many of his colleagues describe him as ambitious. Collins has a simpler explanation. "I'm a workaholic," he says.

This demanding schedule is beginning to take its toll. Just lately, he admits to feeling tired all the time. In the past few months he has fallen asleep at a dinner party in his own home and at a thesis defense. He loses his train of thought in his lectures - sometimes simple adding and subtracting elude him making his explanations in class confusing as he alternately explains something then backtracks because he is wrong. Whoever goes out to Poker with him has to talk to him while he drives back to town to keep him awake. Tonight he falls asleep twice after giving me a chance to take a nap. “He doesn’t bounce back as well now he is middle-aged,” says Marlow.

It’s nearly 8 a.m. Sunlight peeks over the hills. It’s time to close things down for the night. We shut off the laser, cover the telescope mirror and go up to the roof to replace the observation shaft lids. We make a quick sweep of the building, turning off the lights as we go, then head down the hill, sign out and drive back into town. Collins will sleep for a few hours, call friends and family in Ireland to talk about the election results and pull together documents for his tax return. He won’t be doing any deep thinking today.

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It’s a few months later – mid-April to be exact. Collins is back at Poker Flat eking out his last data set from the all-to-brief darkness. Tonight his green and ultraviolet laser systems run in tandem. The UV laser, designed to investigate the excited nitrogen ions produced in auroral arcs, requires some testing, tweaking and maintenance. Comparing its performance to that of the green laser will provide some insights into what further development is required. Over the summer, Collins and his students will evaluate and interpret their data, concoct new research plans and maybe reconfigure some of the instruments. Next fall they will be back at the LiDAR Research Lab shooting lasers into the night sky, probing the invisible turmoil high overhead.