The DIRS Story

John R. Schott

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How the Digital Imaging and Remote Sensing laboratory became the first major research laboratory at the Rochester Institute of Technology and flourished

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Dedication

To the DIRS crew; faculty, staff and students who made it all possible.

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Introduction

In 2019 I wrote and RIT published "Coming of Age: The Center for Imaging Science at the Rochester Institute of Technology" (see Schott 2019). This chronicled the formation and early years of the Center. I left out much of the DIRS story in the "Coming of Age" because the Digital Imaging and Remote Sensing lab (DIRS) was such a large fraction of the Center it would have overwhelmed the Center's story. I promised DIRS that at some point I would try to capture the DIRS story. More recently my youngest son was questioning me wanting to understand how DIRS got to be DIRS (my words not his). He had grown up around DIRS, studied engineering, realized DIRS was not the norm and wanted to know how it came about. I tried the usual platitudes of hard work, luck and being at the right place at the right time. After a half hour of back and forth, Jack said there had to be more to it. So, for all the people who have made DIRS what it is, the many more who will join DIRS, and for Jack, I've tried to capture here how DIRS came into being and became so successful. This chronicle can easily be read on its own but it runs parallel to the "Coming of Age" and the ambitious reader (Jack) could gather more context from that source. The story emphasizes how DIRS came to be and the early years with a nod to the last decade or so. I intended this story to be a living record and hope that at some point one or more of my successors will continue the story as they continue the science.

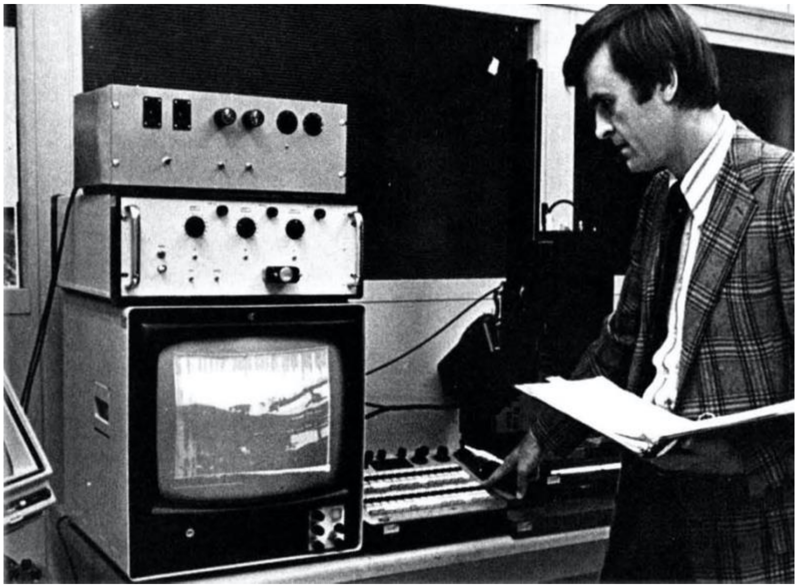
1. **The Calspan Years:** How did your Author get into the story

How does a new academic research laboratory come into being. Since truly new research groups (i.e. as opposed to spin-offs of existing groups) usually form around an individual it is perhaps more appropriate to ask how does an individual decide to build an academic research group. In my case it was not straight forward. I certainly enjoyed my undergraduate academic experience, majoring in physics and sociology at a small liberal arts college (Canisius College in Buffalo, NY). I had some great professors and role models who fostered my interest in learning in general (literature and sociology) and science in particular (physics and math). However, at an undergraduate college with a physics department of four faculty I wasn't really exposed to university type research groups. I did have an opportunity to do some collaborative lab work and got some excellent mentoring from a great physics professor (Dr. Jim Lauffenburger). However, rather than becoming enthralled with academics, much of my first couple of years in college were focused on political activism. By the start of junior year, I was married and had a son so my studies and work (laborer, truck driver, crane operator and eventually unofficial plant engineer all at an ice house) kept me pretty busy just keeping my head above water. I got very lucky and landed a summer job after junior year working at what was then Cornell Aeronautical Laboratory, which became Calspan, in Buffalo, NY. Growing up in Buffalo you came to know that the "lab" was the place to do science. The only major research center in Buffalo was regularly in the local papers. In my case, this was also a family connection as both my godfather (a mechanical engineer) and my brother (also a physicist) worked there. My entrée came through another Canisius physics grad who went on to get a Ph.D. in physics from Cornell University. Dr. Ken Piech had called Lauffenburger looking for a helper for the summer. Piech worked in the Optical Sciences Section at the lab doing Remote Sensing and needed help on a National Science Foundation Grant to study Lake Ontario using aerial photography as part of the International Field Year on the Great Lakes (IFYGL) (see Ludwigson 1974).

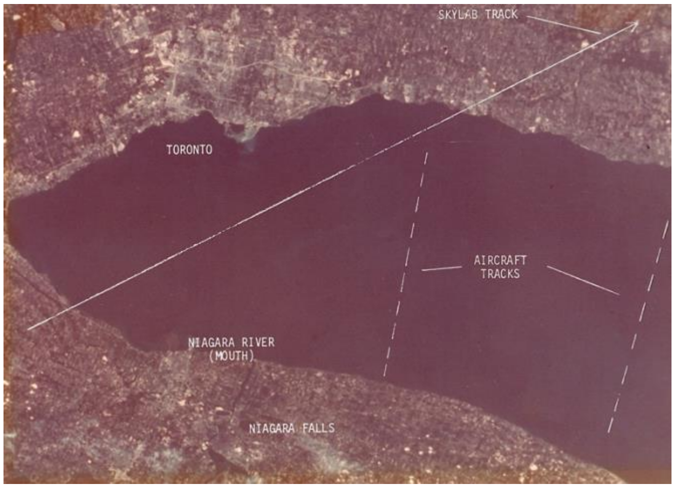
I had grown up during the cold war with the space race, Sputnik and science advances prominent in the news. My ambitions at that time were somewhat modest. I grew up reading about science and scientists and wanted to work with research scientists and somehow help make a contribution, however small, to the growth of scientific knowledge. My siblings and I were the first generation in our line to go to college. My grandfathers were in the trades, my dad worked his way up in the maintenance department of a small plant making powdered iron. However, it was clear growing up that all 5 of us were expected to go to college if we could. We weren't raised to think that if you worked hard, you could do or be anything you wanted. Rather, while it wasn't said out loud, we were taught if you worked hard, you could do better than your parents. Luckily for me this was an era when the country, New York State in particular, valued higher education. With half my tuition covered by a NYS Regents Scholarship and half by a merit-based scholarship from Canisius I was able to afford a private college and able to focus much of my time on my academics (at least for the first two years).

So, I latched onto the summer job at Cornell Lab and convinced the lab to keep me on through my senior year. I had plans and a fellowship to continue my studies in biophysics to study brain mechanisms. But with my wife, a year behind me in school, I decided after graduation to accept a position staying on at Cornell Aeronautical Laboratory. For the next two years I worked on remote sensing projects at work and studied biophysics at the University of Buffalo (UB). It was at UB that I saw first-hand how a research group worked. In particular, I was exposed to graduate students working with Sir John Eccles. Eccles, a Nobel laureate, was one of the pioneers in understanding how signals are transmitted within the nervous system. I had the opportunity to sit in on some of his lectures and had visions of working with him. However, by the time I was ready to go back to school fulltime, Eccles had retired. By then I had realized the potential of "Remote Sensing Science" to have a substantial impact on the world. I decided to study remote sensing and looked for a place to do so while keeping my job. There were no options in Buffalo or Rochester (60 miles away) but Cornell University and the SUNY side of Syracuse University both had programs (each 150 miles away). I had read a recent NASA report on remote sensing of water quality. It described some early work trying to quantify the data extracted from aerial photographs (see Lillisand et al. 1973). This was similar to the efforts we were making at the lab to transform remote sensing from photographic interpretation to a true analytical science. I found out the NASA report was largely the product of the Ph.D. dissertation of Dr. Thomas Lillesand. Dr. Lillesand had just accepted a faculty position at Syracuse University. This made my decision easy and I convinced Calspan to subsidize my studies at Syracuse. For the next two academic years I spent Tuesday to midday Thursday at Syracuse studying fulltime toward a Ph.D. Thursday late afternoon until predawn on Tuesday I worked in Buffalo and, as a single dad, took care of my young son. During that time I learned a lot about research at Calspan and new science and math at Syracuse. I was also exposed to how a small-scale research operation worked at a university. Lillesand was the remote sensing faculty lead at Syracuse and had a trickle of funding as he tried to establish himself.

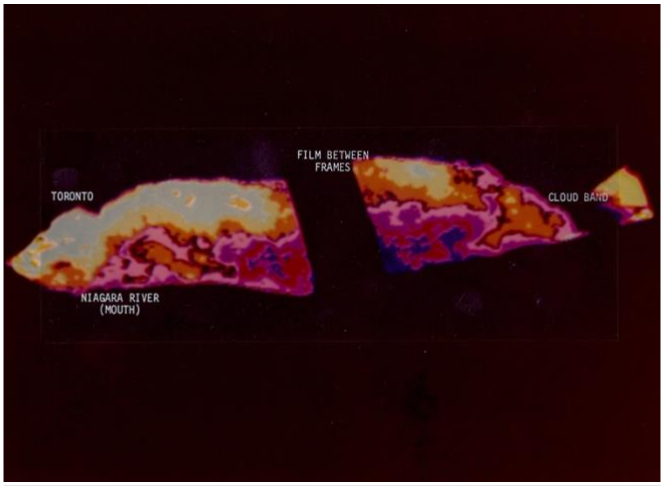
By the time I had finished my two years of course work at Syracuse I had spent five years at Calspan. I worked with and was mentored by two of the early champions of trying to quantify remote sensing science. In particular, I worked with Dr. Ken Piech (see fig.1-1) on developing methods to quantify water quality using color aerial and satellite photographs (see figs. 1-2, 1-3 and Piech and Schott 1974). I worked with Johnnie Walker (see fig. 1-4) on developing methods to quantify vegetation stress using color infrared



1-1. Dr. Kenneth Piech at a component of the Cornell Aeronautical Labs Photo Interpretation Console.



1-2. Color photo of Lake Ontario taken by Skylab Astronauts showing Skylab's ground track and flight lines for the aircraft underflights.

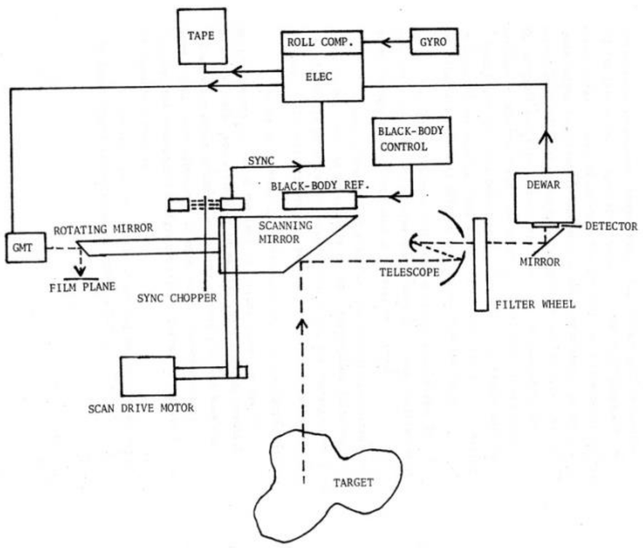


1-3. Color coded map of chlorophyll estimates in Lake Ontario derived from the satellite air photos assuming the color variations were driven primarily by chlorophyll variations.

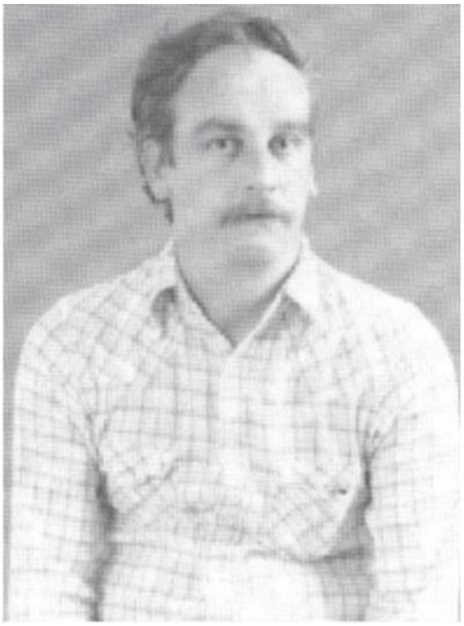
1-4. John Schott seated and Johnnie Walker standing at the Calspan Photo Interpretation console.

1-5. Color Infrared air photo of forested region in Pennsylvania with a gypsy moth infestation. Brighter red is indicative of healthier vegetation. Note, the effects of cosmetic spraying along roadways.

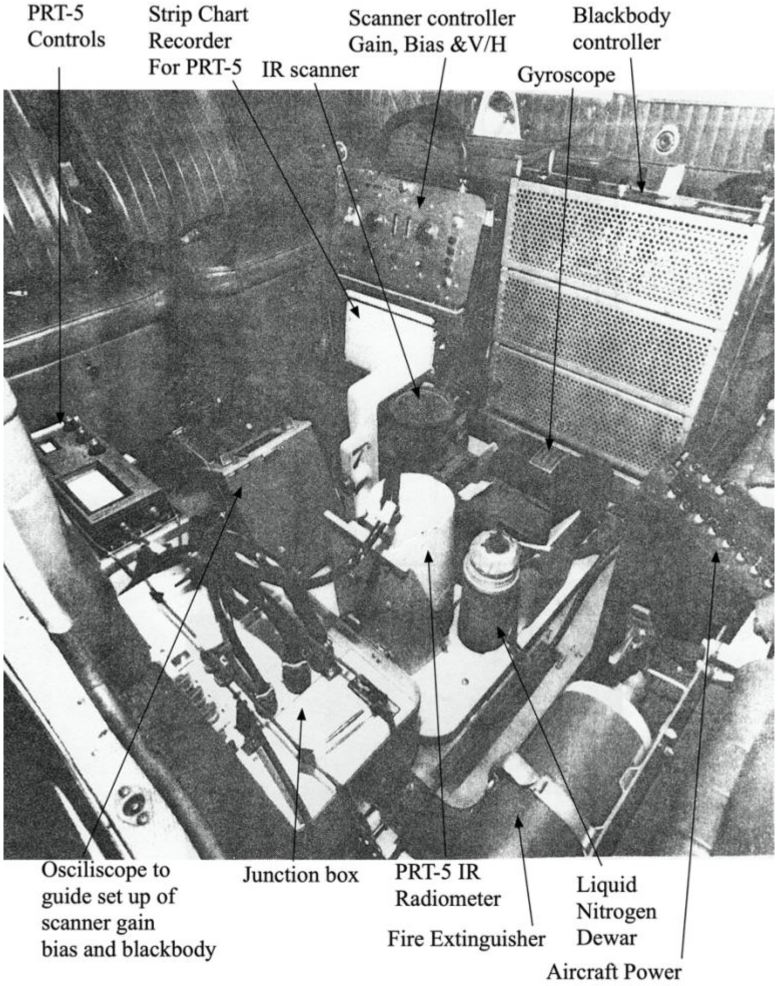
aerial photographs and later Landsat satellite - imagery (see fig. 1-5 and Walker et al. 1978). Piech, a Ph.D. physicist, was bringing advanced analytical techniques to a field that was mostly involved in visual analysis of aerial photographs (i.e. photo interpretation). Johnnie Walker was trained as a civil engineer (also at Cornell) and spent time as a photo interpreter. Together Piech and Walker were trying to bring a more scientific/quantitative methodology to the field of remote sensing (see Piech and Walker 1974). They were an unlikely pair. Piech was tall, slender, meticulous, and very mathematical. Walker was short, husky, intuitive, and very warm (when in a good humor, which was often, he would answer the phone "Johnnie Walker red or black"). I learned a lot from each of them. While working on Piech and Walker's projects, I was encouraged by Walker, who became my boss when the remote sensing section was formed out of the optical sciences section, to develop my own projects. In particular, the lab had a surplus electro-optical infrared line scanner that hadn't been used in a while (see fig. 1-6). Tim Gallagher (see fig. 1-7), the technician who had broken me in when I first arrived, worked with me to get the scanner back in shape (mostly Tim's doing). At this point there was a lot of interest in measuring and mapping the temperature of the cooling waters



1-6. Illustration of a thermal infrared line scanner with onboard film writing system.

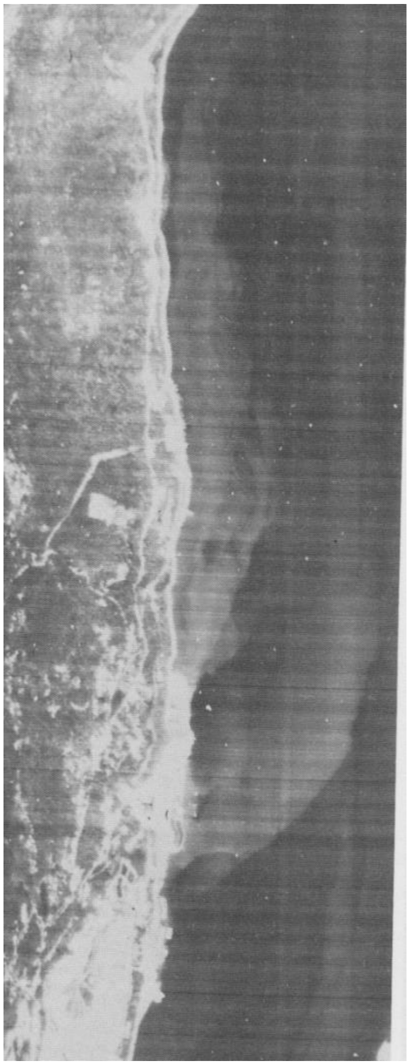


1-7. Tim Gallagher 1970's.

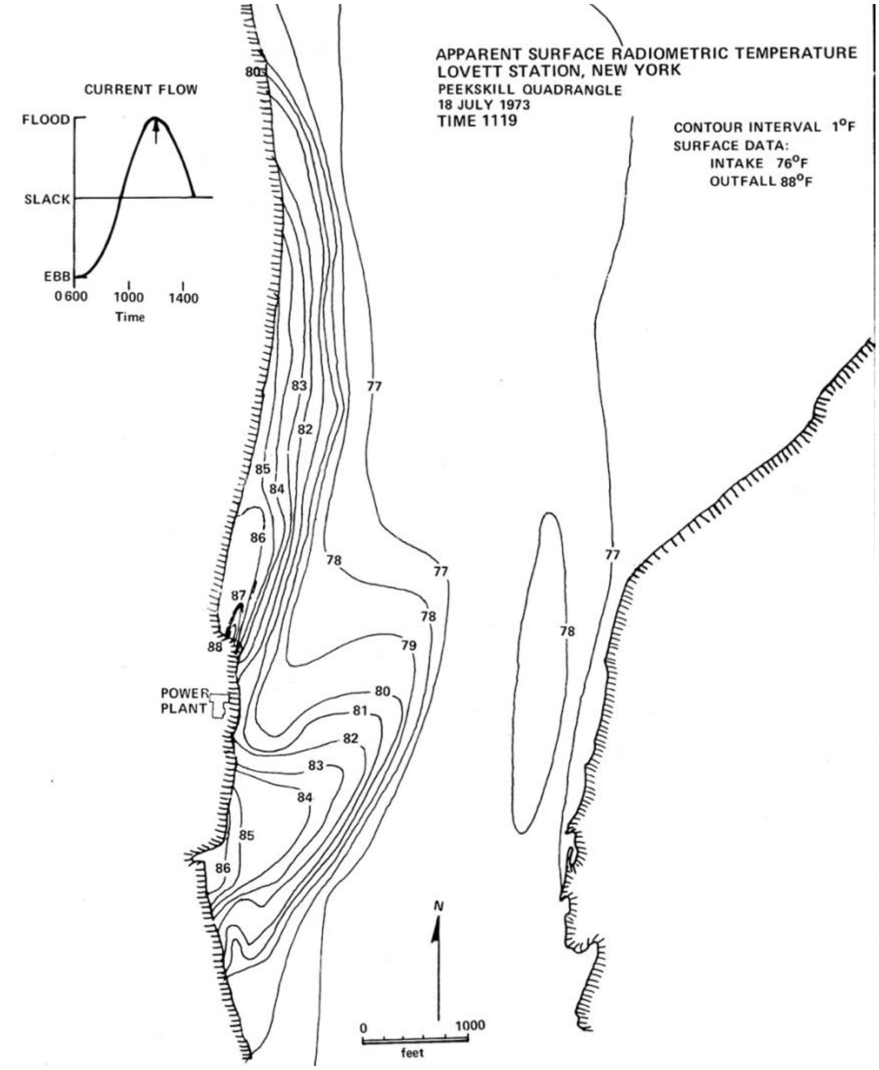


1-8. Infrared line scanner mounted in Aztec aircraft.

discharged into waterways by power plants. State and Federal laws were being passed to limit how much the temperature could be raised and how far the discharge could extend. The state of the art of thermal sensing was that the relative increase in temperature could be detected and with a great deal of field support (what remote sensors call "ground-truth") a quantitative map could be produced. This sort of worked for science experiments but was costly and impractical for operational purposes. We had an idea how to convert the thermal images the scanner wrote onto film into accurate quantitative maps of water surface temperature. I managed to bootleg some test flights on some other flight programs (see fig. 1-8) and eventually won some small programs to demonstrate our solution. Once successful (see Schott and Tourin 1975), these were followed up by some larger contracts to monitor and map all the cooling water discharges in New York State (See fig. 1-9, and fig. 1-10 and Schott 1979). This visibility let me win a position as a principal investigator on a new NASA satellite program called the Heat Capacity Mapping Mission. This was a major national competition with only 12 awards, mostly to government labs and universities, with



1-9. Aerial thermal infrared image of the Hudson River at the Lovett power station showing cooling water discharge (white hot) flowing north during flood tide.



1-10. Temperature map generated from the thermal infrared image showing the extent and magnitude of cooling water impact on the receiving waters.

only two to industry. I don’t think the reviewers realized the person behind Calspan’s thermal programs was only 23 years-old with just a bachelor’s degree.

By the time I had finished my course work at Syracuse, I was ready to start my graduate research. I had already managed to win several grants at Cornell/Calspan. I convinced Syracuse to let me do my thesis work at Calspan on my projects. I would write up a portion of the work on two different projects to constitute my M.S. and Ph.D. dissertations (under review by the Syracuse faculty). This worked out for Syracuse as they didn’t need to fund my research and for me so I could spend my research years (3 in all) back home in Buffalo. While I only visited Syracuse every other month, I got to know a great deal about how to conduct scientific research at Calspan. I also saw how university research worked at Syracuse where my role was somewhere between student and collaborator.

By the time I finished my Ph.D., things had changed at Calspan. From the time I started, the lab had been shrinking. Following the end of the Vietnam War, reduced funding from the Federal Government impacted the lab. Despite this, I had been promoted every year and had taken on more responsibility. Then Piech left the lab and went to work with a competitor. Shortly after that, Johnnie Walker died suddenly. This left me as the only other principal scientist in the remote sensing section. I was asked to become the head of the section. While an honor, it meant I would largely be responsible for rebuilding the section and helping to raise nearly all the funds to keep the group going until it got back on its feet with a new group of senior investigators.

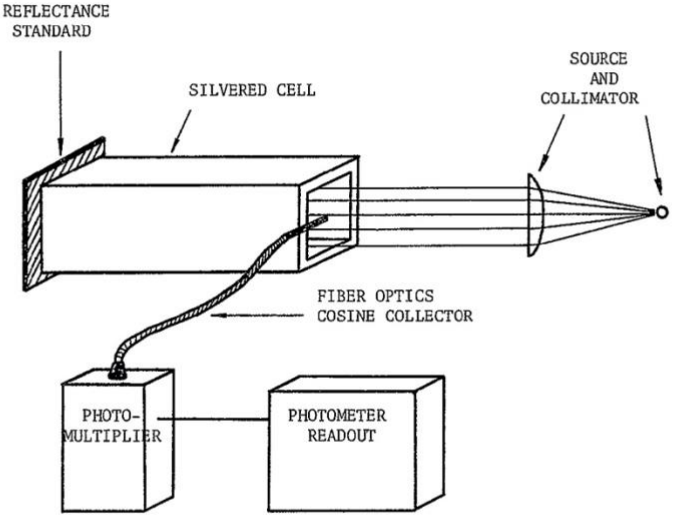
At this same time, I was approached by RIT to consider a faculty position in their department of Photographic Science and Instrumentation (photo science) department. I had met the chair of the department (Dr. Ron Francis) while doing my Ph.D. work. I was impressed with what was being taught by one of my graduate student classmates (Jon Roberts) who had an undergraduate degree from RIT's Photo Science department. RIT did not do any remote sensing. However, the Photo Science department taught their students radiometry, optics, linear systems and statistics along with the required calculus and physics courses. Students also learned about extracting and analyzing data from photographs. At this time, nearly all of remote sensing was still done using photography so these students would have an excellent background for learning how to do analytical remote sensing. The department which had a strong thesis-based masters program was also talking about moving on to a doctoral program. They were also interested in starting up a serious research program. The little research that was going on was largely unfunded or supported by a trickle of funds from local industry. Most of this corporate funding went for materials to support the thesis work of their employees getting their M.S. degrees part time.

2. The Beginning:

This takes us back to the question in the opening paragraph. How does an individual (me in this case) decide to build an academic research program? When I started my career in science, I had the modest goal of working in the scientific enterprise and making a small contribution. Over my time at Cornell/Calspan, I had reset my sights and was striving not just to be a contributor but to be a serious player. Now I had to consider the choice between continuing my corporate career, where advancement almost always meant moving into management and chasing funds (my least favorite part of the job) or starting over and trying to build an academic career. I knew I didn't want a traditional teaching job in a place like Canisius. Much as I enjoyed and appreciated my education, I was hooked on the research enterprise and wanted to do new things and help transform remote sensing from an art or craft to a true scientific discipline. The Photo Science department did not look anything like a research university. They were part of RIT, a major engineering institute, and wanted to grow a Ph.D. degree. They also wanted to build a research program. I reset my goals once again and decided to try and build a small academic research group aimed at continuing my goal of doing quantitative "science based" remote sensing. While my decision to move to RIT and build a remote sensing research group in the Photo Science department seemed logical at the time, it certainly was not. First off, I was nowhere near as sophisticated as I may have thought when I started. I had made a number of assumptions a little homework would have disproven. Coming from Buffalo 60 miles away everyone knew about RIT and what a good engineering school it was. While it was a good "undergraduate" engineering school, I soon learned it did not offer any Ph.D.s and didn't have a charter from the state to offer a Ph.D. The Ph.D. program that Photo Science had talked about when interviewing me would be the first. I also learned that not only did Photo Science not do research but the same was true pretty much across the whole campus. This started to dawn on me as I worked to put in place a couple of subcontracts from Calspan to RIT for ongoing work I had at Calspan. Much of December, 1980 – September, 1981 I worked from Buffalo on the RIT payroll on these subcontracts. I continued to work with my team at Calspan who were funded by the prime contracts. These subcontracts were rather small and straight forward contractually. I was both the source (as Calspan) and the recipient (at RIT) and could shepherd the process at Calspan with a contract office I knew well. It also helped that the ultimate government sponsors were people I had worked with for several years and were very supportive of the move. While we made this all work, it became clear to me that RIT was not very familiar with this process. They could sort of make it happen but it was anything but routine and doing it fast and often was going to present problems. Nevertheless, I was committed and decided to give RIT some time.

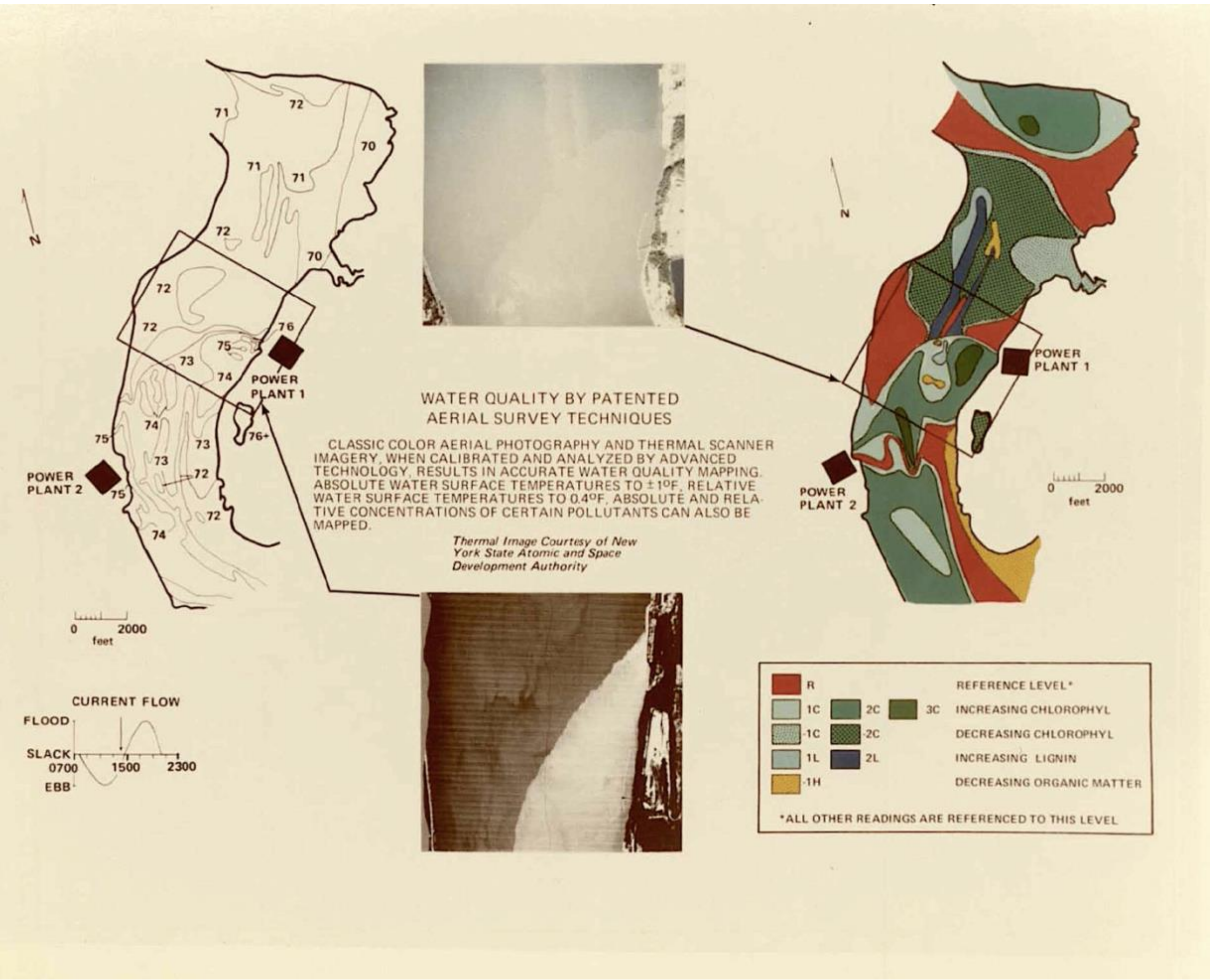
3. Calspan's contribution (aka what I brought with me):

Remote Sensing at RIT (DIRS as we would become known) owes much of its success to Calspan. When I departed, Calspan chose to get out of the remote sensing business and donated much of the remote sensing equipment to RIT including the airborne infrared scanner. Within a year or two they would also send two more people. Tim Gallagher the senior technician who had broken me in at Calspan almost a decade earlier joined me at RIT in 1981. He would become a mainstay, responsible for building and maintaining all manner of doohickeys and thingamabobs for the next 20+ years. Shortly afterwards Ned Schimminger, a young software engineer I worked with at Calspan, joined us. Most importantly, Calspan provided me with a lot of experience and the associated credibility. In retrospect, although I was just 29 when I joined RIT, my 8-9 years at Calspan prepared me well for what was to come at RIT. In my first few years at Calspan I was the new kid (meaning I was cheap labor) and I was tasked to work on a wide range of projects. This work included collecting laboratory and field data, building laboratory and field measurement instruments, analyzing imagery for water quality, forestry, defense and intelligence applications, and eventually integrating lab, field, aerial and satellite data to extract information and learn about whatever we were studying. Luckily, the more senior people were focused on the big programs mostly for the Air Force and the intelligence community. As a result, I was able to rather quickly take on responsibility for some significant parts of some of the smaller projects (which still seemed huge to me). These early projects included trying to figure out how to measure the volume spectral reflectance of water in the lab and then figuring out how it might relate to water quality observed from photos taken by astronauts on the Skylab space station (see fig 3-1). Shortly after I was hired, Calspan started to slowly shrink with lay-offs hitting anyone without projects to charge their time to (no matter how senior or how capable). I realized I needed to learn how to win my own projects. Walker, my section head at the time, told me I could write some proposals to get some experience. After putting in some nights and weekends I managed to win a couple small contracts, keep the sponsors happy, grow the contracts and then win some bigger ones based on the early successes. Through both my own projects and by working for Piech and Walker I started to make business and government connections that would have long term consequences. For example, on Walker's Gypsy moth work I met Darrel Williams from NASA who was doing his Ph.D. on remote sensing of Gypsy moth defoliation. I would go on to work for him on a number of Landsat projects. Many of the projects at Calspan set the stage for studies we would continue for decades at RIT. These "themes" that would continue and grow at RIT included:



3-1. Laboratory device for measuring the volume spectral reflectance (VSR) of water. The cell and sensor would be submerged in a fish tank full of the water to be measured.

Water quality: This started with my work on Piech's IFYGL project to use aerial photography informed by field measurements to study Lake Ontario water quality. The work continued when Piech won a NASA grant to study water quality using photos from the Skylab space station (a precursor to the International Space Station). Later, I leveraged some of my work for the New York State Energy Research and Development Authority (NYSERDA) to win a multiyear grant to study the impact of power plant cooling water discharges on receiving waters using a combination of aerial thermal and visible imagery (this was also my Ph.D. see Schott1979 and fig. 3-2). This led to NYSERDA funding for another multiyear study on the use of aerial photography to study the impact of acid rain on aquatic and terrestrial ecosystems. When I retired, after more than 35 years at RIT, we were still doing water quality research.



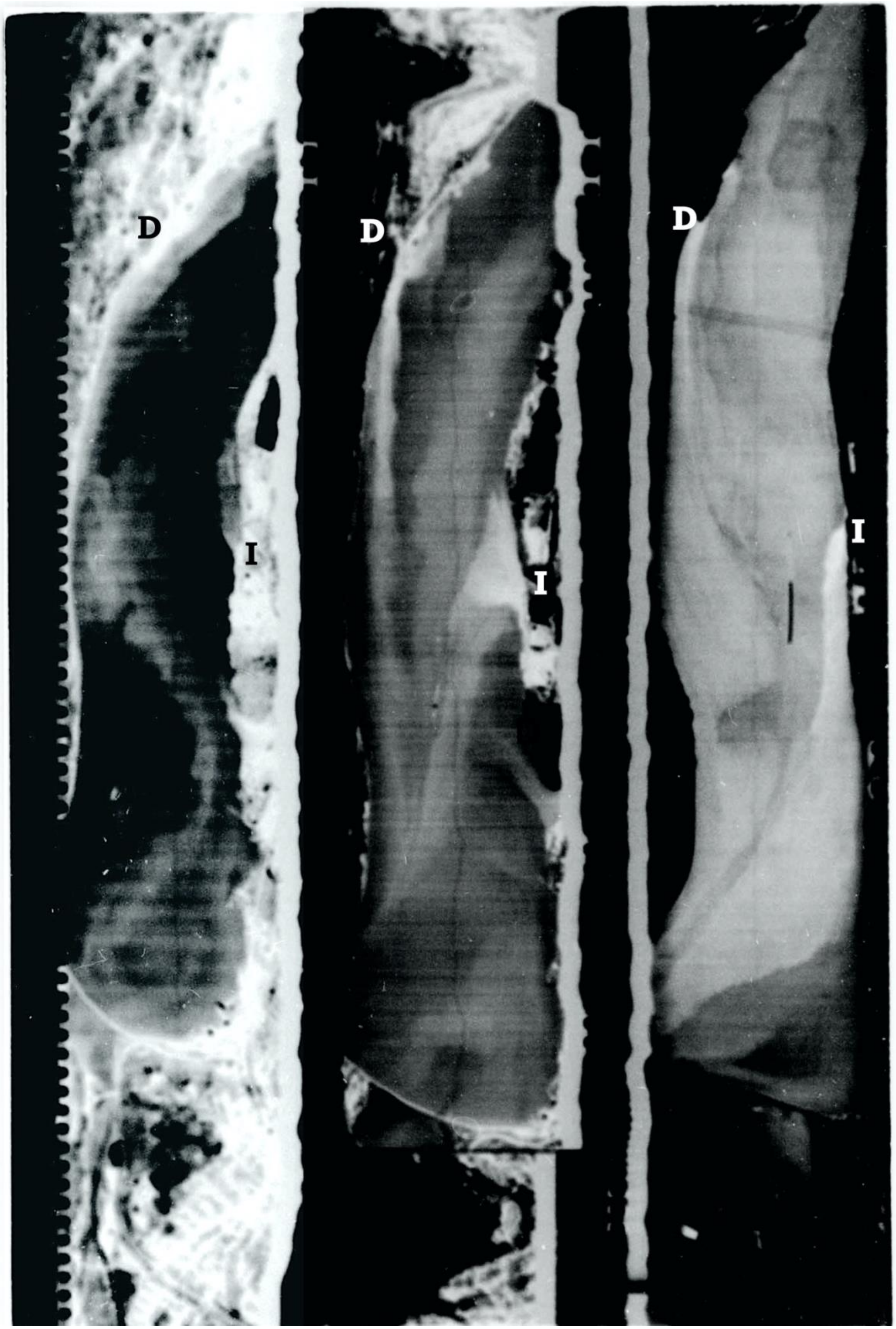
WATER QUALITY BY PATENTED AERIAL SURVEY TECHNIQUES

CLASSIC COLOR AERIAL PHOTOGRAPHY AND THERMAL SCANNER IMAGERY, WHEN CALIBRATED AND ANALYZED BY ADVANCED TECHNOLOGY, RESULTS IN ACCURATE WATER QUALITY MAPPING. ABSOLUTE WATER SURFACE TEMPERATURES TO ±1°F, RELATIVE WATER SURFACE TEMPERATURES TO 0.4°F, ABSOLUTE AND RELATIVE CONCENTRATIONS OF CERTAIN POLLUTANTS CAN ALSO BE MAPPED.

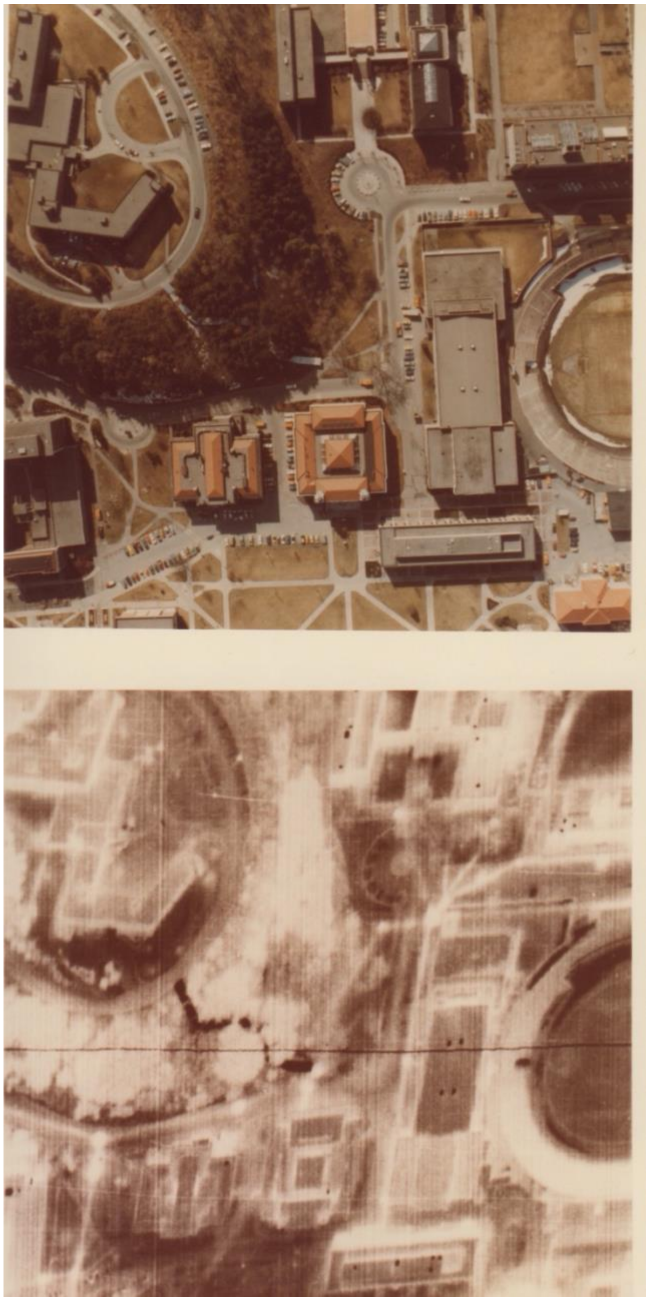
Thermal Image Courtesy of New York State Atomic and Space Development Authority

3-2. Calspan public relation chart showing off color and thermal infrared aerial images and derived water quality and temperature maps. Note how water quality can now be attributed to multiple sources.

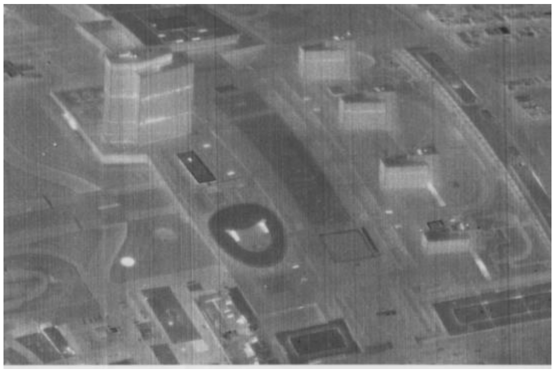
Thermal Infrared sensing: There wasn't much access to remotely sensed thermal data in the 1970s with only a few sensors flying and few civil applications demonstrated. Having received a scanner that Calspan had largely abandoned, I started trying to figure out how to calibrate it to get repeatable temperature measurements. Once the instrument was calibrated, we developed a way to compensate the calibrated measurements for atmospheric effects in order to map true water surface temperatures. This was done with a trickle of funds from NYSERDA. They then funded a more serious study to perfect and demonstrate the calibration/atmospheric compensation methodology (this was my Masters thesis, see Schott 1978). NYSERDA followed this with funding to geometrically correct the thermal images to enable accurate spatial mapping of the surface temperature of cooling water discharges for all of the nuclear and fossil fueled power plants in New York State (see fig. 3-3). We repeated these surveys over several years.



3-3. Aerial thermal infrared images of a portion of the Hudson River at three points in the tidal cycle: flood tide (left), near slack tide (center) and ebb tide (right). The plumes from the Danskammer power plant (D) on the west shore and Indian Point (I) on the east shore can be seen to change dramatically with tidal conditions.



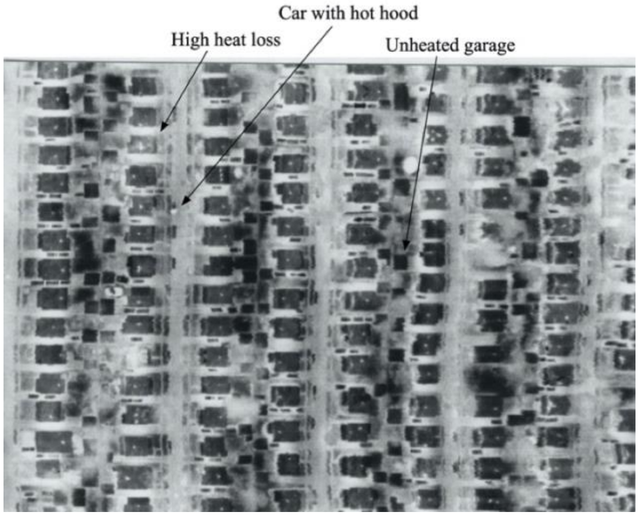
3-4. Day time color and night time thermal infrared aerial images of a portion of the Syracuse University Campus (before the dome installed at football stadium). Note the linear white features in the thermal image (bottom) often with white dots that don’t correlate with patterns on the visible image. These are buried steam distribution lines and manhole covers showing significant heat loss.



3-5. Winter night time thermal infrared image of Rockefeller Plaza in Albany, NY showing a slant view of the Arts Center (locally, the Egg). Note the two mechanical floors in the tower and one each in the agency buildings showing much higher heat loss and how the heated theater section of the Egg shows up dramatically through the roof along with the two roof top ventilators.

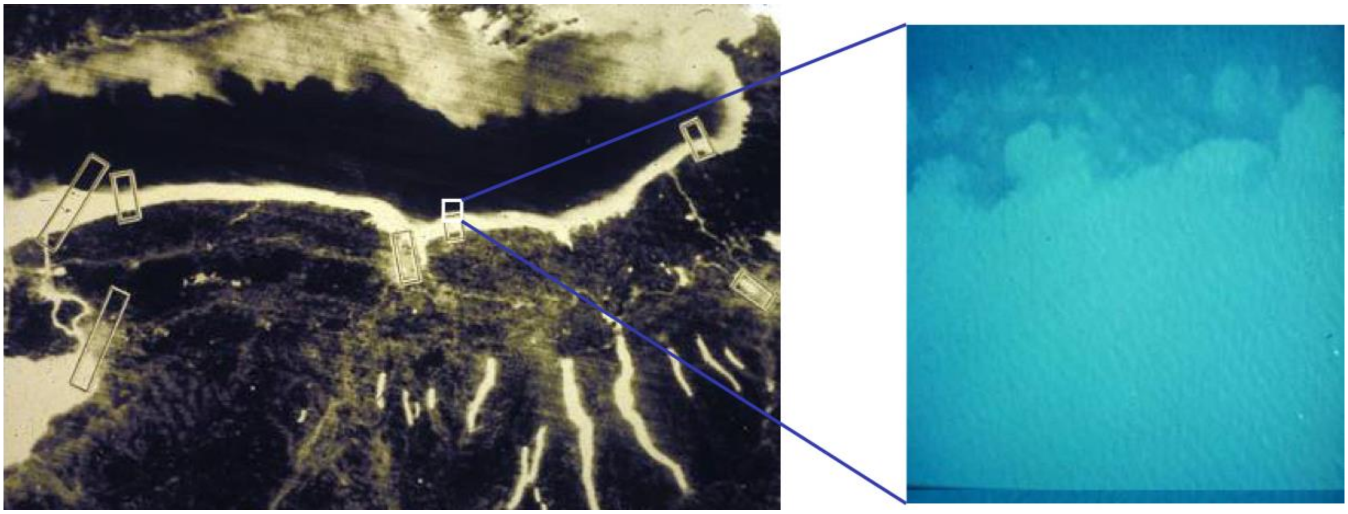
Having a healthy, well calibrated thermal infrared imager let us win some programs to develop and demonstrate the potential to use airborne thermal infrared imagery to detect, and eventually quantify, heat loss as part of energy conservation studies (see fig. 3-4). This work was initially done for NYSERDA to study rooftop and buried steam lines at a number of state hospitals, prisons and universities (see fig. 3-5). Then after we improved the resolution of the infrared scanner the US Department of Energy (DoE) and NYSERDA jointly funded programs to demonstrate the potential to map heat loss from residential buildings on cold winter nights (see fig. 3-6 , and fig. 3-7). Along the way I managed a major success by leveraging our thermal expertise to win a NASA grant to be an investigator on the Heat Capacity Mapping Mission (HCMM). We were tasked with flying under HCMM and validating the on-orbit radiometric calibration of this early space-based thermal imager. We also assessed the utility of the HCMM data for studying the thermal bar on the Great Lakes (see fig. 3-8). Curiously, none of the other Calspan investigators got involved with thermal sensing, so for my time there I owned that field and it would remain a focus for my entire career.

Instrument Calibration and Atmospheric Compensation: When I started at Calspan Piech and Walker had just come up with an early method to calculate the reflectance of a target on the



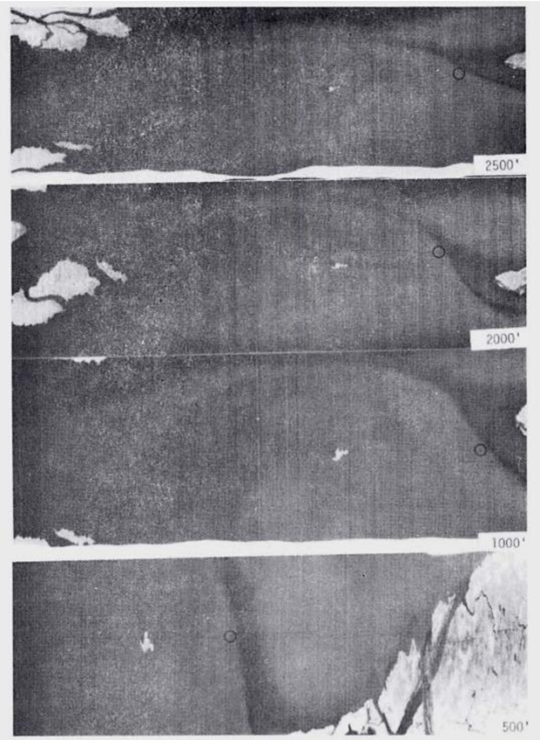
3-6. Winter night time aerial infrared images of a residential neighborhood used to assess heat loss (white is hot).

3-7. Liz Wilkinson of Calspan who collaborated with Schott on a number of projects taking measurements as part of a community heat loss dissemination project using a Calspan developed heat loss quantification assessment apparatus.

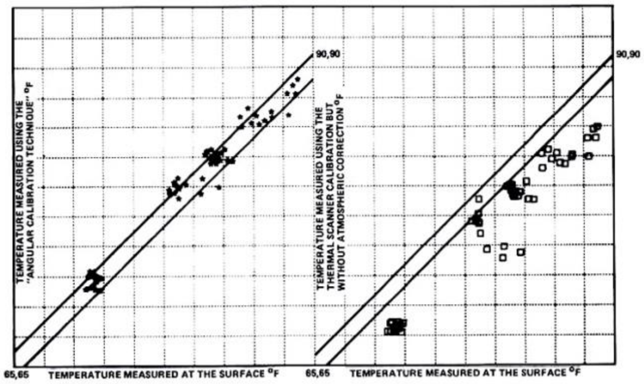


3-8. Thermal infrared HCMM image of Lake Ontario and the Finger Lakes (left) showing the spring thermal bar of warm (brighter) near shore water and rectangles illustration the coverage area of the aerial under flights. Right: true color aerial image at the edge of the thermal bar showing turbid water in shore of the bar and clearer mid lake water beyond the bar.

ground from the optical density of an aerial image of that target (see Piech and Walker 1974). Over my first couple of years at Calspan much of my time was spent perfecting and demonstrating that technique. This involved calibrating the film to enable relative exposure to be computed from the optical density of the film and then compensating for atmospheric and illumination effects to convert exposure values to surface reflectance values. This is a critical step in generating measurements that helped to transform remote sensing from photo interpretation to an objective repeatable quantitative science. Seeing early the power of this new way of looking at remote sensing as a quantifiable science motivated me to look for similar approaches as I began to learn about thermal imaging when Gallagher and I started tinkering with the lab's thermal infrared line scanner. This was an airborne electro-optical imager that had a single cryogenically cooled detector used to opto-mechanically scan the ground to build up an electronic signal to modulate a light source that was similarly used to opto-mechanically scan a



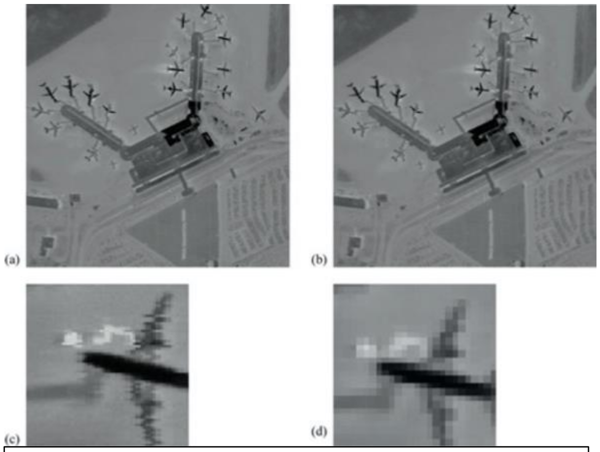
3-9. A series of four thermal infrared images taken over the same spot (circle) at different altitudes only minutes apart can be used to study the effects of the atmosphere and remove them from the aerial thermograms.



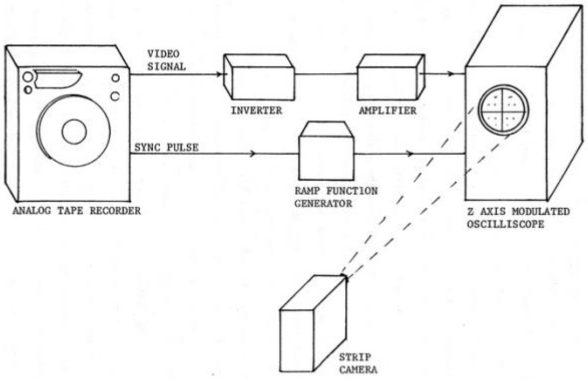
3-10. Plot of water surface temperature measured by a boat for a number of locations and times plotted against the temperature predicted from the simultaneously acquired aerial thermal imagery after atmospheric compensation (left) and without atmospheric compensation (right).

photographic negative and form an image. The optical density of these thermal images was related to the thermal radiance reaching the sensor from the objects on the ground. The calibration of the scanner involved careful laboratory procedures to characterize the instrument, in flight procedures to capture the response of the detector and the recording system and the implementation of analysis procedures to convert the optical density to sensor reaching radiance or apparent temperature. Then in order to relate the sensor reaching radiance to the ground leaving radiance and ultimately the surface temperature, it is necessary to compensate for the effects of the atmosphere as the radiance propagates to the sensor. We came up with an atmospheric compensation technique that eliminated the need for a simultaneous ground collection program, that was the norm at the time, making quantitative aerial thermal imaging more practical and stimulating more thermal imaging work (see fig. 3-9, and fig. 3-10). This success was particularly instrumental in helping convince NASA to fund us to support the under-flights of the HCMM instrument to assess its calibration. The HCMM work was also the precursor to decades of work at RIT calibrating the NASA/USGS Landsat satellites.

Instrument Science: It was common practice at Calspan to build things; from wind tunnels, to modified aircraft, to crash test dummies. So, not surprisingly, I found myself building instruments for measuring the reflectance of water, the emissivity of natural surfaces and the reflectance of samples in the field. Most importantly having taken ownership of Calspan's infrared line scanner and winning a number of programs that depended on it, it became my responsibility to keep it up to the state of the art. This meant that after a few years I needed to figure out a way to improve its spatial resolution without sacrificing its radiometric sensitivity (see fig. 3-11). To achieve this, I also had to develop a way to record the images and the platform orientation so the images could be written out later (see fig. 3-12, and fig. 3-13) in a more controlled georectified fashion (or later digitized). This meant I had to learn more about optics, radiometry, electronics, signal processing, geometric correction, signal to noise etc. In the end we had a souped-up line scanner that met all our requirements and I set myself up well for working instrument science issues on a number of future programs. In particular, I think it made me more ready to quickly embrace the transition



3-11.Thermal infrared image of Buffalo airport acquired with Calspan's improved infrared scanner (left) and what it would have been before improvements (right) with zooms of one aircraft and support (fueling) equipment showing how much more detail can be seen of the fueling process.

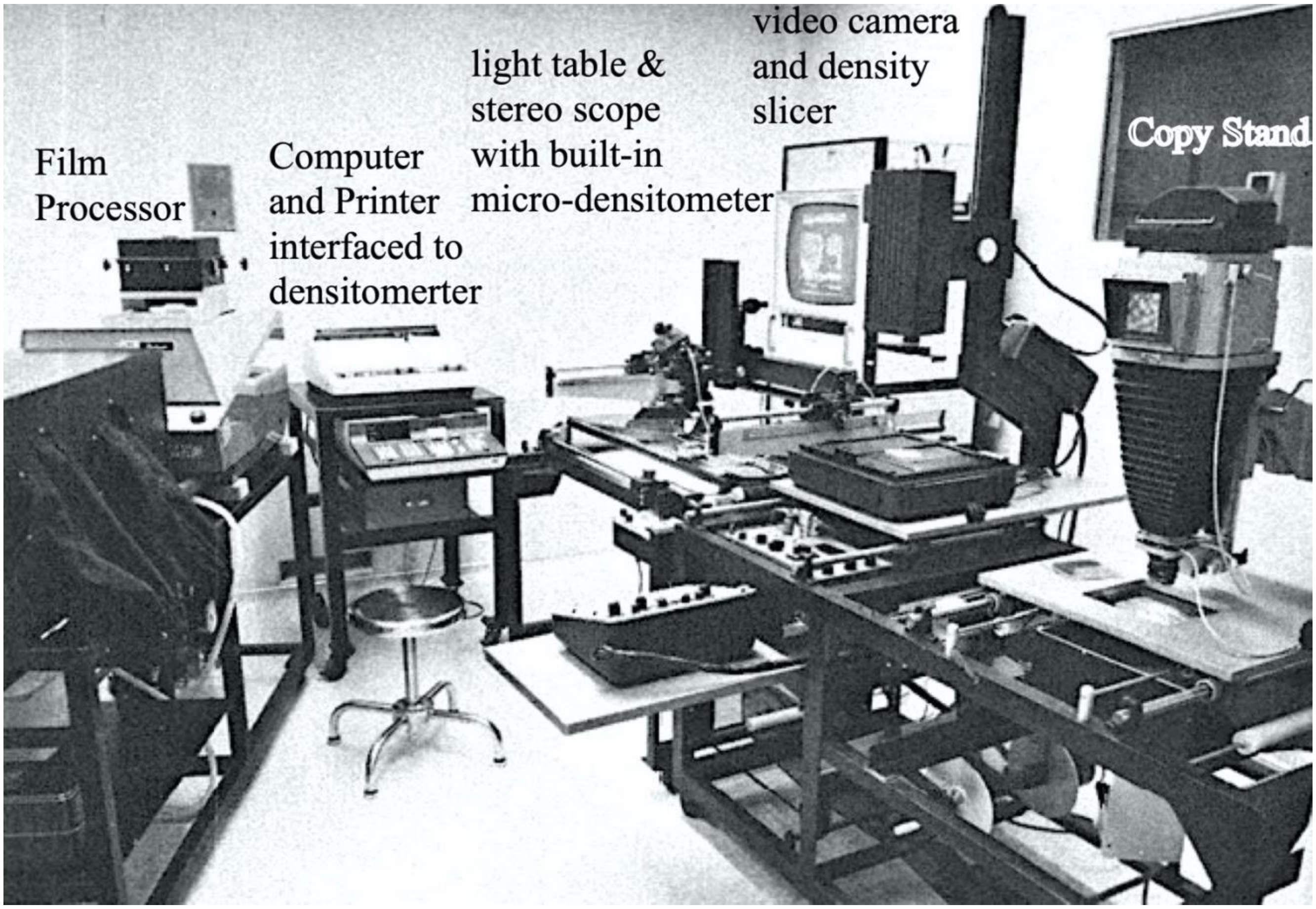


3-12.Illustration of how analog tape-recorded data from the line scanner was used to drive the intensity of a line across the Z axis modulated oscilloscope which is imaged by the strip camera. The strip camera images line after line of data building up the 2-dimensional image.

3-13.Gallagher (left) and Schott (right) with the tape recorder and film writing system. Note the oscilloscope viewer has a flip mirror to send the signal to the strip camera above and the conventional oscilloscope (top) is used to set up the Z axis (i.e. intensity) modulated oscilloscope.

to digital sensing and digital image processing that was just around the corner. I thought of a remotely sensed image at this point not just as a photograph but rather it could take on many electronic or digital forms.

Dual-use: Dual-use is a term used to describe products, technologies or instruments that can be used for both civilian and military purposes (civil and defense/intelligence as used here). For example, ammonium nitrate which has been used as an explosive and in fertilizer since the second world war. This could be described as a dual-use product. Remote sensing is clearly a dual-use technology, and the aerial and satellite sensors it uses are dual-use instruments. I was exposed to both sides of dual use at Calspan working for a range of civil agencies as well as defense/intelligence agencies. In fact, one of Calspan's biggest programs during my time there was to design and build a photo interpretation console for the Air Force (see fig. 3-14 and Piech et al. 1977). We built a duplicate at Calspan to enable us to continue to develop and deliver theoretical and software image exploitation tools for the defense/intelligence community. Much of my work on my civil programs used this same console. Most of the console moved with me to RIT though its utility quickly diminished as we moved to electronic and digital systems. At Calspan we were often tool builders. For example, we developed some of the earliest methods to atmospherically compensate aerial images. These tools were immediately put to use by both the civil and defense/intelligence communities. This focus on the science of remote sensing and the building of analytical tools to advance that science (rather than just applications to forestry or weapons targeting for example) meant that much of our work at Calspan and what followed at RIT was of use to both dual-use communities and as a result we worked extensively with both communities.



3-14.Labeled photo of the quantitative photo interpretation console Calspan built for the Airforce.

4. The RIT Environment

In December, 1980 when I started at RIT it was a pretty big place; about 12,000 students maybe 1,000 of them graduate students. These graduate students were mostly in part-time evening programs designed to serve local industry in 8 or 9 colleges. It looked a lot like a major university but without Ph.D. programs or research. In a lot of ways, it was poised to take a big step. In a lot of ways, it was not. The faculty were by and large not interested in making the change to a research university, the infrastructure (grants and contract office, graduate programs office, financial offices) was not in place, and most of the board of trustees thought RIT's primary function was to provide entry level employees for the thriving local industries. Things were not much better within the Photo Science department. While some of the faculty expressed interest in expanding to a Ph.D. program, half did not have Ph.D.s. There was essentially no research going on and almost no specialized research grade equipment. On the other hand, there were very well-equipped teaching labs for learning every aspect of photographic systems. At least for the next several years photographic systems would remain a mainstay of the remote sensing enterprise. In addition, the head of the Photo School (Dr. Russel Kraus), that Photo Science was part of, was very supportive of getting research started and of the potential move to a Ph.D. I would eventually learn the then brand-new president (Dr. M. Richard Rose) was at least not hostile to the idea and would eventually embrace it. Clearly if we were going to move forward, we would have to make some friends/supporters in a hurry.

The limitations of the infrastructure soon became glaringly apparent. A month or two after I started I went to Dr. Ron Francis, my department head, to find out how to book a trip to Washington, DC. I needed to start some business development activity to try and begin to let potential sponsors know RIT was in the remote sensing research business and would be looking for funding opportunities. I knew that submitting "cold" unsolicited proposals or competing without prior contacts for solicited proposals was unlikely to be very fruitful because RIT had no research history and no reputation in the remote sensing field. Francis encouraged me to try and take the trip but informed me the department's total travel budget was only a few hundred dollars and it was spent in the first half of the year (this was January and the fiscal year started July 1). I went to see Dr. Russell Kraus, head of the Photo School, who said he would find a couple hundred dollars to fund the trip I had already booked but indicated he also had limited discretionary funds. When I started asking about bid and proposal (B&P), internal research and development (IR&D), and capital equipment budgets (all things I was familiar with from Calspan), he told me such things didn't exist but he would try to help me when I got back from Washington.

Kraus was as good as his word. Shortly after I returned, he got an appointment for me to meet with the vice president for finance, Mr. Bill Dempsey. This bypassed several layers of management (most obviously the dean and the provost) who Kraus indicated would not be able to help. I don't remember thinking how unlikely it would be for that meeting to be successful. I was a 29 year old kid who had been working at RIT for only a couple of months, and I wanted to put in place a whole new business model. I had the very naïve perspective that I wasn't really asking for anything. So, I met with Vice President Dempsey and explained that I had been hired to start a research program and that to do that I needed to spend time and money marketing and selling proposals (B&P budget), getting us smart enough in new areas to write winning proposals (IR&D budget), and buying or building research-grade equipment (capital equipment budget). As he started to usher me out the door, I went on to point out that I had just brought into RIT about $50,000 in contract money all carrying full overhead (subcontracts from my Calspan contracts). While RIT had an incredibly low overhead based on what I was used to in industry and even low compared to other universities, this still represented about $10,000 in overhead monies. It seems like nothing today but at the time most external funding at RIT carried little or no overhead. They were typically more gift/grants than quid pro quo research/contracts. I told Vice President Dempsey it was my intent to continue to grow the number and size of contracts but I couldn’t begin to do this under the current finance system. I told him in my experience research overhead was collected for the purpose of supporting all the things I needed to have funded. I didn’t want any new funding lines but only the overhead returned so we could keep the research funding coming in. Mr. Dempsey took a totally different attitude and we quickly negotiated a deal where half the overhead generated on research programs would be returned to support future research grant development. While this was half of what I had asked for it was sufficient to allow us to move forward. From Mr. Dempsey’s perspective he walked away with $5,000 and a potential new revenue stream. He also became very interested in the research we were doing and became a long-term friend and supporter of the DIRS lab. This overhead recovery system became the start of the overhead recovery plan still in place in some form today. We had made a critical new friend.

Up to this point I have largely told my personal story and chose to do so in the first person. For the next nearly twenty years I would remain the only remote sensor on the faculty. However, there would be a host of others on the DIRS staff who would make the place function. I have therefore chosen to tell the rest of the story in the third person. I don’t claim that the story becomes any more objective from this point but perhaps easier to follow and certainly easier to add to if someone chooses to continue the story at some point in the future.

5. Getting Started 1980-1985

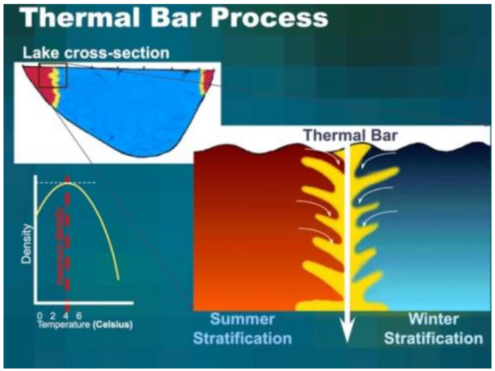
Looking back, the first five years were a mad scramble to understand RIT and to get a working research environment established. When Schott started on December 1, 1980, it was after RIT's winter quarter had started so he had until late February to prepare for his first course in the spring quarter. He would teach a one-quarter graduate course in Remote Sensing that quickly grew to a full-year course over the next couple of years. He also, for most of his career, taught a required undergraduate course in radiometry that let him meet all the undergraduates and encourage the best and brightest (not always the same) to consider graduate work in Remote Sensing. He was very lucky in his first couple of weeks at RIT to meet a young man (young is very relative here, he was maybe 4 or 5 years younger than Schott) who would become his first full-time graduate student/employee (Mr. Joe Biegel). Biegel had finished his B.S./M.S course work and was hanging around the department helping out as a teaching assistant looking for a research project for his M.S. thesis that didn't involve photo-chemistry (the only topic with any hope of funding that year). To say it was kismet would not be far off. As much as Biegel needed to learn to do research, Schott needed extra hands, insight into the inner workings of the photo school and eventually a great friend. Biegel went right to work on a project Schott had brought from Calspan to develop quantitative measures of building heat loss in the winter using night time thermal infrared aerial images acquired with Calspan's (later RIT's) infrared line scanner. The film writing and analytical part of this work was mostly taking place at Calspan in Buffalo where Schott still lived until September, 1981. Biegel moved into Schott's attic that spring and summer and threw himself into the work. Biegel quickly became invaluable and worked on numerous projects over the next several years (see fig. 5-1). He also worked for the department as an instructor in statistics. During that early period, they worked to finish the projects Schott had ongoing at Calspan and to move much of his equipment to RIT. Most of this equipment was somewhat dated and all of it analog in a world that would soon be transitioning to digital. Nonetheless, most remote sensing was still being done using film and it gave them a great start. All the equipment was set up in a lab that had once been the high-speed photography lab. The walls still had splatter from eggs, bananas, and tomatoes that were photographed as bullets pieced them. The photo building was very crowded and space would be at a premium for the next decade. Schott eventually moved his office into the storeroom off the lab in order to turn his office over to the growing research staff.

5-1. Joe Biegel in Remote Sensing Lab with computer monitors and Gould DeAnza Displays.

5-2. Bob Desmond at Industrial Associates meeting.

During that first year Schott wrote a number of proposals to try to get research work started and made what would turn out to be a very valuable connection at the recently formed RIT Research Corporation. Dr. Robert Desmond (see fig. 5-2) was in

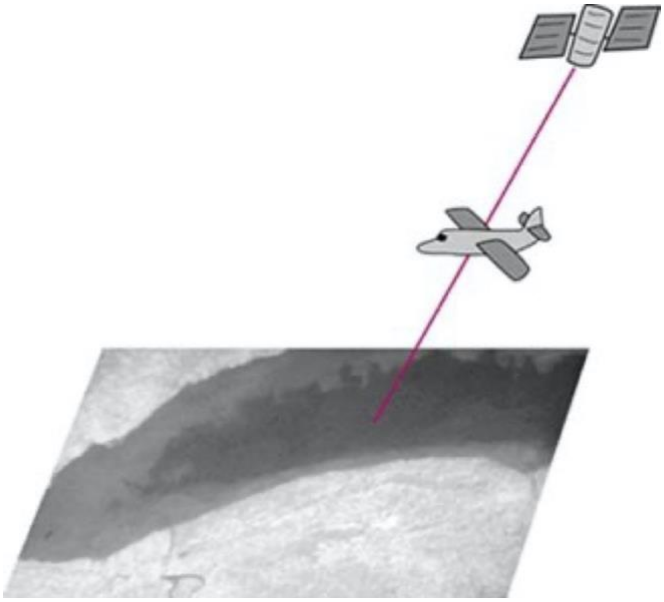
5-3. Calspan’s Aztec C aircraft.



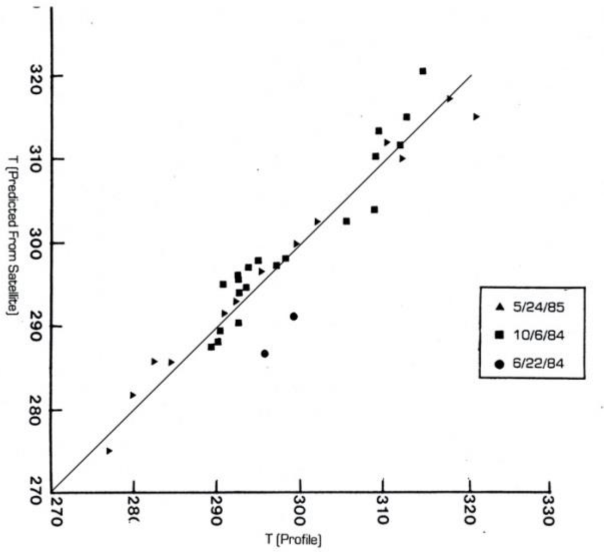
5-4. Illustration of the thermal bar in a large lake. The cross section shows the warm in-shore water in red in summer stratification with warm water on top, the cold mid-lake water in blue in winter stratification with the cold water on top, and the thermal bar in yellow where the hot and cold meet at the surface and the 4˚ C water of maximum density sinks to the bottom forming the thermal bar preventing the pollutant rich in-shore water from mixing in the deep lake waters.

the process of taking over the nascent RIT Research Corporation (RITRC). RITRC was formed in 1980 as a for-profit corporation to promote research by taking advantage of the intellectual resources on campus. Desmond had been Head of the Mechanical Engineering department which had been responsible for a prototype energy efficient demonstration house which was a showcase for RITRC. Desmond and Schott had very parallel goals. Desmond needed to build the tiny RITRC into something viable (profitable). Schott was a one man show trying to build a viable research group. Desmond soon realized Schott had one of the few marketable research operations on campus. Schott wanted to maintain his independence and not for profit status but saw some advantages in running some of his work through RITRC. So they struck a deal that if RITRC brought work to Schott, he would run the contract through them (sub-contracted to RIT). In addition, it soon became clear that he couldn’t cost effectively bid small flight programs through the Institute. Calspan would continue to fly its specially configured Aztec (see fig. 5-3) for RIT for over a decade. They then made arrangements to sell it to an upstate NY company DIRS suggested who would continue to provide flight support to RIT. However, many things could go wrong on a flight program and Schott estimated maybe 1 in 5 flights might need to be re-flown. In a business with a financial buffer he could bid flight costs at 125% of expected costs on firm fixed-price contracts and be comfortable he could cover any collection failures. With no “bank” he had to bid 200% of expected costs to cover potential failures which made costs too high. So, he agreed to run all small (a few thousand to $20k) flight programs through RITRC at 125% of expected flight cost if they would cover any needed re-flights in return for the increased profits. Schott ended up focusing most of his program development on major aerospace contractors and government agencies. RITRC tended to focus its marketing on local industry where Schott had no connections and didn’t see a long-term future. As a result, in the first few years Schott did a number of small projects with or through RITRC and Schott and Desmond became close friends. In the late 1980’s Desmond, after leaving RITRC, would head Schott’s academic group (The Center for Imaging Science, CIS) for a year, the following year he served as Dean of the College and later still as Associate Provost. In all these roles he supported the growth of the Remote Sensing programs as well as CIS.

A major step toward firmly establishing a remote sensing group came within a year of Schott’s joining RIT when he was named an investigator on NASA’s Landsat Image Data Quality Assessment (LIDQA) program. This small group of investigators from government (only 10 non-government), industry, and academia became in effect the Landsat Sciences Team for the Landsat 4 and Landsat 5 satellites. This was a major accomplishment both financially and in terms of the visibility and credibility it brought to Schott and RIT. It was one of the first opportunities to join a premier satellite science team with all the major players from across the country and around the world competing, with Schott being among the successful half dozen from academia. Schott’s proposal heavily leveraged his success under flying the HCMM satellite while at Calspan and his work with Piech while at Calspan studying Lake Ontario. It focused on the thermal bar, a ring of warm water that forms around the shore of large lakes for many weeks in the spring preventing pollution rich spring runoff from being rapidly diluted in the deep mid-lake waters (see fig. 5-4). Schott would continue to study water quality and the thermal bar for



5-5. Illustration of under-flight concept: with Aztec aircraft under-flying Landsat over the thermal bar in Lake Ontario.



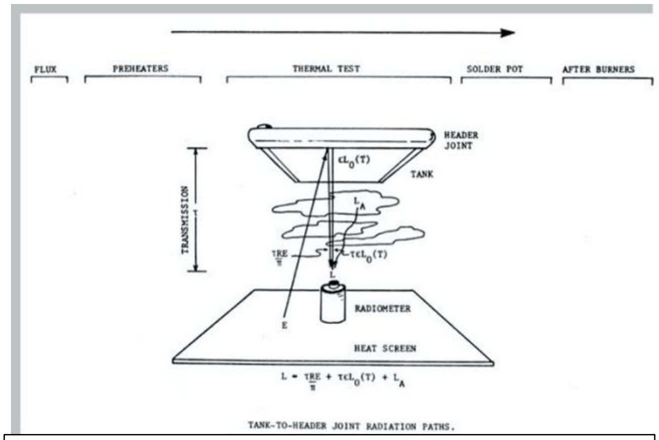
5-6. Plot of predicted radiant temperature at the Landsat 5 space craft based on three under-flight data sets (T(profile)) versus the measured radiant temperature at the satellite showing the satellite in good calibration shortly after launch.

5-7. Landsat 5, May 11, 1992: true color image of Lake Ontario (left) showing the turbid near-shore water in shore of the thermal bar (clouds top right in image) and thermal infrared image showing the warm (bright) waters ringing the lake in-shore of the thermal bar. Note, how the much shallower Lake Erie has already almost completely gone into summer stratification.

most of his career. This multi-year contract to assess the calibration of the thermal band on the new Thematic Mapper (TM) instruments (see fig. 5-5, fig. 5-6 and Schott and Volchok 1985) and to study the thermal bar in Lake Ontario using the added bands on TM would be the cornerstone of the remote sensing research program for the next four years (see fig. 5-7 and Schott 1985). It also thrust RIT's upstart remote sensing program onto the national stage alongside scientists from leading remote sensing academic programs (Purdue, Arizona, Georgia), as well as, from leading national industries (ERIM, Earth Sat, Hughes SBRC, Battelle) and national labs (NASA Goddard, JPL, Ames, and Johnson, USGS

5-8. Spray chopper before taking off to mark ice on Lake Erie. Note: red stain from test spray under spray rig.

5-9. Image taken out window of Aztec aircraft while photographing Lake Erie ice.

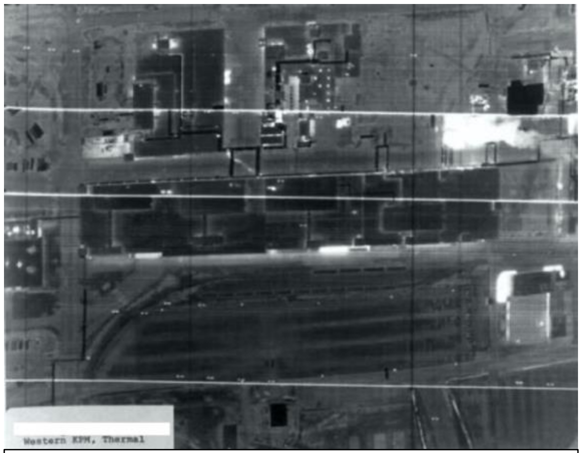


5-10. Illustration of test setup used to measure the radiator tank to header joint on assembly line.

5-11. John Schott (left) and Amit Ghosh looking at echocardiogram image on DeAnza display.

and USDA). This one program did not by any means make RIT a player but it made it clear they might be waiting in the wings.

This same year Schott won a few small grants. One, for NYS Sea Grant, to study the dynamics of the ice on Lake Erie involved flying a helicopter with a crop-dusting spray rig to put environmentally safe red stains on the ice (see fig. 5-8). This ice would then be photographed over time from high enough altitude that the aircraft location could be tied down from shore points (pre-GPS). This approach turned out to be a total failure (any slight melting or snow fall and the red “x’s” disappeared). Luckily it turned out the ice itself generated enough structure (pressure ridges) that common points could be located and tracked from day to day (see fig. 5-9). Another early study is indicative of what Schott would end up describing as the going into business sale. This was brought to Schott by RITRC and involved a Mobile chemical division that extruded products (e.g. coffee cups) from a moving web of Styrofoam that had to be kept within a narrow temperature range to operate successfully. The study involved adapting remote sensing thermal imaging equipment to monitor the moving web and demonstrate that infrared imaging could be used to monitor and control the production. Interesting engineering but not the overhead imaging research that was the group’s goal. Nonetheless, the group would take on a number of these tasks in the first few years to pay the bills and raise the funds to buy the digital image processing equipment they needed to help lead the transition to the digital age. Some of the other “going into business” projects included studies of image quality from electro-photographic systems, demonstration of the use of half-tone generation on a photo-typesetter, use of thermal imaging systems to control solder joints on automobile radiators (see fig. 5-10) and multiyear studies for the National Institute of Health (NIH) aimed at 3-D reconstruction of the heart from echocardiograms (this was a joint study with RIT mechanical engineering and the University of Birmingham Heart Center) (see fig. 5-11). In particular, these studies enabled Schott to first add technical staff and later pay for critical equipment as the digital age dawned.



5-12. Thermal aerial image of Kodak Park site acquired as part of heat loss study.

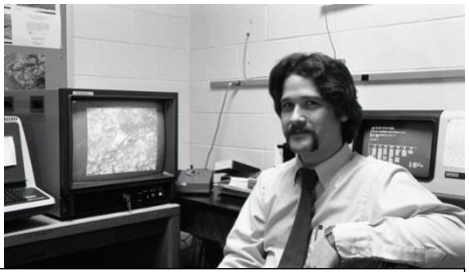
5-13. Single frame from thermal video images taken from helicopter of power lines.

The first two technical staff hired were Tim Gallagher (1981) as a fulltime technician to maintain, build, and operate hardware and Ned Schimminger (1981), to develop software and help with data analysis. Both had worked with Schott at Calspan and could hit the ground running. Gallagher, in particular, knew all the equipment Schott had brought from Calspan and had helped build much of the specialty equipment. This was the start of what would grow to quite a large staff supported by research grants and contracts.

5-14. Schott with bank of image processing displays in background showing a number of different images of Lake Ontario.

Along with the "going into business" contracts, a number of small aerial remote sensing projects were awarded during these first few years. These included a heat-loss study for Syracuse University of their buried steam line system (a follow-on from earlier Calspan work) and a heat-loss study for Eastman Kodak of their Rochester manufacturing facilities (see fig. 5-12). Another study for Rochester Gas and Electric involved thermal infrared studies of high voltage power lines using a helicopter-based video thermal imaging system (see fig. 5-13) to look for high resistance points in the lines. All of these took advantage of the rather unique thermal sensing instrumentation Schott had brought from Calspan (and added to at RIT) and his agreements with RITRC to backup any aerial collection failures. In practice failures were increasingly rare and RITRC did quite well on the deal as did Calspan which continued to provide flight support for all the fixed wing aerial collections (these used Calspan's specially modified twin engine Aztec C aircraft with a large hole in the belly). Calspan, though out of the remote sensing business, remained very much in the flight research business and would provide flight support to RIT for some years.

During this period of the early 1980's it was becoming obvious that the imaging world was turning from analog to digital. The remote sensing group was rapidly investing in computers and early digital image display systems and by the mid-eighties they were investing large sums in digital image array processors and display systems. This push to digital was motivated early on by the NASA Landsat project. The only way to get truly quantitative data from the Landsat sensor was to get digital data on magnetic tapes (in the early days one 1600 bit per inch (bpi) tape per band for each of the seven spectral bands). These tapes were then loaded onto a large magnetic tape-player and the image transferred to a general-purpose computer. A 512x512 pixel subset of the image (6000x6000 pixels for a Landsat TM image) could then be transferred to the display buffer of an array processor. It could then be read out at video rates to drive a cathode ray tube (i.e. a TV monitor, see fig. 5-14). Recall that computer displays still only had alpha-numeric displays at this time (see fig. 5-15). In the early eighties Schott had invested essentially all of his overhead recovery money, as well as some contract funds, into acquiring a Gould

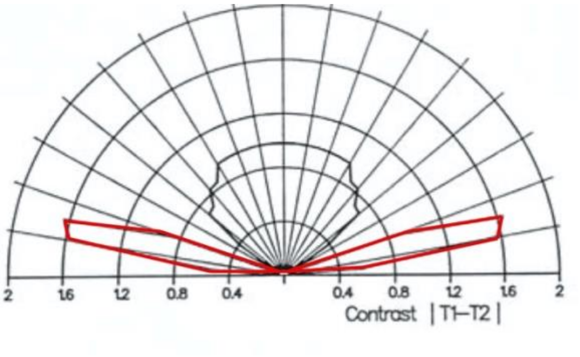


5-15. Schott (1984) in the Image Processing Lab with an image processing display left and a conventional alpha-numeric computer display right.

5-16. DIRS staff and students in lab celebrating the new image processing equipment (~1985). Seated: Tim Gallagher, Jeff Pelz, Rolando Raqueño. Standing: Carolyn Kitchen, Wendy Rosenblum, Joe Biegel, Gene Kraus, John Francis and John Schott.

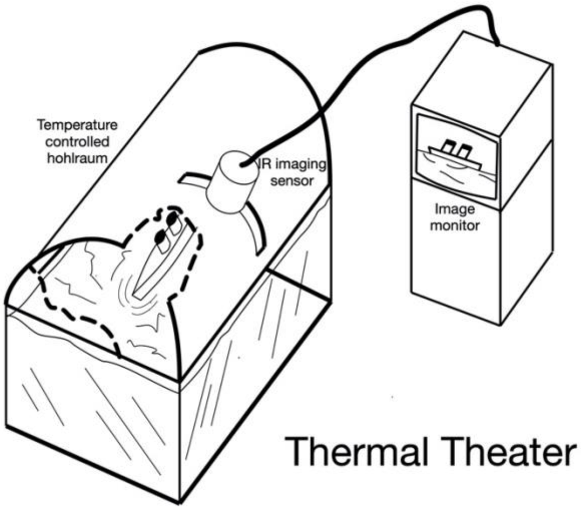
DeAnza Image Array Processor (see fig. 5-16). In order to justify this purchase and to pay for the additional computers and processors that would be needed over time, the research group would take on a number of image processing tasks as part of the “going into business sale” (e.g. the echocardiogram reconstruction project for NIH).

About 1983 the Remote Sensing Lab, as they had been loosely calling themselves, decided they needed to formalize their identity. So much of the effort at this point was directed at learning and doing digital imaging that the Digital Imaging and Remote Sensing (DIRS, pronounced “deers”) Laboratory name was adopted. The exact date has been lost (as the lab dates itself to when Schott won the first contracts in 1981) but by 1984 it was showing up in memoranda and on reports and it has persisted for over 40 years.

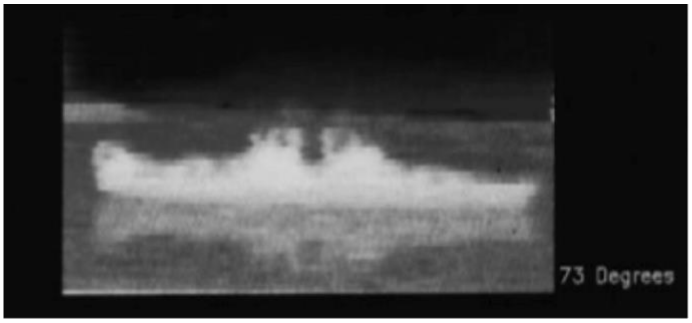


5-17. Illustration from a report to the Navy predicting the contrast between a ship and the sea showing a contrast reversal at about 30˚ and high reverse contrast (ship hot) at about 15˚ (red). Schott thought these “walking head” results grossly simplified the problem by ignoring ship to ship and ship to sea interactions.

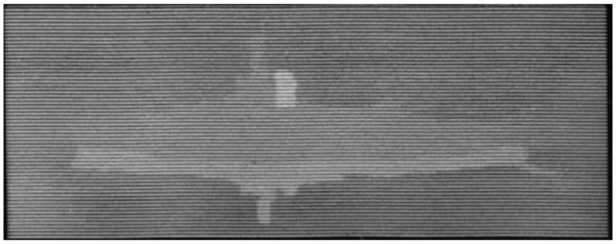
By the summer of 1983 Schott was convinced he needed to do more to extend his connections in Washington and sought and received a summer fellowship at the Naval Research Labs (NRL). His work focused on estimating the thermal infrared signature of ships at sea as viewed from space. He spent the summer at NRL on the banks of the Potomac writing some computer codes to propagate the signals to space through various atmospheres and look-angles for a range of ship surfaces and temperatures. A major input to this process was generated by Biegel at RIT who would do a range of Lowtran (later Modtran) runs to generate atmospheric transmission and path radiance values. Similar calculations for the radiance from the sea reaching space could be used to calculate the difference in observed signal between the ship and the sea or the contrast signature a future sensor might use for target detection (see fig. 5-17). The Navy was happy with the summer’s results, but Schott was not. He became convinced that modeling the ship’s deck and the sea as separate entities over simplified the problem and that the radiometric interactions of the ship with itself and the ship with the sea could dramatically alter the expected signatures. By the following year (1984/1985) Schott had convinced the Navy that more detailed studies were required to properly model the thermal infrared signatures of ships. This resulted in a sizable program that would extend over the next 6 years. It started with measuring the



5-18. Illustration of the thermal theater.



5-19. Thermal infrared image acquired with a thermal imaging camera looking at a model ship in the infrared theater. Note how the warm ship is strongly reflected in the water.



5-20. Early computer-generated image of a cool ship with a warm stack and the much warmer appearing reflection of the ship on the otherwise cold sea.

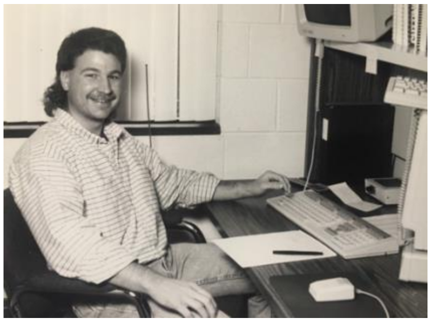
emissivity of ship materials. However, to do this devices needed to be designed and developed to measure the long-wave infrared emissivity of large surfaces (i.e. 10's of square inches). This was followed by development of methods to measure the emissivity of roughened water surfaces and to characterize the surface slope of roughened surfaces. Then an infrared theater was conceived and built. This consisted of physical models of ships in a fish tank with a cold sky produced using a hohlraum with chilled antifreeze circulating through it (see fig. 5-18). An infrared video imaging system could view the scene thus created through a range of view angles and under varying water, ship and sky temperatures (see fig. 5-19). While all this was going on it became clear that a computer model of these target/background environments was needed to extend Schott's summer fellowship studies to more realistic conditions. This was difficult using the limited computing and digital display tools readily available in the early eighties. but by the time the project wrapped up it had begun to focus on development of computer-generated synthetic image generation models (see fig. 5-20).

By the summer of 1985 DIRS had established itself as RIT's leading research laboratory. Research volume had grown from $13,000 in 1981 (Schott only at RIT for 7 months) to $164,000/year (that's nearly a half a million 2023 dollars) with an in-house backlog of over $200,000. Five students had already graduated with M.S. theses on Remote Sensing topics and over a dozen publications per year were being produced. Largely spurred by the success of DIRS, RIT formed its first joint academic/research center, reconstituting the Photographic Science and Instrumentation program (which had been renamed Imaging and Photographic Science) as the Center for Imaging Science reporting to the Dean of Graphic Arts and Photography. Also, along the way Schott went up for tenure. He had been granted two year's credit toward tenure when he was hired based on his experience at Calspan. When it came time for his tenure review, it was suggested to him that he might want to wait as his teaching was somewhat limited. In the Photo school it was common for faculty to teach as many as three courses a quarter. Schott typically taught one or at most two courses a quarter and bought himself out of the classroom with funding from grants/contracts (an unheard of concept at the time). Schott decided if he was going to be denied tenure for doing too much research, he would rather get it over with and move on. Luckily for Schott and DIRS the anti-research back lash in the tenure review committee was not as strong as some thought and he was granted tenure.

6. DIRS in Transition (1985 – 1990)

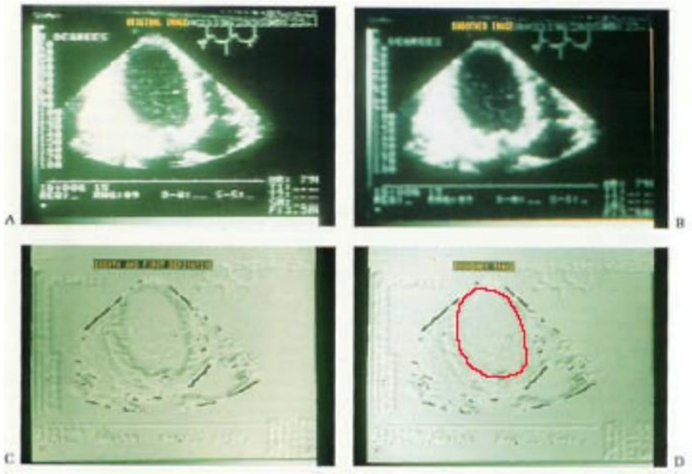
The next five years would bring huge changes to RIT and the Center for Imaging Science in particular, all of which would impact DIRS. Fund raising for, designing, and occupying a new building would change the physical environment. In parallel, designing, justifying, and pushing through the approvals for a Ph.D. in Imaging Science (RIT's first Ph.D.) would dramatically change the academic environment. DIRS, by far the largest research group in the Center, would play a major role in these changes. In keeping with these large changes, the DIRS group set itself a new goal of becoming a major player on the national stage. 1985 – 1986 saw some changes in DIRS personal. Joe Biegel, who as student, staff member, faculty member, colleague and friend had played an outsized role in getting DIRS started and the Center formed, took a job at Itek Corporation and finally finished his M.S. (in that order). Ned Schimminger, who had commuted from Buffalo throughout his time at RIT decided he had had enough of the Thruway and took a software position in Buffalo. Three new characters joined DIRS at about this time. All of whom would be with DIRS for many years. Steve Schultz came on as a software engineer and later systems administrator (see fig. 6-1). Steve was a Computer Science major with tremendous programing skills and would spend much of his time programming the Gould DeAnza image array processors and building up the DIRS computing environment. (At this point this was also the Center's computing environment as the Center had not yet invested in establishing computing infrastructure). Steve was a classic computer nerd, more interested in computers and computing, working strange hours and doing the impossible than taking courses and getting degrees. With encouragement, nagging and threats from Schott and others, he eventually finished his B.S. degree after about 10 years at DIRS and would go on to help start up Pictometry International and help build it into a major remote sensing corporation. Carl Salvaggio, as he completed his BS/MS in imaging with Schott, would transition to a full-time research staff member (see fig. 6-2). Carl would also stay with DIRS for a decade, leave for almost a decade to work on remote sensing in Washington, D.C. and then return as a faculty member in 2002. Also, in 1985 Schott received a call from the head of the computer science department looking for funding for a computer science graduate student. The student, Rolando Raqueño, had some experience programming the Gould DeAnza array processors that were critical to the DIRS image processing work (see fig. 6-3). Raqueño ended up doing his M.S. computer science degree on Schott's echocardiogram program (see fig. 6-4, fig. 6-5, and fig. 6-6 and Schott et al. 1987) and transitioning to the DIRS research staff where he continued on and off for many decades. Both Salvaggio and Raqueño would go on to get Ph.D.'s from SUNY Syracuse with DIRS support (note, Syracuse, not RIT, to avoid any taint of nepotism associated with the just minted RIT Ph.D. program). So, with four research staff (including Gallagher) and a half-time secretary, DIRS set out to establish itself as a significant player on the national stage. Carolyn Kitchen (see fig. 6-7) had also joined the department and worked half-time as the DIRS secretary

6-1. Steve Schultz (~1985) at computer.

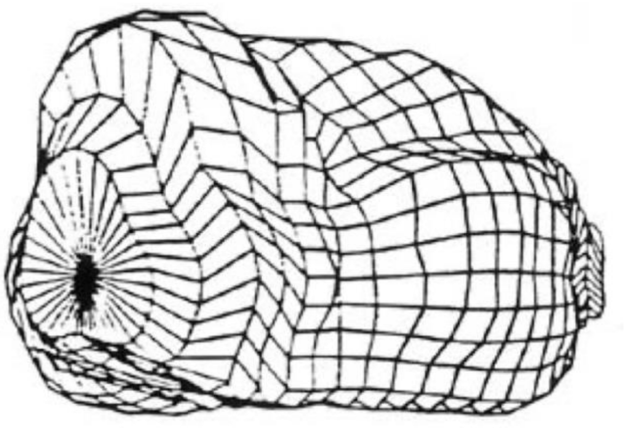


6-2. Carl Salvaggio (late 1980s) at his desk.

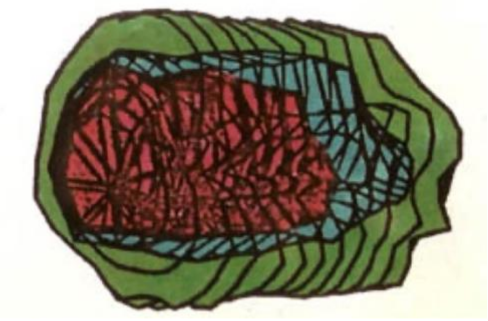
6-3. Rolando Raqueño (late 1980's) in Image Processing Lab.



6-4. Echo cardiogram image of the left ventricle (top left), filtered for noise reduction (top right), sharpened to enhance edges (bottom left) and with wall highlighted (bottom right).



6-5. Three-dimensional reconstruction of the left ventricle produced by analysis of a number of samples taken with rotations of the echo probe.



6-6. Three-dimensional reconstruction of the left ventricle wall from numerous echocardiograms (green) and low and high-speed velocity 30 isopleths’ created from multiple doppler echocardiograms.

6-7. Carolyn Kitchen, long-term DIRS administrative assistant.

and half-time as the Center Director’s secretary. She would soon become full-time with DIRS and would also be a major resource for decades. She did, over those decades, periodically point out to Schott that she could have chosen to work for the Center Director rather than him.

In the mid 1980s RIT Imaging Science and the U of R Institute of Optics jointly proposed and won a New York State Center for Advanced Technology (CAT). These funds would go to the two university groups to fund research in support of topics of interest to local (i.e. NYS) industry. DIRS, the only major research group in the department at this time, ended up with a significant portion of RIT’s share and focused much of its funds on acquisition and programing of digital image processing systems, a topic of significant interest to many of the major corporations in Rochester (particularly Xerox and Eastman Kodak). Commercial digital image processing and display devices were just transitioning out of the national labs at this point. DIRS acquired one of the first of these array processors that allowed images to be loaded into the 512x512 arrays from a general-purpose computer or by digitizing a video signal. The data in the arrays (4 in RIT’s first processor) could be mathematical or logically combined at video rates to process the 512 x 512 images. Finally, the images at any point in this process could be read out from the array and displayed as conventional video signals on a color cathode ray tube (CRT). The CAT was a multi-year effort and would provide support over the next several years for development of digital image processing tools and techniques for remote sensing. Digital image processing required massively more computer processing, input/output (I/O in the form of high-speed tape drives) and computer memory than was required for most scientific computing in the early 1980s. In addition, DIRS needed its computers physically connected to the image array processors it started acquiring in about 1983 to support high speed image transfer from computer to processor and back (recognize that networking was still primitive and slow in this era). High speed mini computers were just coming on the market and would supplant mainframe computers for instrument control/interface tasks like image processing. These mini computers dropped the costs for the high-speed 32- bit computers by more than an order of magnitude. Digital Equipment Corporation (DEC) with its VAX computers was beginning to dominate the mini computer market. DEC had just formed an imaging group to try to understand the emerging imaging industry needs, make their products more attractive, and market their products to that industry. In the earliest days of this emerging field the big money was being spent by the defense/intelligence industry. The head of the small DEC imaging group eventually contacted Schott at DIRS and told him several of the key government players (to whom he wanted to eventually sell lots of DEC equipment) suggested he talk to RIT. He was looking for a university to collaborate with to help demonstrate the potential of VAX computers for image processing in general and remote sensing in particular. On a follow-up visit Schott's team demonstrated what they were struggling to do with a surplus 16-bit DEC PDP computer, a 1600 bpi tape drive and a first-generation image array processor to respond to the needs of a range of sponsors. The DEC imaging rep encouraged Schott to pursue a major equipment grant from DEC corporate which DEC imaging would endorse. DEC was in the business of selling computers not giving away money and universities all over the country were seeing the value of the new generation of VAX computers. As a result, DEC grants were rare and primarily consisted of a 50% discount on DECs already generous academic prices (DEC knew that if you hooked computer scientists on your products in college, it would likely be what they would buy when in government or industry positions). Even at discounted rates Schott knew he needed about $100,000 worth of DEC equipment (a large highspeed general purpose computer networked to a computer with a high-speed back plane to interface to the array processors, several terminals and a 6250 bpi tape drive to move images to and from the compute environment). He also knew he would shortly need a bigger (1024x1024x8 plane) image array processor. He figured he could scrounge about $25,000 from his grants toward computing and he asked RIT for an internal matching grant of $25,000 so that RIT would ask DEC for $100,000 in equipment at academic rates for which it would pay $50,000. With the high demand from academia for its machines DEC only awarded a few of these grants. RIT management hadn't had much luck with this type of highly competitive grant and didn't think it was likely to be successful. Thinking it was a low risk venture they signed off on the university matching share. A couple months later (April 1986) Schott was asked to come visit DEC for a strategy session with DEC imaging at their facility in southern New Hampshire. He was told to fly to Boston Logan and meet someone at the airport who would see about getting him to the DEC facility. On arrival he was led to the other side of the airport put in the copilot seat of a small DEC helicopter and whisked off to the Nashua facility (apparently nobody senior needed the shuttle that morning). As a remote sensor that was an exciting ride as the pilot flew low and Schott looked past his feet out the bubble. He remembers thinking how excited his father would be to hear about the adventure. As the meeting began Schott and DEC reviewed Schott's plans for what he hoped to do with the new equipment and they let him know they had advance word from corporate that he and they had been successful and he would be receiving a grant. This was not just a big win for Schott but also for the tiny DEC imaging group. As the planning session continued Schott was called from the meeting for an important call (pre cell phones) to learn from his secretary, Kitchen, that his father, who had been ill with leukemia, had died. It was a bitter sweet return trip to Rochester.

The DEC equipment greatly facilitated the DIRS group's advances in image processing. In an era when almost no one had well integrated image capture, computing, image processing, and image display hardware in an environment where image analysis software tools could be quickly developed and demonstrated, this equipment opened many opportunities that DIRS was quick to take advantage of.

As the NASA-Landsat-LIDQA work wound down, the late 1980's saw the DIRS group's support increase from the defense/intelligence sector. With the Federal government moving to commercialize the Landsat program, NASA's support to academia faded for over a decade and many remote sensing science programs across the country suffered. DIRS really didn't have the option or the interest to heavily pursue remote sensing applications research. Without strong supporting programs in application areas like forestry, agriculture, geology, oceanography, environmental science etc. it was hard to put together competitive application-oriented programs. In addition, RIT/DIRS was trying to carve out its role in the remote sensing research community as a place where new remote sensing science would come from. This would take the form of new tools (hardware, software and analytical) that could be used across the application sciences to enable better use of remote sensing for scientific studies and problem solving. From this perspective, the tools that the defense/intelligence community needed were very similar to what other application areas needed and there was a great deal of interest in adding more science to what had been largely a photo-interpretation field.

Two things happened in 1985/86 that kicked off and exemplify the nature of this expanding work for the defense intelligence community. The first was a small grant from Eastman Kodak that was brought to DIRS through RITRC. This involved an effort to demonstrate ways to automatically register (align) overhead images to maps. This is pretty strait forward today but in the early days of digital imagery this was a new thing and concepts like using image chips as ground control points and digital correlation between images and image chips were new concepts. For Schott, this was his first exposure to the Kodak Federal Systems Division (FSD). Through local professional societies he had some connections to Kodak Aerial Systems which designed and sold the specialty aerial films used for aerial reconnaissance. However, even after five years in Rochester this was his first real contact with FSD. This was a very large division which supported the national defense/intelligence community. They did everything from making satellite sensors (cameras), specialty films, and processing film to having a large group continuously trying to improve the quality of reconnaissance imagery and developing better image analysis tools (The Image Chain Analysis, ICA, group). Most people in Rochester didn't know about Kodak FSD. Most of FSD's work was classified and Kodak corporate choose not to advertise its connection to the defense/intelligence community despite the important role it played in early space reconnaissance in the 1960's.

This first small study by DIRS apparently served as a get acquainted/test case. Over the next several years Kodak FSD funded an increasing number of research programs (several hundred thousand dollars from 1988-1990) aimed at topics including atmospheric normalization of multispectral multidate imagery, selection of optimal spectral bands for new sensors and synthetic image generation. These programs were typical of DIRS relationships with the aerospace contractor community in the 1990's and beyond. Sometimes the funds would come from internal research and development aimed at getting the company better placed to win contracts in the future. Sometimes the funds would be a subcontract where the company needed help with a small part of a large government effort. DIRS often had unique skills, or was significantly less expensive, than doing the work in-house or through a smaller aerospace subcontractor.

The second, even more significant, thing that kicked off a major push of research in support of the defense/intelligence community involved a visit Schott received around 1985. He was in his office (in the storeroom off his main lab) when two visitors came in to see him. He had a large partner's desk and they took seats on the opposite side. Later, Carolyn Kitchen, who sat just outside the office in a partitioned space, told him one of the visitors had called saying he was an image science graduate and wanted to drop in for a surprise visit. The guests, a man and a woman, both wearing trench coats (perhaps one or both wore a fedora), introduced themselves and said they were in town and wanted to say hello. Schott, a little befuddled, said: "Hello?". Without further ado, barely keeping straight faces, the man said "we're with the government and (not the expected "we are here to help" but) we need your help". Over the next hour or so they explained that Bob Mericsco had indeed gotten his B.S. in photo science years earlier and in collaboration with his former professor, Ron Francis (who had recruited Schott to RIT and been his first boss) had decided to have some fun and visit in trench coats. It turned out they were in town on business but also had business with Schott. They worked for the CIA's Office of Development and Engineering (OD&E) and knew of Schott through his classified work at Calspan and through Francis, who had been encouraged by his agency contacts to hire a remote sensing faculty member to enhance the Photo Science department's offerings. They wanted Schott to renew his security clearances (dropped when he left Calspan) so they could brief him on OD&E technical problems hoping that the courses he would be developing could better provide tools to the graduates. Those graduates might then

6-8. Willem Brouwer, founding director of the Center for Imaging Science.

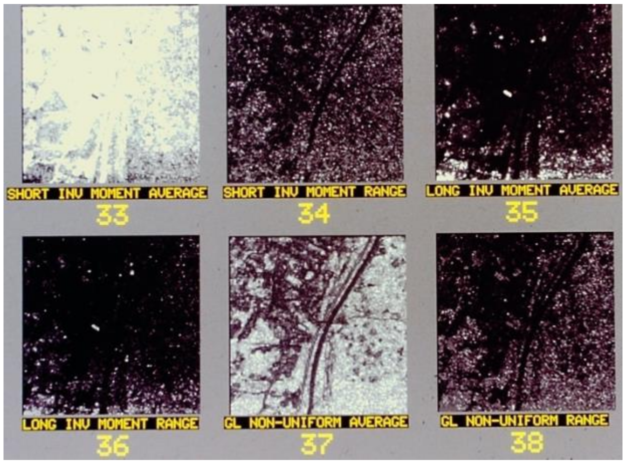
6-9. Willem Brouwer sitting on his favorite mountain behind his vacation home in New Hampshire. Photo used as part of image processing exercises in DIRS Lab.

6-10. Landsat color infrared images of Rochester acquired in 1982 (top) and 1984 (middle) and the 1982 image transformed to look as though acquired with the same atmosphere and illumination conditions as the 1984 image (bottom). Note how turbid the Genesee River appears in transformed image image due to a major storm a few days prior to image acquisition.

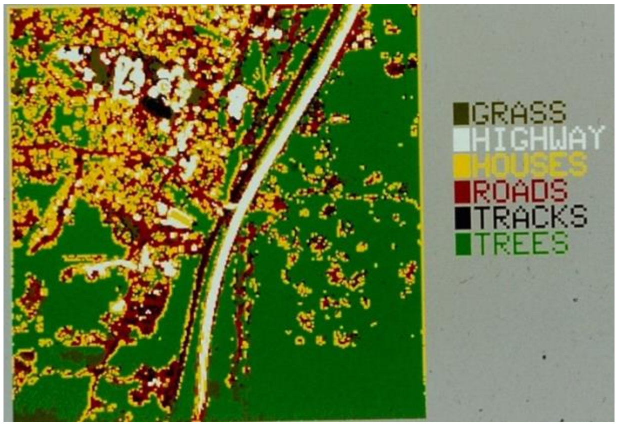
work for the government or their contractor base. Of equal interest was the hope that the agency and DIRS might find some research areas of mutual interest.

Imaging Science already had a small relationship with the CIA, but nothing directly to do with remote sensing. Because so much of the CIA's business involved scientific imaging (most notably aerial/satellite imaging), they had long recruited photo science graduates. From 1966 on the agency had sponsored an annual grant which during Schott's time saw the $20,000 in funds targeted at buying equipment and supplies to support student capstone projects (B.S. & M.S.). In return, the CIA got copies of the final reports or thesis. The CIA's major purpose was to demythologize the agency in the hopes of recruiting students to its own offices or to its contractor base. This approach seemed to work, with RIT being the largest supplier of agency employees to the Science and Technology directorate in the 1980's. In the mid 1980's another major CIA connection arose when Dr. Willem Brouwer (see fig. 6-8, and fig. 6-9) joined the department and eventually became the first CIS director. Brouwer's career had included designing reconnaissance cameras and he had interacted with and had a solid reputation with the CIA. By the time the Center was formed, the RIT administration was pushing to take advantage of CIS's connections to the CIA. In fact, the CIA, and in particular Robert Kohler the head of CIA's Office of Development and Engineering (OD&E) and a 1959 Photo Science graduate, had an interest in expanding the research relationship with RIT.

This culminated in 1985 with the first of what would become an annual research contract through the late 1980's between the CIA and RIT's DIRS group. The DIRS work for OD&E during these years focused on a series of fundamental research objectives of broad remote sensing utility. One of these involved attempting to develop tools to compensate for the changes in appearance between two overhead images of the same site caused by changes in the atmospheric and illumination conditions. The goal was to process one or both images to the same state so that only real changes would have different brightness values (colors). Over several years RIT came up with a theoretical basis for and then developed, implemented and eventually automated the Pseudo Invariant Feature (PIF) technique to effectively adjust one image to "look" as though it had been imaged under the same conditions as another (see fig. 6-10 and Schott et



6-11. Six examples of the tens of texture images that can be derived from an overhead image.



6-12. A land cover class map produced from a subset of the texture images derived from the original overhead image.

al. 1988). Other research in the 1980's for OD&E included using image derived spatial texture to generate multidimensional feature vectors from monochrome images and then using these higher dimensional feature vectors in multiband land cover classification algorithms to segment monochrome images into land cover classes. This work helped DIRS learn about high dimensional data and begin to develop tools to take advantage of high dimensional data for scene classification and target detection. The first work on this topic at DIRS was conducted by a Canadian Air Force officer, Denis Robert, as part of his masters program (see fig. 6-11, and fig. 6-12, and Robert 1989). Robert would leave RIT with his masters degree and shortly afterward with his future wife, Schott's niece. OD&E also supported some of the DIRS groups early work on generating thermal infrared synthetic images using computer models of the three-dimensional structure of objects (see fig. 6-13). This modeling tool became known as the Digital Imaging and Remote Sensing (DIRS) Image Generation (DIRSIG) model and its evolution goes on today as more and more functionality is continuously being added. The primitive early results of this modeling tool were captured in the first M.S. thesis on DIRSIG in 1990 (Shor 1990). While crude, even by the standards of the time, with the support of a wide range of sponsors over the ensuing decades the DIRSIG model would become a major national resource supporting a wide range of remote sensing sensor, algorithm development and testing programs (see fig. 6-14).

This wealth of work for Kodak FSD and CIA OD&E significantly increased DIRS's visibility and credibility through the 1980's (lots of conference and journal articles, as well as briefings where government and aerospace industry scientists were present). This helped attract other support including several subcontracts through Autometric Inc on Air Force contracts. Autometric, a major player in early satellite imagery analysis, headquartered in the Washington, D.C. area had a division in Rome, NY supporting the Air Force's Rome Air Development Center (RADC). Schott had worked on RADC sponsored projects while at Calspan and had connections to scientists at Autometric's Rome and D.C. operations, including a colleague (Dave Gaucher) who left Calspan to join Autometric. Autometric (particularly the Rome Division) felt strongly about their photo interpretation and mapping skills. They had good connection and insight into RADC, but often looked elsewhere for more fundamental/theoretical remote sensing science expertise. As a result, DIRS bid with them on a number of projects at least three of which were awarded in the late 1980's. These included study of the potential to use a Fraunhofer line discriminator (FLD) sensor to detect camouflage (vegetation luminesces, camouflage doesn't and an FLD can "see" luminescence in the Fraunhofer lines) (see Gaucher et al. 1987). Another pair of studies through Autometric kicked off the DIRS group's long-term interest in imaging spectroscopy. These interests focused on estimating the impact illumination and atmospheric conditions would have on transforming the reflectance spectra of a target on the earth to the signal

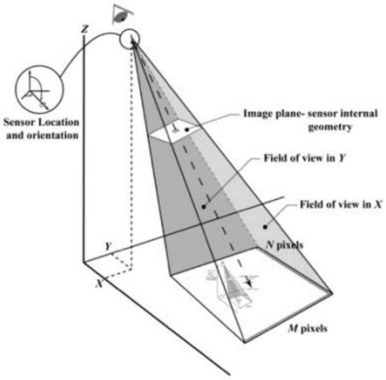
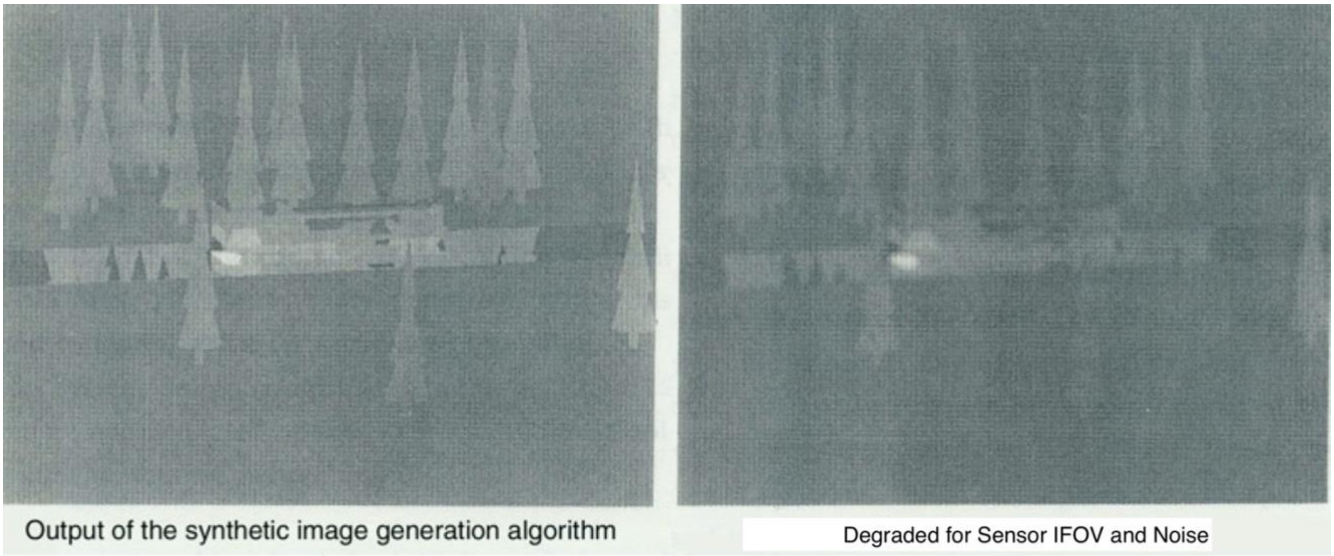


Illustration of the ray-tracing process for a simple framing camera. To generate an $N \times M$ radiance array, rays are traced from the focal point through each pixel center in an $N \times M$ image plane. Note the N x M array is denser than the final image array to allow convolution and resampling with the instrument PSF.

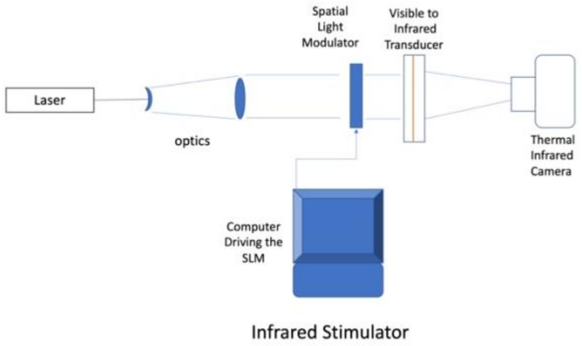
6-13.Illustration of the basic ray tracing process used in the production of a DIRSIG scene produced for a simple framing camera.



6-14. Very early DIRSIG thermal infrared images of a truck (left) and the degraded version a particular sensor might record. While incredibly crude by today's standards, these early results helped DIRS understand important phenomenology and drove the rapid evolution of DIRSIG.

recorded by NASA's Airborne Imaging Spectrometer (AIS) and assessing the utility of AIS data in detection of camouflage (see Gaucher et al. 1989). The AIS was a NASA testbed that first introduced the concept of overhead imaging spectroscopy. While the AIS data were primitive by the standards of later imaging spectrometers, these two studies got DIRS thinking about and working with imaging spectroscopy decades before such data would become common. The third Air Force/Autometric program included DCS corporation and Dr. Azriel Rosenfeld and his group from the University of Maryland (Rosenfeld was one of the pioneers of digital image processing). The project was to develop an automated target recognition (ATR) system for use with forward-looking infrared (FLIR) sensors. The DIRS role on this multi-year effort was to compare modeled estimates of target surface temperatures and sensor-reaching radiance values that would be used in the ATR algorithm to actual temperatures and radiances. A huge long-term benefit of this effort for RIT/DIRS was familiarity with and eventually access to the Air Force's thermal model (THERM) that DCS had helped develop. It would be modified for use in DIRSIG to model the temperature of objects in DIRSIG's synthetic images.

Another major short-lived grant that showed up in 1988/1989 and continued into 1989/1990 was a congressional appropriation (aka ear-mark) that RIT's lobbyist had managed to work into a Department of Energy (DOE) appropriation. The grant called for DOE to fund CIS for several years for studies in areas of imaging science related to their mission (note, while we often think of DOE and solar/wind energy and energy conservation, recognize that DOE also runs the National Laboratories at Los Alamos, Savanah River, and Sandia among others and had a major involvement in nuclear medicine). While this was a CIS grant, DIRS as the only major lab would end up having to do much of the work to justify the expenditures and Schott was assigned as the principal investigator. Some of the funding went to the nascent optics group and some to the also nascent image processing group. DIRS tackled two problems. The first was aimed at acquiring or building instruments that would allow the characterization of the bi-



6-15. Illustration of the infrared scene stimulator used to produce a temperature varying 2-D surface from a synthetic video image that could be imaged by a thermal infrared sensor.

6-16. Single frame from a thermal infrared image acquired with the infrared stimulator. Note the black dot in the center is a reflection of the cryogenically cooled infrared imaging camera in the infrared transmitting window of the Bly Cell.

directional reflectance distribution function (BRDF) of materials across the spectrum from the visible through the long-wave infrared. This type of data was critical to performing material identification with the range of spectral remote sensing sensors that were expected to be developed in the coming decade. The second effort was aimed at designing and demonstrating a dynamic real-time thermal infrared synthetic image generator that could be used to inject images into thermal infrared imaging sensors to test and train ATR algorithms. To accomplish this, DIRS generated synthetic images in DIRSIG and sent the images to a spatial light modulator (SLM) illuminated with a high intensity laser. The light passing through the SLM becomes a high intensity two-dimensional "image beam" that was projected onto a visible to infrared transducer (VIRT). In the test case, the VIRT was a Bly cell which consisted of a very thin transparent cellulose nitrate membrane coated on one side with gold black which is highly absorbing in the visible and highly emissive in the thermal infrared. The membrane is located inside a vacuum cell with a visible window on one side and an infrared window on the gold black side. When illuminated, the gold black absorbs energy proportional to the illuminating intensity and heats up radiating the energy away to be detected by an infrared imaging sensor observing through the infrared transmitting window (see fig. 6-15). This study focused on building a prototype system and designing and implementing methods and devices to characterize its spatial and temporal response (see fig. 6-16). Schott, who for some time had consulted with the Los Alamos National Lab (LANL) had designed these studies to be of use to the remote sensing side of the National Labs, particularly in their nuclear non-proliferation role.

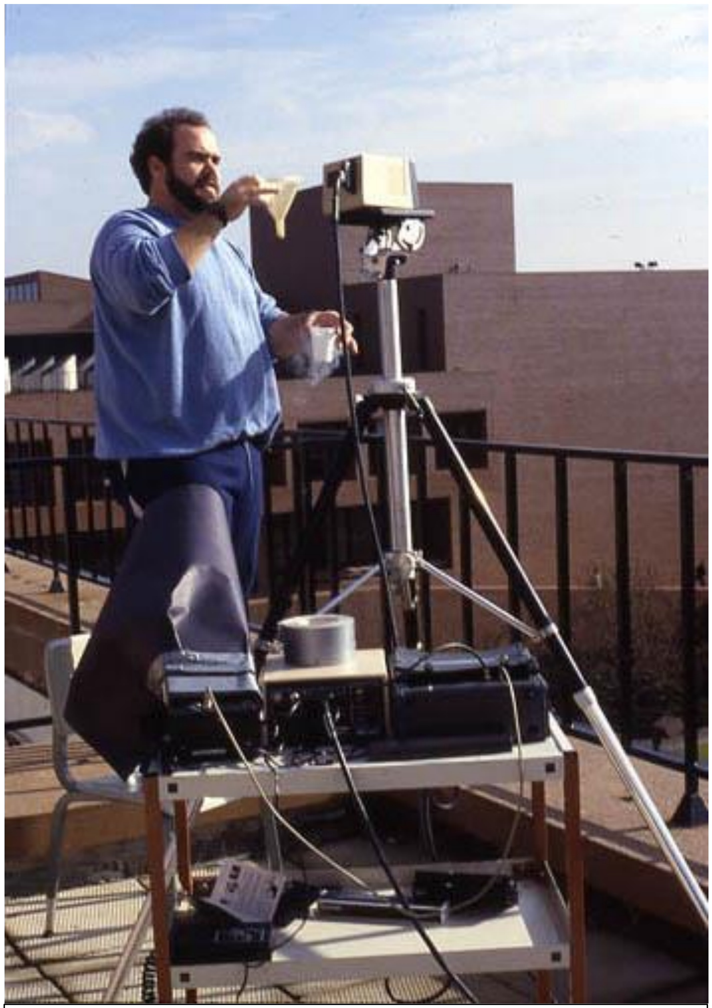
Congressional appropriations are often completely political actions in which a senator or congressman is convinced by a constituent of the value of a program and directs an agency to fund that program. This often ruffles the feathers of agency personnel, particularly if the funding doesn't include a plus-up. In those cases, the agency must redirect some of what they think of as their own funds away from their programs to the earmarked program. It is common for the agency to just issue the contract and wash their hands of the program. In this case, DoE ignored the program until late in the first year when they scheduled an on-site program review. Schott's boss, Dr. Rodney Shaw, told him not to worry that the reviewer was an old friend. Schott worried and organized a thorough briefing emphasizing the remote sensing activities that were the most mature. It was obvious throughout the day long briefings that the review's results were preordained. When the reviewer, who was a medical imaging specialist, met with Schott at the end of the day he indicated that the science was interesting and rigorous but not relevant to DoE and the program would be shut down at the end of the first year. Schott could only say so much in response since much of what he knew of the work at the National Labs was not public. Needless to say, this left a sour taste in Schott's mouth where earmarks were concerned. He scrambled to find (internal) funding to wrap up the student's thesis work on what had been planned as multiyear efforts. He was particularly irritated when a few months later that same reviewer called out of the blue to say he had just been at an internal DoE briefing and could clearly see how the DIRS' work (which he had shut down) was very DoE mission relevant.

In addition to these new thrusts in support of the defense/intelligence community, DIRS continued a number of small flight programs during the late 1980's. These included another streamline heat loss survey for Syracuse University, a power plant cooling water discharge study for an engineering firm and a study for the Coast Guard assessing the visibility of personal floatation devices (in support of search and rescue operations).

6-17. Test set up (top) and sample image (bottom) used in the study to standardize assessment of wrinkles.

Continuing the "going into business sale" theme led to a string of programs for Johnson & Johnson to look at the potential to use imaging: to assess sunscreen efficacy, to look at skin moisturizer efficacy, and a third to look at antiwrinkle lotion efficacy (see fig. 6-17). All of these studies involved development of image acquisition systems and analysis of images of human subjects aimed at quantifying/objectifying the condition of skin subject to various treatments (i.e. skin care products) and in some cases stressors (e.g. sun lamps). Another interesting effort in this period was a study for Eastman Kodak looking at the use of imaging ellipsometry to detect and characterize flaws in surface films. This project involved designing, building, and demonstrating an imaging ellipsometer. Another rather strange project for Johnson & Johnson involved a study to measure the image quality of a new line of contact lenses. This involved building up a special optical bench where the lenses could be suspended wet and test targets projected through them to test their modulation transfer function (a measure of resolution). This was a hush-hush project where DIRS was asked to keep the nature of the project quiet for a year and to not release the specific results. This was because J&J was nervous about Bausch & Lomb (headquartered in Rochester) getting early access to their approach and results. This worked out fine for the student as his focus was on the devices and methodology not the specific results, and it took a year or more to write it all up and get his masters thesis approved. It is somewhat curious, given what was to come, that this project involved more "secrecy" then all the DIRS work for the CIA which was all unclassified and in the open.

By the time the eighties ended as many as 7 technical staff were employed by DIRS and over a dozen graduate students were working on DIRS research projects. Gene Kraus was a mathematician who worked on algorithm development and stayed with DIRS for several years. Bernie Brower (see fig. 6-18) and Jim Warnick (see fig. 6-19) were M.S. students who stayed on for a few years after graduation and then went on to jobs at Kodak FSD. In Brower's case he was in what the department called the 5



6-18. Bernie Brower on North Range Lab adding liquid nitrogen to infrared video imaging camera as part of the Infrared Shadows Project.

6-19. Jim Warnick (left), Carl Salvaggio (center) and John Schott (right) in the new Image Processing Lab

year B.S./M.S. program but what the students called the N year program since so many of them stayed several years working on their M.S. degrees. One day Schott looked up from his desk to see a middle-aged women, with surprisingly red hair, standing in the door. She said “I’m Monica, Cindy said you could help. All he’s interested in is football! But he’s good at math”. With that she reached into the hallway and pulled Bernie into Schott’s field of view. It took Schott a minute but he remembered that Cindy, a classmate from graduate school who he had hired to work with him for a short time at Calspan, had mentioned her brother Bernie. Schott told Brower about the imaging program and Brower showed up as a freshman in the fall. Schott kept an eye on him and from junior year on he worked for DIRS and joined the staff when his course work was completed. It took some prodding by both Kodak and Schott but Brower eventually finished the N year Masters program after starting at FSD and he and Schott interacted for decades as Brower became a major contributor at FSD.

By the end of the 1980s, with major programs for the civil, as well as the defense/intelligence communities, DIRS had established itself as a player at the national level. DIRS publications were well represented in the proceedings of the major professional societies and the scientific journals. Late in 1989 DIRS, along with the rest of CIS, moved into much better facilities in the new CIS building. DIRS started to take on Ph.D. students and looked forward to a bright future by taking on larger and more rigorous projects. DIRS would benefit from the well-trained doctoral candidates and the more involved theses their longer tenure would allow.

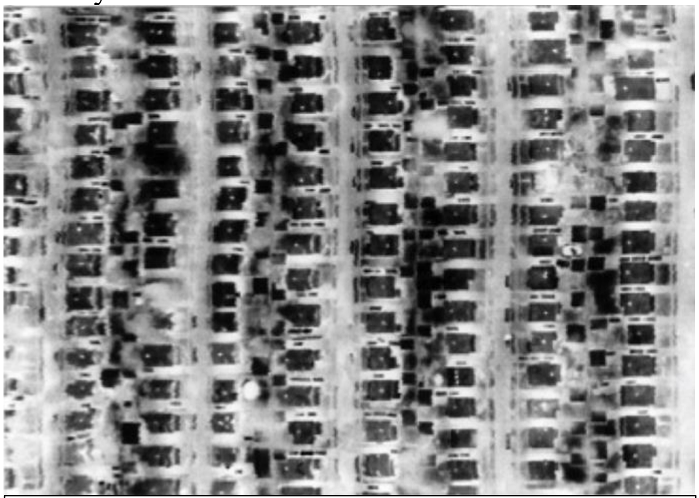
DIRS Contributions to the Remote Sensing Community

When we look to what long lasting and substantive contributions DIRS has made to the remote sensing community, DIRSIG always comes to mind. When DIRS started in the thermal infrared synthetic image generation business in the mid 1980s, there were several other models in play. In particular, Georgia Tech, ERIM and the Army Night Vision Lab had well respected models. In the ensuing decades DIRSIG's fidelity and capabilities grew. They included: multispectral, hyperspectral, lidar, lowlight, radar, polarimetric imaging, dynamic scenes, dynamic sensors, phenological development, full BRDF, volumetric scattering and transmission, and full polarimetric and path length effects of the atmosphere. The other models have largely faded, with a very large contingent of the defense/intelligence community turning to DIRSIG for scene and sensor simulations along with algorithm testing and training. DIRS' goal with DIRSIG has always been to incorporate as much of the physics of targets, background, sources, propagation, propagating media, and sensors and detectors as we understand. This focus on getting the physics right has paid off many times to provide useful tools and answers for the user community.

DIRSIG oblique image of the Harvard Forest test site and zoom of instrument tower (left) and zoom of understory (center and right). This site was constructed based on extensive field surveys including location, species, size…

7. The Dark Years 1990 – 1995

A new building, the approval of the Ph.D. program, the continuing work for the civil sector, and the rapid expansion of research for the defense intelligence sector made for a bright start to the 1990's. Schott's opening remarks from the 1990/1991 DIRS Annual Report, included as appendix A, captures some of the excitement and optimism of this time. Regrettably, a shadow would fall over RIT in the spring of 1991 that would impact DIRS. A series of news articles "exposed" RIT's relationship with the CIA and questioned the appropriateness of aspects of this relationship. Note this relationship was covered extensively elsewhere and will not be rehashed here. Because the work DIRS did for the CIA was both unclassified and fully reported in the technical reports available in the RIT library, DIRS was not drawn deeply into the furor despite numerous efforts to paint it with a broader brush. The negative publicity did, however, have a negative impact on DIRS programs. The CIA, because of the nature of its work, does not care for extensive publicity and apparently felt it would be in its interest to calm the waters and let its relationships with DIRS lapse when the current contracts ran out. The CIA was a significant sponsor but never dominated DIRS funding. On the other hand, this bad press and the withdrawal of near-term CIA funding also made it hard for a while to attract support from the rest of the defense/intelligence/aerospace community who were reluctant to be exposed to the negative publicity the CIA/RIT relationship received. As a result, the growth of DIRS contract volume slipped slightly in the early 1990's.



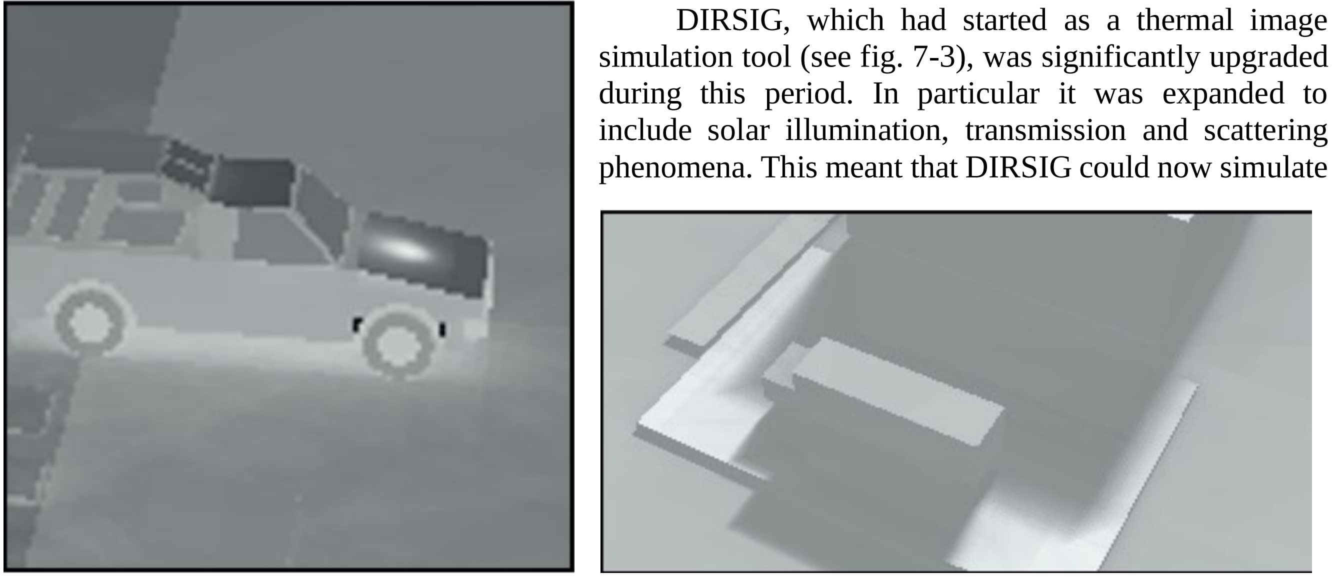
7-1. Night time winter thermal infrared aerial image of Rochester neighborhood used for heat loss study.

7-2. Night time street view still from thermal infrared video images (bottom) acquired from a van and used for heat loss studies (top).

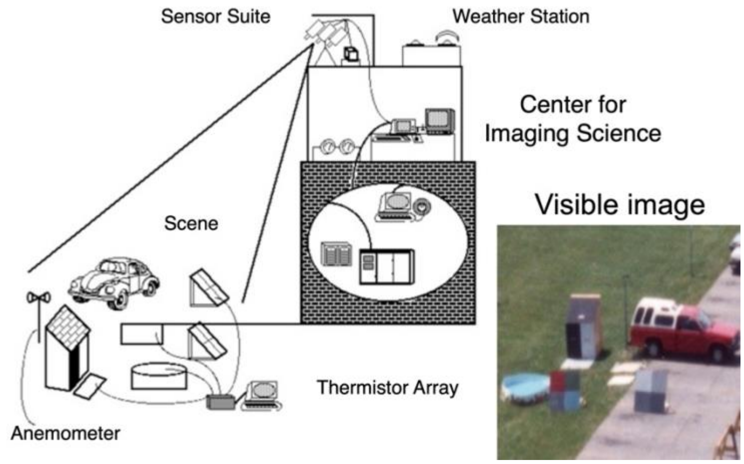
So once again DIRS needed to find some new funding sources. Luckily, as the CIA funds ran out over the next few years, a major program to support the New York State Energy Research and Development Agency (NYSERDA) started up. This program was a large multiyear effort designed to develop and demonstrate an integrated system to assess the heat loss from residential buildings and to provide that information to local utilities and homeowners. This program involved the collection and merger of nighttime winter thermal infrared aerial images, street-level thermal infrared video imagery and daytime street-level video imagery in an analytical system to quantitatively assess building heat loss. These data would then be available to homeowners (see fig. 7-1, and fig. 7-2). It required the development of a system to store and quickly access large amounts of image data (over 10,000 structures) at a time when image data was not readily manipulated. The study also included field surveys as part of an effort to validate the image derived data. This program wrapped up in 1994 and with it the research of the remote sensing group's first Ph.D. student (Dr. Will Snyder) was completed (see Snyder and Schott 1994).

In addition to the heat loss study, the research thrusts of the early 1990's shifted to fewer larger projects and away from the somewhat frenetic "going into business sale" pace of the first decade. In part, this was just maturation and stabilization of the group, but it also reflected the access to Ph.D. students and their ability to take on more sophisticated projects. Two thrusts of the early 1990's were improvements and validation of the DIRSIG model and a major new push to build a new airborne sensing system.

DIRSIG, which had started as a thermal image simulation tool (see fig. 7-3), was significantly upgraded during this period. In particular it was expanded to include solar illumination, transmission and scattering phenomena. This meant that DIRSIG could now simulate scenes as they would be viewed by visible to long ware infrared sensors. Rather than do this using broad band approximations, the decision was made to do all calculations spectrally and integrate wavelength by wavelength weighted by the sensor's spectral response. Doing the physics right may have appeared just an academic nicety when first proposed, but within just a few years it would have a huge payoff when DIRSIG was challenged to simulate imaging spectrometers. With DIRSIG already doing all its calculation spectrally this would turn out to be a simple step. Another big effort during this period was a major validation study of DIRSIG's thermal infrared modeling capability. The study utilized the north range lab which had been designed into the new image science building. It consisted of a penthouse lab on the roof of the building and a pad that extended to the northeast corner of the building such that imaging sensors and other test equipment could image test scenes around the building. The test consisted of acquiring mid-wave infrared (MWIR) and long-wave infrared (LWIR) images of a highly instrumented scene over a 24-hour period (see fig. 7-4). DIRSIG was then used to simulate these same scenes on hourly centers over a 24-hour period. The extensive measurements of the actual temperatures of various target surfaces were compared to those predicted by the DIRSIG model. In addition, the



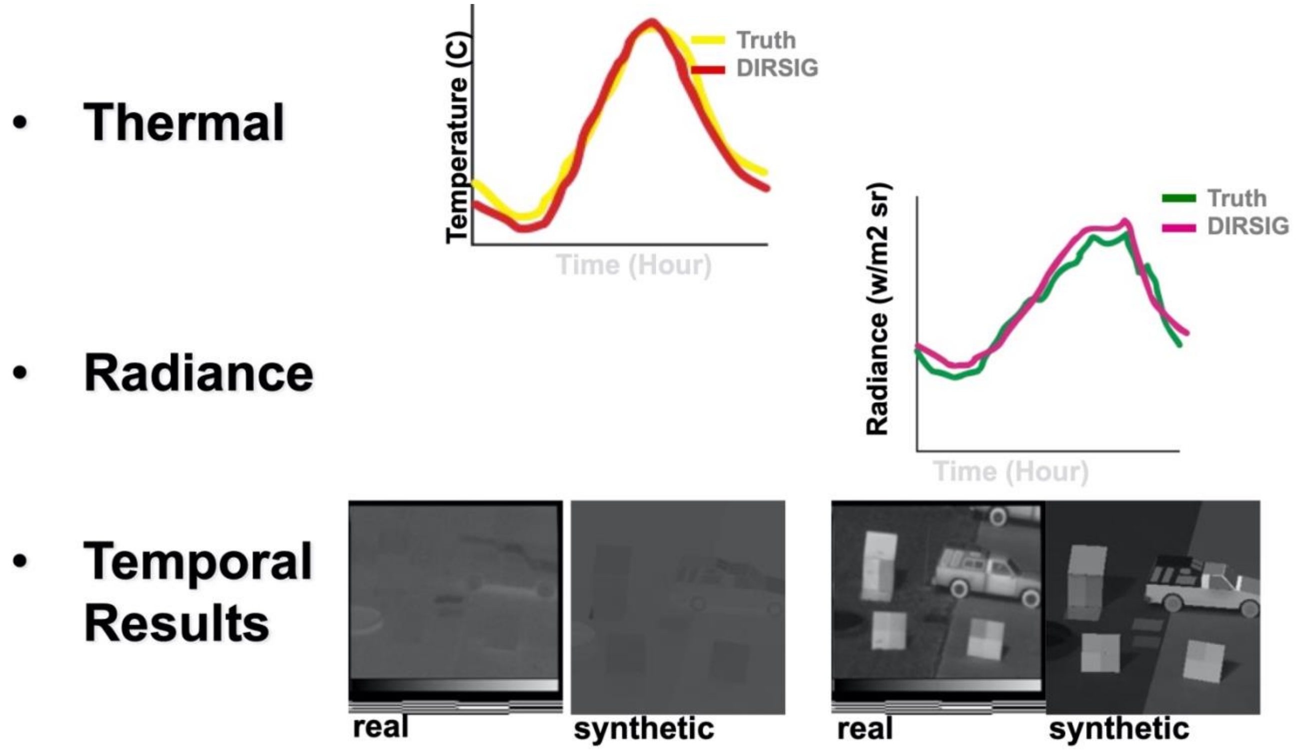
7-3. Early DIRSIG thermal infrared images showing the detail in the thermal and radiation physics incorporated even in the early versions of DIRSIG. The left image is a night time image. The thermal model "knows" the roof of the car will have radiantly cooled to the "cold" sky. It also "knows" the engine heats the hood above it. The sides of the vehicle are warmer than the top because they are in a radiational exchange partly with the cold sky and partly with the warmer ground. The pavement under the car is warm because it only "sees" the relatively warm car. The right image is a daytime thermal image showing how the shadow history that DIRSIG calculates feeds the thermal model which predicts that the grass in the sun will be cooler than the grass in the shade and that this effect will be quite quick (low thermal inertia) so the thermal shadows are relatively sharp. On the other-hand the concrete has very high thermal inertia so the thermal shadows take longer to form or fade as the solar shadow moves, resulting in much softer shadow edges and gradients away from the edge.



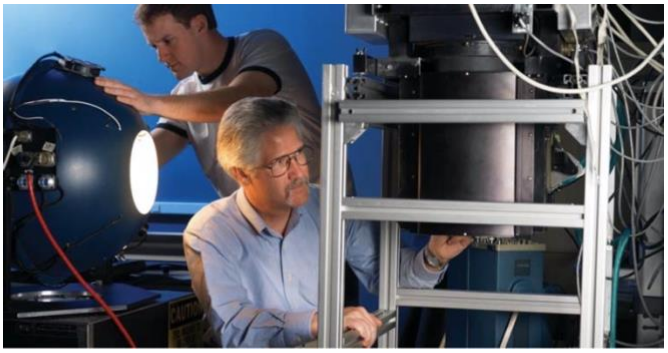
7-4. Illustration of the DIRSIG thermal validation setup which included visible, 3-5 um and 8-14 um cameras acquiring images every half hour for 24-hours of a highly instrumented scene. A visible picture from the roof is shown bottom right.

7-5. John Schott with his ugly mug and Donna Rankin Parobek.

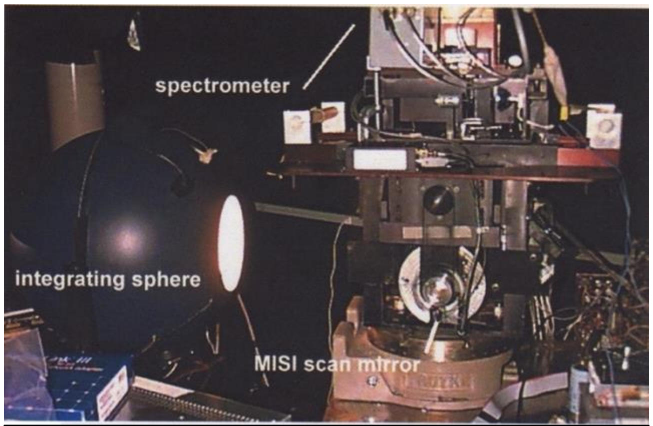
observed and predicted sensor reaching radiance values were compared. This represented the first rigorous quantitative testing of a synthetic image generation model (see Schott et al 1992). This extensive data collection and quantitative analysis effort was not only the first rigorous test of DIRSIG but of any advanced image simulation model. The study was the focus of a masters thesis by Donna Rankin (see fig. 7-5) who did most of the analytical work. Happily, DIRSIG did quite well though some issues were pointed out by the results that motivated future improvements (see fig. 7-6 and Rankin et al. 1992) and Donna got a degree.



7-6. Sample results from the DIRSIG validation study. Top left shows the DIRSIG predicted temperature for a target in the scene vs time as well as the thermistor “truth” recorded for the target. The second plot show the DIRSIG predicted radiance versus the observed “truth” radiance measured from the 8-14 um thermal infrared sensor image. At the bottom are night time and daytime real and synthetic 8-14 um thermal images showing that DIRSIG closely matches the real data. The differences between real and synthetic were as interesting as the similarities as they point out to the DIRISG team where improvements are needed.

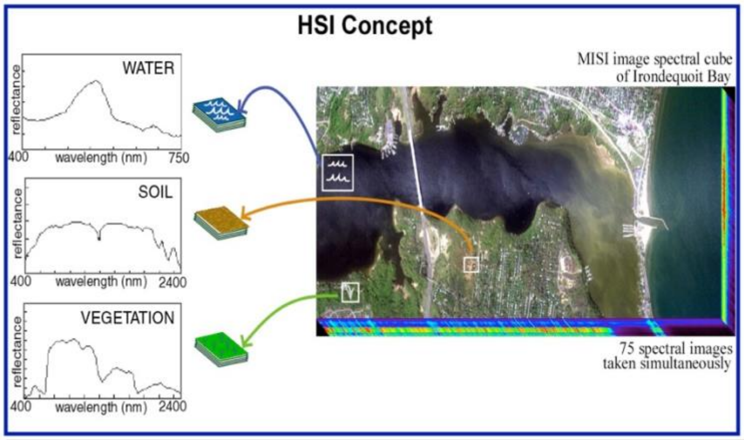


7-7. Student Brian Daniels and Schott in Lab calibrating the imaging spectrometer portion of MISI with a large integrating sphere.



7-8. MISI under calibration in the lab. The metal plate just above the sphere aperture is at the level of the floor of the aircraft with the scan mirror assembly projecting down into the camera hole and the spectrometers and electronics accessible in the passenger compartment.

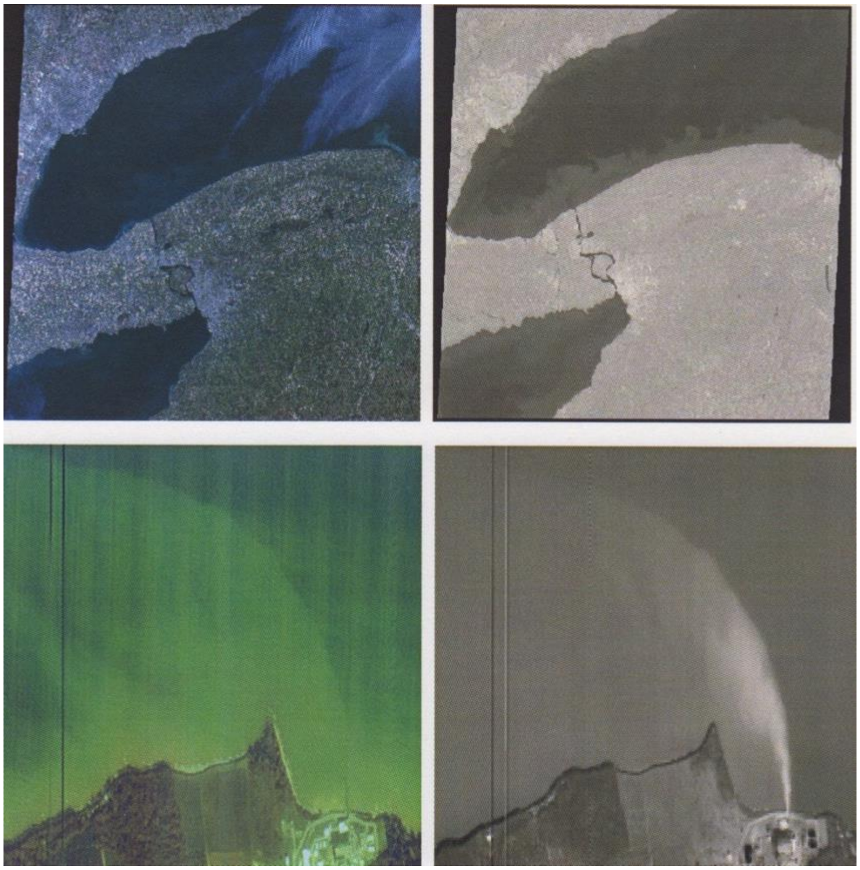
Over this same period of the early 1990's, DIRS designed and initiated development and testing of a new airborne sensor. This sensor was designed to replace DIRS existing airborne infrared line scanner which Schott had brought from Calspan and had modified several times pushing its capabilities to the limit. The new system's primary function was to maintain the spatial resolution of the old system, to significantly improve the signal-to-noise ratio and to add multiple thermal bands (see fig. 7-7, and fig. 7-8). In addition, the new sensor was designed to collect spectral data over the visible through near infrared spectrum (see fig. 7-9, and fig. 7-10). Aerial imaging spectrometry was just becoming a major research thrust across both the civilian and defense/intelligence sectors. By building and operating an airborne imaging spectrometer DIRS planned to thoroughly learn the hardware issues associated with imaging spectrometers (see Feng et al. 1994). Then they hoped to be able to use their own collection capability to support spectral algorithm development and application programs. While it was never expected to compete with the NASA and Defense/Intelligence test beds, it was hoped that hands-on experience with this new technology would make DIRS' students more valuable to their future employers and DIRS more useful to potential sponsors. This build was initiated slowly with internal funds but was supported by a number of sponsors (CIA, NASA) as it came to maturity.



7-9. MISI image of Irondequoit Bay with a true color representation shown on top of the 75-band spectrometer cube. Each point (pixel) on the image can be "probed" to see the spectrum of the target.

Other significant projects during this period included a series of efforts for Kodak FSD. These efforts were aimed at enhancing the spatial resolution of thermal, multispectral, and hyperspectral imagery by fusing it with higher resolution panchromatic (black and white) imagery (see fig. 7-11). These projects included design and development of "sharpening" algorithms, testing of competing approaches and assessment of whether the sharpened images improved algorithm performance for applications such as land cover classification and subpixel target detection (see Munechika et al. 1994).

Schott took a long-planned sabbatical in 1993/1994 to work on a remote sensing textbook. Dr. Phil Slater from the Optical Science Center at the University of Arizona had become a mentor to Schott and had finally conceded he would not rewrite his excellent text. Slater had encouraged Schott to do a book himself, saying there was no money in it but that Schott was young enough to get a good career boost from the visibility and credibility which a good remote sensing text could provide. So, in the summer of 1993 Schott packed up his family and moved to his cottage in Canada with a commitment to himself that he would get a first draft done over the next 12 months. He had just enough connectivity to send and receive text documents over a phone modem and he returned periodically to meet with graduate students. The research staff was smaller than in the late 80’s (Warnick, Kraus, and Brower had moved on by 1991/1992. R. Raqueño had also left DIRS to see what working for industry was like at Kodak FSD. To offset these loses Dr. John Mason, a fresh physics Ph.D. from the University of Rochester had joined the DIRS staff in 1992/1993. Schott was confident the Drs. Mason and Salvaggio, with his support from a distance, could effectively manage the rest of the DIRS staff and students and perform on the ongoing research grants. Particularly since the contract volume was down somewhat with the CIA work running out.



7-10. Landsat visible and thermal images of Lake Ontario and MISI visible and thermal images of the Ginna Power Plant taken as part of an under-flight.

7-11. Left: Landsat color infrared image (30 m. pixels), Right: SPOT panchromatic image (10 m. pixels), Center: fused image combining the Landsat spectral data and the SPOT spatial data to form a 10 m. pixel sharpened color infrared image. This is one of many “sharpening” algorithms DIRS would develop for a number of sponsors.

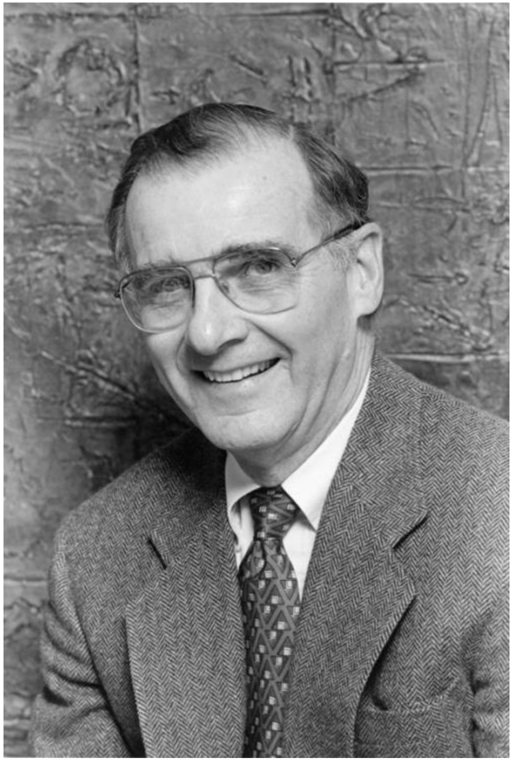
While DIRS was largely autonomous, it was very much a part of CIS and Schott was very involved as a CIS faculty member. CIS was becoming embroiled in faculty unrest leading up to Schott’s sabbatical year which erupted while he was away. In 1992 CIS Director Dr. Rodney Shaw left RIT after disputes with CIS faculty and administrators. Dr. Robert Johnston (former Dean of RIT’s College of Fine and Applied Arts) stepped into the Director’s position. Regrettably, the strife within the Center continued and came to a head during Schott’s sabbatical year. In May, as Schott was preparing to leave, the administration rejected a divided faculty recommendation for a new director after a national search. The administration said they did not want to bring someone into the turbulent environment until the Center had a plan for how to move forward. In September the administration rejected a strategic plan put forward by the divided faculty. One of the issues among some of the faculty was that not enough money was being invested in their research areas. This was particularly hard as RIT was in a belt-tightening mode. DIRS however, appeared to be thriving, and to an already disgruntled faculty, it appeared that somehow DIRS must be receiving funds they should have. To some extent, to those not heavily involved in large scale research (which included essentially all of the CIS faculty at this time), it is understandable that DIRS might appear to be lopsidedly benefitting from the Center's budget. It was obvious that DIRS had full-time research staff. In addition, some of the Center's staff worked some of the time for DIRS, DIRS had a full-time administrative assistant and DIRS was always buying equipment. What wasn't obvious (and no one asked) was that DIRS staff were paid 100% by DIRS grants or overhead recovered on DIRS grants, as was the DIRS administrative assistant. When CIS staff worked for DIRS the funds for their salary, fringe, and overhead were pulled directly from DIRS grants. Similarly, all the equipment DIRS purchased, including the compute environment that the entire Center used, was purchased from DIRS grants or recovered overhead. In practice DIRS tried to draw as little as possible from CIS accounts, recognizing that DIRS had far larger discretionary budgets than the Center. Apparently, unaware of this, the faculty called for an audit of the Center's/DIRS' books. Johnston, who as director was responsible for the Center's accounts, refused saying there were no issues and he would not conduct a more formal audit. The Dean of the College of Imaging Arts and Science (which CIS was part of by this time) catching wind of this reported that she did conduct a private audit reporting she found "no evidence of misuse or bending of the rules" (Report of the RIT Faculty Council (1996)). A divided faculty continued to fight among themselves on a range of issues into the spring of 1994 and voted "no confidence" in the Director by a 10-5 vote. The administration asked Johnston to stay until they could bring in a "hired gun" to see if the Center could be sorted out or if it should be shut down. These were horrible times at the Center (see Schott 2019) and are raised here only because of their impact on DIRS. Schott was the only remote sensing faculty member and was not there to daily tamp down the rancor or defend the remote sensing group who of course heard about and felt the animosity from some of the faculty. Salvaggio, and to a lesser extend Mason, who represented DIRS/Schott at various meetings during Schott's sabbatical took the brunt of what was really intended for Schott. Schott was aware of some of what was going on through phone calls and his infrequent trips to Rochester where he tried to focus on his student's thesis issues.

7-12.Scott Brown (~1994) as a student. Brown would go on to become the lead DIRSIG developer.

When Schott returned from sabbatical in the fall of 1994, Salvaggio and Mason both told him they had had enough of CIS and would be departing. Mason went to Kodak FSD and Salvaggio to a contractor in D.C. and later would set up his own consulting company supporting the defense/intelligence industry. This was a big blow. Mason, though he had only been with DIRS a couple of years, had been able to make good use of his physics degree to quickly learn imaging and had begun to lead programs and help guide grad students. Salvaggio had been with Schott for nearly a decade, had just finished his Ph.D., was a critical part of all of DIRS activity, and was the lead on DIRSIG development which had become a major part of DIRS research. Salvaggio and Schott were very close and, knowing the blow the departures would be, Salvaggio had recruited R. Raqueño back from Kodak FSD. In addition, he suggested Schott consider hiring a young student, Scott Brown, who had just finished his B.S, in imaging science to take on some of the DIRSIG programming challenges (see fig. 7-12). "He programs better than me" was high praise indeed from the lead DIRSIG developer.

Schott had to decide what he would do at this point. An easy step would be to also leave RIT and focus for a time on his consulting company while he sorted out his future. Schott, who had consulted for years as an individual on small programs that only needed his help, had formally registered his firm as SIDE in 1993. Unofficially, “Schott in the Dark Enterprises” (SIDE) had been around for years. The name was coined by Joe Biegel to cover anything Schott did outside RIT from “satellites to storm doors” as he put it. While Schott had little interest in building a consulting company and tried to deflect all work to DIRS, which was his love, there were a number of programs after the RIT/CIA blowup that sponsors wouldn’t or couldn’t bring to RIT. In addition, there were a number of important (sometimes important sponsor, sometimes important work) developmental or demonstration projects that didn’t have enough of a research component to make them appropriate for a university. In the 1990’s SIDE was quite busy and several of the DIRS staff picked up extra income working a few hours there on nights and weekends.

Over the summer and early fall Schott had met with Dr. Ed Przybylowitz (the “hired gun” President Simone had brought in as Director to sort out CIS). Schott made it very clear that if Przybylowitz in anyway thought Schott was part of the problem at CIS and not part of a solution going forward, Schott was prepared to quickly depart (see fig. 7-13). Schott and Przbylowitz rapidly developed a mutual respect and would become good friends. Schott decided he owed too much to his sponsors and students to walk away. He went to work trying to get all the ongoing contracts and thesis projects completed without his 2 lead research staff. Most importantly, he had to get R. Raqueño and Brown up to speed and producing. This was heavy lifting for all of them. In many ways it was a good thing that DIRS research volume was down somewhat after the RIT/CIA blow up. DIRS/Schott also had to deal with the continuing turmoil within CIS though this was no longer directed very specifically at DIRS. For 1994/1995 and into 1995/1996 Schott refrained from proposal writing. He focused on trying to keep the existing projects on track while trying to help sort out the problems within the Center and trying to decide where the future lay. During 1995/1996 Schott became convinced that Przybylowitz would be successful in putting CIS back on track and that his efforts to rebuild DIRS credibility and capability would be successful. He started writing proposals and rebuilding the DIRS research volume.

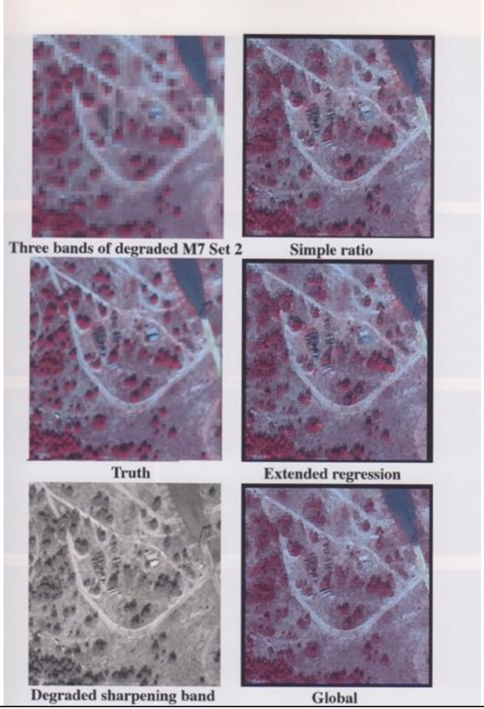


7-13. Edwin Przybylowicz, CIS Director 1994-1996.

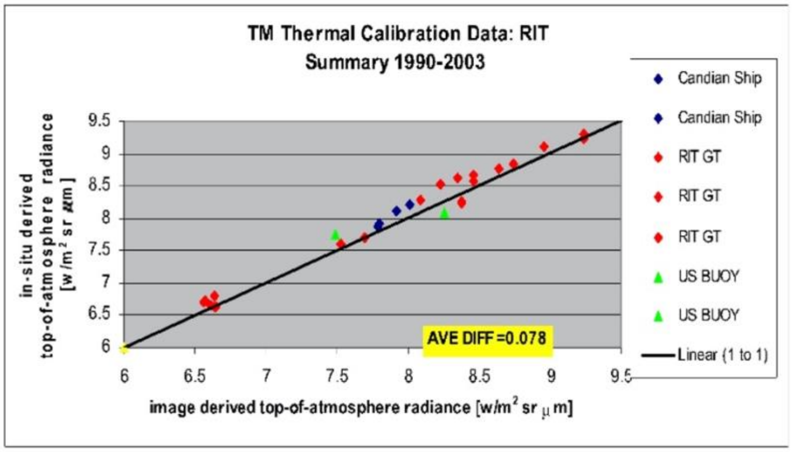
Schott’s uncertainty and unhappiness with things at RIT and struggles to keep afloat during this period are perhaps reflected in the fact that DIRS did not put out annual reports for 1993/1994, 1994/1995 or 1995/1996. These are the only periods during Schott’s tenure for which there is no record. Research reports to sponsor, technical publications and thesis defenses continued and from these it is clear that by 1995 DIRS had 3 – 4 research staff and about a dozen grad students. Thus, over the period of the early 1990’s the number of research staff shrunk and graduate student numbers were largely unchanged, although more of them were Ph.D. students which somewhat compensated for the reduction in staff when it came to research productivity.

8. Refocus 1995 – 2000

The late 1990’s saw DIRS revive, resurge and push in some new directions. The early years of this period saw a continuation of a number of projects for several different units of Eastman Kodak. This included continuation of work on fusing multiresolution images for FSD Image Chain Analysis (see fig. 8-1), imagery data storage and retrieval for FSD Information Systems, and ground truth support for testing of new films for FSD Aerial Systems. The National Reconnaissance Office (NRO) also became a significant sponsor in 1996 with a long term multitask contract. The NRO is responsible for the design, development, launch and operation of the nation’s reconnaissance satellites, including some initial processing to make the data useful. Just one satellite can be a billion-dollar decade-long investment that no one would trust to a university. On the other hand, there were always dozens of ideas for new sensing, processing, fusion and analysis approaches for systems years to decades away. It was in these areas that the NRO saw a role for university research where they could explore potential new directions at a small fraction of the cost such exploration would cost using their industry base. At the same time, it would train experts who were likely to pursue careers with the government or the aerospace industry. DIRS work on these efforts included assessment of the impact of various sensor and processing parameters (e.g. MTF (resolution)) on the performance of analysis algorithms and assessment of various methods to compensate remotely sensed data for atmospheric effects (the bane of nearly all remote sensing systems).

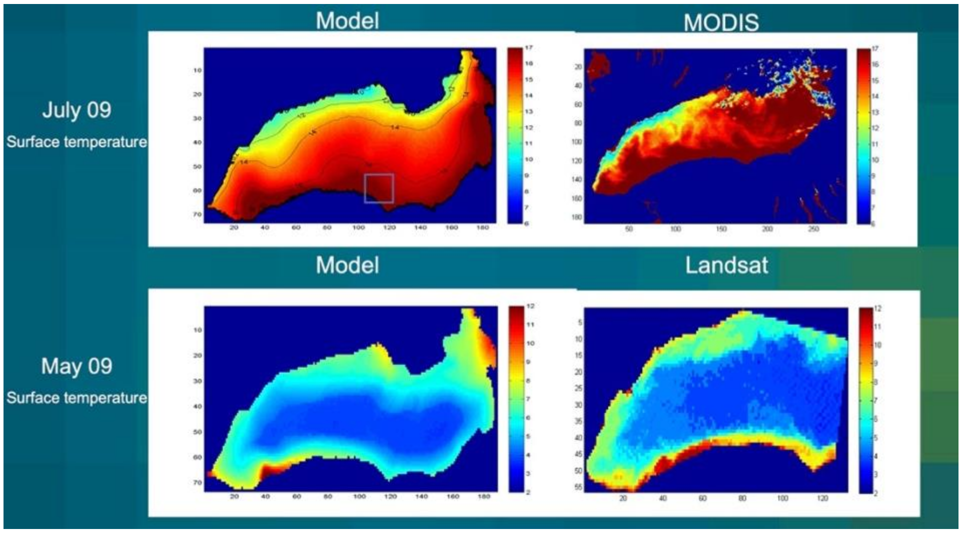


8-1. Comparison of three spectral sharpening algorithms. Top left: low resolution false color infrared image produced from three bands of the M7 multispectral scanner, Center Left: high resolution reference image, Bottom Left: black and white high resolution panchromatic image used to sharpen the top left image and results of three sharpening algorithms (right).



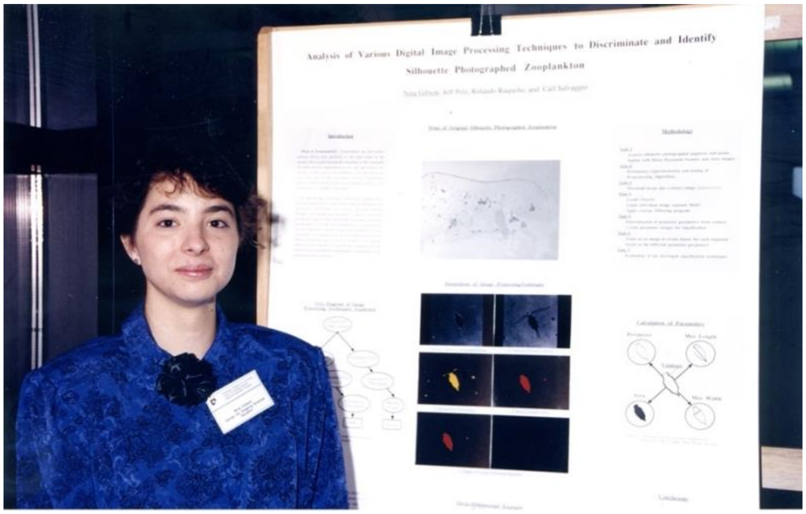
8-2. Plot of Landsat 5 observed sensor reaching radiance vs radiance predicted to reach the sensor based on propagating ground truth data to the satellite. The data indicate the sensor is reading slightly low after years when calibration was neglected. This was corrected in later processing.

In 1996 DIRS went back to work for NASA in a big way when Schott was named to the Landsat 7 Science Team (one of only eight academics). This team was assembled well ahead of the launch of Landsat 7 to reengage the remote sensing research community with Landsat. During the “commercialization” period of the 1980s and early 1990s Landsat imagery had become so expensive that university researchers had been forced to largely abandon it as a data source for most earth resources studies. Even though launch would not be until 1999, DIRS was tasked with calibration of the thermal band (see fig. 8-2) and also assessing the utility of existing Landsat satellites to study the thermal bar in Lake Ontario. This effort would extend DIRS earlier work for Landsat and would include flying the new MISI instrument under Landsat and collection of "water truth" to augment the MISI data.



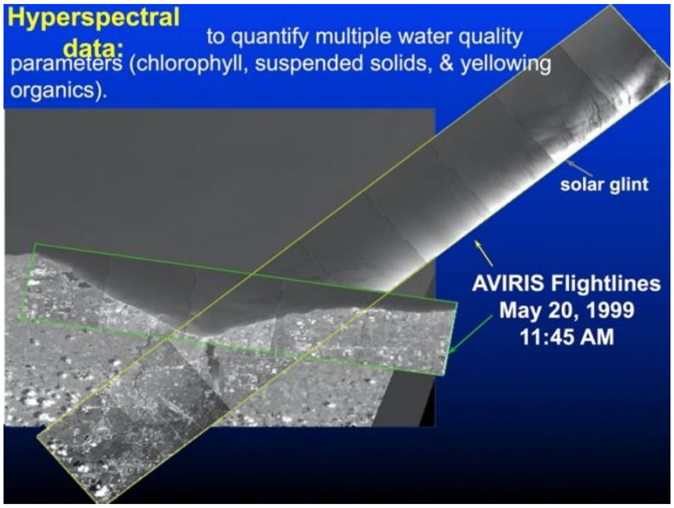
8-3. Color coded surface temperature map predicted from a 4-D model (x,y,z and time) of Lake Ontario (left) for two different dates and observed surface temperatures on those dates using the same color scales from MODIS (top right) and Landsat (bottom right) showing high correlation with the model.

The Lake Ontario component of the Great Lakes research would be augmented through the late 1990's by funds from the Wiedman Professorship. In 1997 Schott was named the Frederick and Anna B. Wiedman Professor in Imaging Science. R. Frederick Wiedman had donated the chair to RIT in honor of his parents in the early 1980's and it was first awarded to Dr. Ronald Francis. After Francis' death it bounced around a bit and Wiedman wanted to see some return on his investment, particularly if RIT was hoping for another large donation from him (and it was). Much of the endowment from the Wiedman Professorship had gone to pay some of the salary of the previous chairs. Because Schott's grants already paid part of his regular salary and any summer salary he drew, essentially all of the Wiedman endowment was available to support new research thrusts. Schott had decided to utilize the funds initially for internal research and development on remote sensing of the Great Lakes. In the late 1990's this involved modeling of the hydrodynamics of Lake Ontario as driven by and reflected in the temperature of the lake. The goal would be to use satellite measurement of the surface temperature to help to calibrate (nudge) the hydrodynamic models to better understand large lake processes (see fig. 8-3). This also linked in with the other thrust DIRS initiated with the Wiedman funds to expand outreach to the local K-12 community using remote sensing of the lakes as a theme. Nina Gibson Raqueño (B.S. Imaging Science, graduate studies SUNY CESF), who had been consulting on Geographic Information Systems (GIS) for a number of years, joined DIRS full-time to support GIS, data collection and outreach (see fig. 8-4).

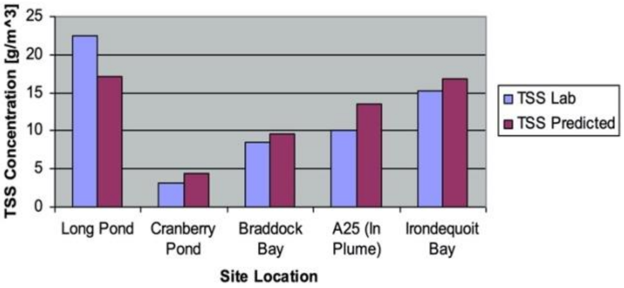


8-4. Nina Gibson (later Raqueño) as a student with her senior project poster.

DIRS investment in Great Lakes studies had an early payoff when it helped them secure a joint effort with Eastman Kodak as part of the NASA EOCAP Hyperspectral Program to help develop new commercial remote sensing capabilities. This multiyear effort focused on the development and testing of algorithms to map and monitor water quality using VNIR imaging spectrometer data. As part of the

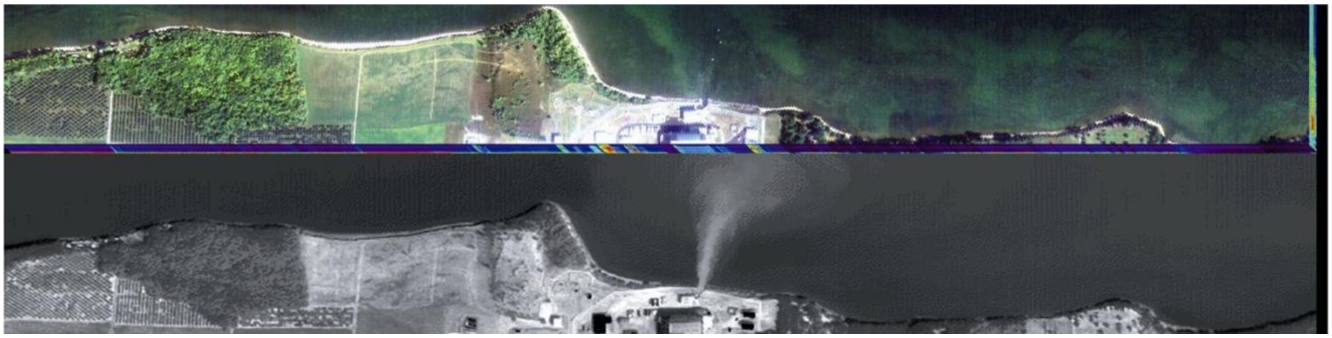


8-5. AVIRIS flight lines over Lake Ontario superimposed on a Landsat image.

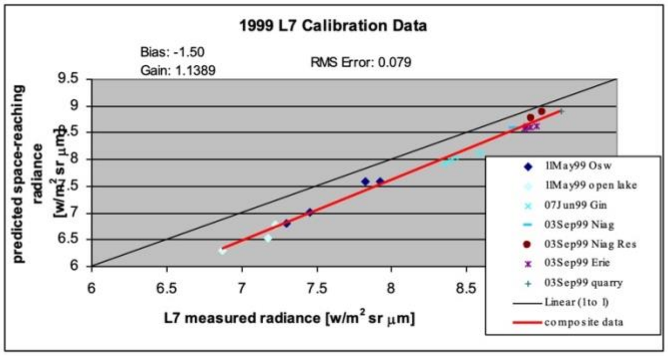


8-6. Comparison of AVIRIS image derived total suspended solids concentrations for five water bodies in the AVIRIS image and the lab values measured from the ground truth water samples showing good agreement with a slight bias.

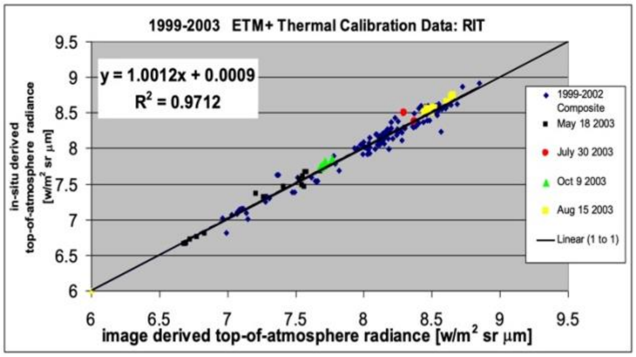
program NASA would fly its AVIRIS test bed over DIRS "water truth" collections along the Lake Ontario shore. This was the first hyperspectral coverage of the Great Lakes and the beginning of a number of water quality studies by DIRS (see fig. 8-5, and fig. 8-6). The need to have MISI ready to under fly Landsat, plus the support the Landsat program brought in, gave a major push to get MISI fully operational. This included spectral and radiometric calibration and development and testing of a high volume-high speed flight worthy digital recording system. During the years of MISI design, building and lab testing, the data recording aspect had been delayed as DIRS watched the digital data recording and control technology rapidly advance. By the late 1990's when it became critical for simultaneous recording of MISI's 70+ spectral bands, the technology was not only available but affordable. This multiyear period of working through a myriad of optical, mechanical, opto-mechanical, electrical, computational, radiometric and systems issues was trying but eventually rewarding as MISI began to acquire useful data (see fig. 8-7). By underflying Landsat, the well-calibrated MISI thermal data was used to determine that Landsat 7's thermal band was not in calibration immediately after launch. Thankfully, MISI also helped determine what adjustments were needed to bring it into calibration (see fig. 8-8, and fig. 8-9). Much of the work on the Landsat calibration effort became part of Julia Barsi's masters thesis (see Barsi 2000). When Barsi was getting close to graduating, she came to talk to Schott about career opportunities (see fig. 8-10). This was normal and Schott had a series of questions he usually asked to help both himself and the student focus their career interests. Were they interested in government, industry or academia, east coast, west coast or somewhere else, defense/intelligence or civil, big company or small...? He would then recommend some places where they might want to apply. Schott felt it was part of his job to help students find a position and generally tried to connect students with opportunities. It was rare for students not to have good job offers soon after graduation with an employer close to their interests, but Barsi posed a challenge. Barsi's answers were government, east



8-7. Portion of a MISI flight line along Lake Ontario showing a hypercube (top) with a true color image on top and a thermal image bottom.



8-8. Plot of Landsat 7 observed radiance versus radiance predicted by propagating ground truth to the satellite showing serious mis-calibration of the thermal band shortly after launch.



8-9. Plot of Landsat 7 observed radiance versus radiance predicted by propagating ground truth to the satellite showing that the adjustment to the sensor calibration based on the ground truth had been corrected.

8-10. Julia Barsi as a student viewing Landsat color and color infrared images of Lake Ontario shoreline.

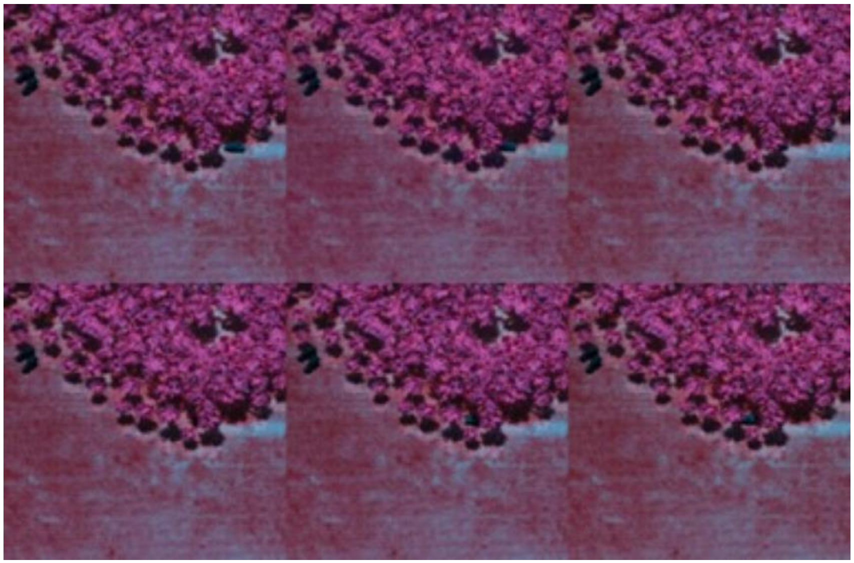
coast (Baltimore-Maryland), and civil. She went on to say she really wanted to work for NASA. She particularly wanted to work at NASA Goddard, and ideally, she would like to work on the Landsat program on instrument calibration. Schott asked "could you maybe be a little more specific?" before telling her he would see what he could find out about civil jobs in the D.C. area. Barsi was a strong student and he decided to go the extra mile for her and call his colleague and friend Dr. Darrel Williams, who by this point was the Landsat 7 project scientist, to see if he was interested in Barsi. Williams said the last of Schott's students he had hired had worked out well and he thought he could find a place for her. Barsi would join the Landsat calibration team and collaborate with DIRS on their Landsat thermal band calibration work for over 20 years.

Atmospheric compensation has been mentioned several times and continued to be a major research thrust for DIRS in the late 1990's. Essentially all visible through thermal infrared remotely sensed data benefits from compensating for the atmosphere and converting recorded radiance values to physically meaningful surface reflectance or temperature values. The problem is that it is difficult to do, spatially variable (the solution at one point in an image is not necessarily valid at another), and the algorithms vary depending on the resolution, number of bands, wavelength region, and spectral resolution of the sensor as well as the target (e.g. water vs. land). DIRS worked on developing and testing a variety of compensation algorithms for a number of sponsors. This work included studies for NASA (thermal), DoE-LANL (hyperspectral) and CIA Office of Research and Development (ORD) (hyperspectral). In the mid-1990s NASA and the defense/intelligence community were test flying the first generation of airborne imaging spectrometers and everyone wanted to know what you could do with them, so there was a rush of research to develop and test a range of new atmospheric compensation algorithms (see Sanders et al. 2001). DIRS, which had a long history of atmospheric compensation, was able to capitalize on this history and attract a number of research programs (including the renewal of support from the CIA).

DIRSIG also really came into its own in the late 1990's. The combination of maturity of the software that had been under continuous development at RIT for over a decade and the rapid advances in computing power over that same period, meant that more complex scenes and more complete and

8-11. DIRSIG nighttime thermal infrared image of a largely residential portion of Rochester including the Genesee River and the Kodak Hawkeye plant lower center.

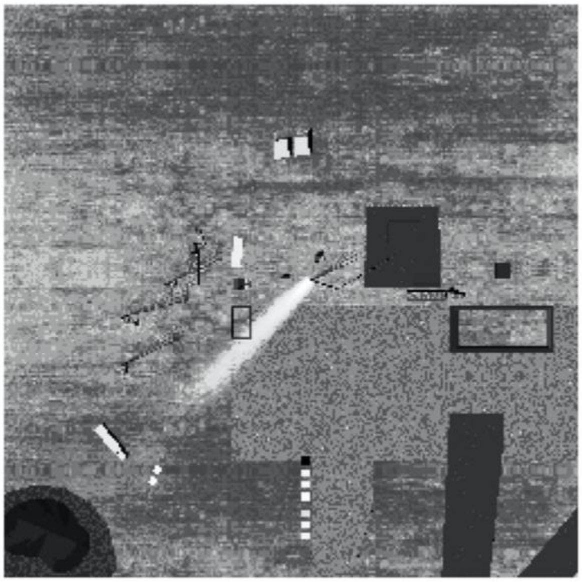
8-12. Degraded resolution DIRSIG daytime true color image of a portion of Rochester, including the Genesee River, the Driving Park Bridge and the Kodak Hawkeye Plant.



8-13. Sequence of DIRSIG images showing a vehicle moving into concealment in a tree line. The images were used to test the performance of target detection algorithms. Note: that by this time trees were modeled with individual leaves that had both reflectance and transmission spectra and the DIRSIG ray tracer included multiple bounce effects.

rigorous modeling of the illumination, atmosphere, targets, and backgrounds was possible. DIRSIG was also now able to function from the visible to the longwave infrared (see fig. 8-11, and fig. 8-12). As a result, sponsors began to use DIRSIG for studies not only related to thermal infrared sensors and sensing technology, for which it was initially developed, but also for VNIR sensors and most significantly for algorithm development and testing (see Schott et al. 1999). This algorithms work was a reflection of the fact that DIRSIG-generated images had sufficient fidelity to mimic the critical spatial/spectral aspects of a real scene to the point where running algorithms against them made sense (see fig. 8-13). In many cases DIRSIG was now in use in government and aerospace labs and DIRS built the capabilities into DIRSIG for users to simulate their own sensors or algorithms. During the late 1990's, one push was for DIRSIG to build larger scenes. This included larger in spatial extent which meant more rigorous modeling of texture and transition between material types, but also spectrally, with scenes/sensor able to span from the visible to the LWIR with fine spatial detail. It was during this period that DIRSIG leapt ahead of the competition. The decisions DIRS had made almost a decade earlier to treat the physics correctly and rigorously on a spectral bases paid off in the late 1990's when interest grew in understanding spectral sensors and scenes. All DIRSIG needed to model imaging spectrometers was expanded spectral data bases; all the physics was already in the models imbedded in DIRSIG.

8-14.DIRSIG oblique nighttime “low light” camera image heavily contrast stretched to show scene detail (right). Note: the different color spectra from the tungsten, mercury and sodium lamps The zoomed image at left shows another contrast stretched DIRSIG “low light” camera image of a portion of the Kodak Hawkeye plant where the light from fluorescent ceiling lights shows through the windows and allows some view into the building.



8-15. DIRSIG thermal infrared image of a facility. The transmission, absorption and self emission of the plume are all modeled along with the temperature and dissipation of the plume.

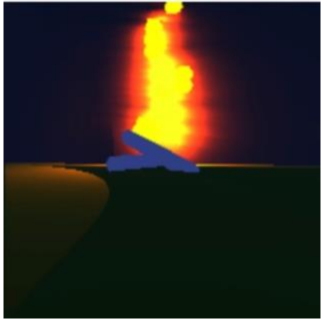
This period also saw interest in modeling new sensors. DIRSIG was modified to simulate Fourier transform infrared (FTIR) sensors and low light sensors (see fig. 8-14). In addition, ability to simulate new phenomenology was added to allow modeling of factory stacks (see fig. 8-15) and chemical weapons plumes which required incorporation of the structure and dynamics of plumes, as well as the emission and scattering properties of plumes (see Kuo et al. 2000). To take advantage of the low light sensing capabilities, the ability to model the spatial and spectral distribution in the intensity of artificial light sources also had to be added (e.g. tungsten, sodium and mercury street lights, fluorescent lights shining from windows and auto head lights) (see Ientilucci et al. 1998). Emmett Ientilucci who had developed the low light capability in DIRSIG as his Masters thesis project joined the DIRS staff and would go on to obtain his Ph.D with Schott. The interest in DIRSIG was very broad. Sponsors included the intelligence community, the Army’s Aberdeen Lab, DOE-LANL, and aerospace contractors.

For quite some time Schott had been trying to convince RIT to hire additional remote sensing faculty to; offer additional courses, help with student and staff supervision, and to increase research volume. While the research staff helped with some of the student mentoring and managed some of the smaller programs, Schott was responsible for nearly all of the student’s research work and for writing most proposals and managing most of the research. The CIS

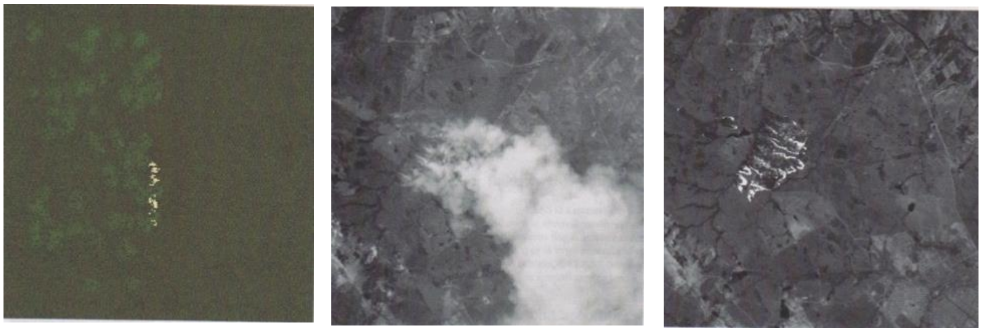
8-16. Tony Vodacek shortly after joining RIT faculty.

8-17. Mike Richardson at his desk (~2000).

faculty had always pushed back saying more diversity was needed before CIS added depth. Finally, in 1998 CIS hired Dr. Tony Vodacek to join the faculty (see fig. 8-16). Vodacek was wrapping up a post-doc at the University of Maryland and was a recent Cornell Remote Sensing graduate. As Vodacek was settling in he was finishing some work from Maryland and started some small efforts at RIT on his specialty area of water quality. This work included mapping of bottom-type and water depth, atmospheric compensation of NASA's Sea WIFS data and water sample analysis as part of a team studying Lake Superior. Then in 1999 DIRS was awarded a grant to locate forest fires from space. This was an earmark that directed NASA to jointly fund a study (FIRES) by RIT and an Italian space agency with RIT as the lead. This had been justified based on DIRS former work for NASA and their expertise on thermal infrared sensing. Since Vodacek had not yet established any significant funding, Schott recommended Vodacek take on this very substantial project (the sour taste of the last earmark might also have played a part in this). In 2000, as the FIRES project was still getting underway, the CIS director, Ian Gatley, hired Mike Richardson from Kodak FSD as a distinguished researcher to help develop new funding sources and to help manage research contracts (see fig. 8-17). This was a new function at CIS and Gatley hoped Richardson could help some of the faculty initiate or expand their research activities. In practice, FIRES had just started up. Vodacek had scientific skill but no experience with managing large projects. So Richardson was put on the FIRES contract part time to help manage it while he spent the rest of his time looking for ways to grow research at CIS.



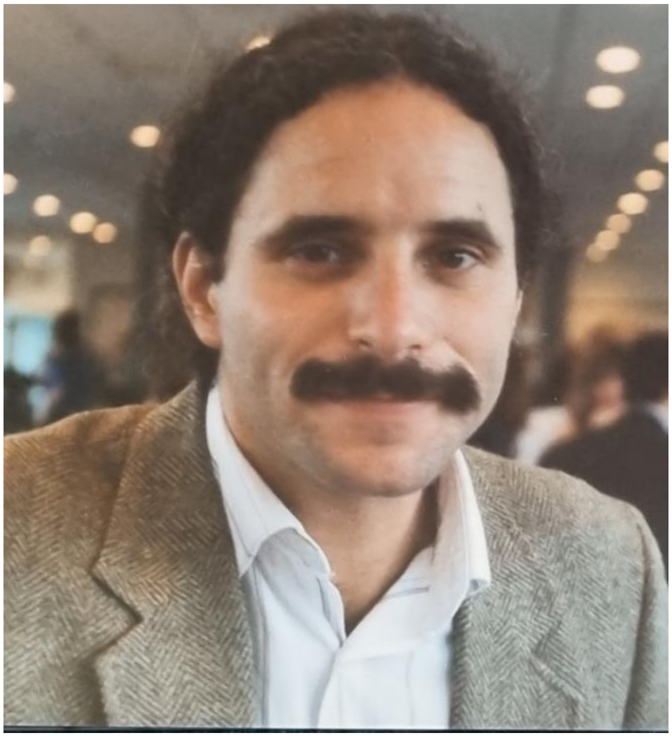
8-18. Early true color simulation of a fire in DIRSIG as the physics of fire are initially added to the model and tested.



8-19. DIRSIG visible image of a grass fire at the edge of a forest canopy (left) and AVIRIS images of an actual fire in the blue region of the spectrum (center) showing smoke obscuration and in the short wave infrared (right) showing significant smoke penetration, raising the question of whether thermal infrared sensors are necessary for fire detection.

The first years' work on FIRES included three directions. A survey to assess user's needs for detection and monitoring forest fires. Initiation of development of tools to simulate forest fires in DIRSIG (see fig. 8-18) and planning of MISI flights over fires (see fig. 8-19). The last two efforts were intended to help better understand the physics of fires and fire sensing and to look for alternatives to sensing in the LWIR (which can be cost prohibitive).

As the millennium came to an end and another began it was a time of reflection. This kicked off on a bittersweet note as DIRS threw a going away party for Carolyn Kitchen, who had organized so many events for DIRS over nearly 20 years. Kitchen came on as the Department/DIRS secretary shortly before the Center was formed in 1985. Her desk sat in the remote sensing lab right outside the door to the storeroom Schott used as an office. Shortly after she started Schott, and one of his favorite grad



8-20. William (Billy) Volchok as a student.

8-21. Carolyn Kitchen at her desk in the new Center for Imaging Science Building.

students, Bill (Billy) Volchok (see fig. 8-20), came in on a Saturday and built partition walls to form an office of sorts which Kitchen commanded until moving to the new building. Her office in the new building had her guarding access to Schott for over another decade (see fig. 8-21). She was very devoted to DIRS which she saw through both the good and the bad, and she was much loved by the students. The Air Force grads (current and past) in particular paid special tribute to Kitchen at her retirement party (fig. 8-22, and fig. 8-23). She served as Schott's executive secretary (though RIT didn't use the term). In the days before desktop computers, she typed and filed all the memos, proposals, and reports. Her IBM Selectric typewriter always had several font balls sitting beside it which had to be swapped out several times to type the involved equations that showed up in every proposal, report and journal article. Over the years she would quickly convert to the first generation of word processors (Xerox), followed by a rapidly changing range of computers. As DIRS grew, she helped design and then operate an accounting system to let DIRS function much more quickly than the Institute's accounting system would allow. She learned how to efficiently move proposals and contracts through the RIT labyrinth where papers could take a day or more to move from office to office for signature (5 signatures – 2 weeks). Before cell phones and internet, nearly all-important communications took place over the phone. Kitchen knew all of DIRS' long-term sponsors and contacts and who to put off and who to put on hold while she tracked Schott down. More often the sponsors knew who ran the show and would just ask Kitchen the status of a report, contract, bill payment … She had the same role when it came to mail (snail and later email). She filtered all the mail, passing on to Schott what he needed to deal with and taking care of the

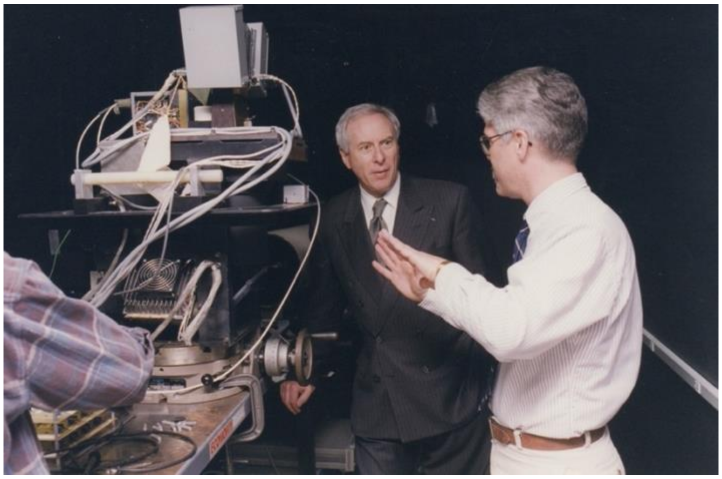
8-22. Carolyn Kitchen receiving a shadow box from some of the US Airforce students who could make it to her retirement.

8-23. Picture of the shadow box the Airforce students spanning many years presented to Carolyn Kitchen to honor her contributions on her retirement.

rest herself. It is hard to even remember today, but in the early days with no internet just making travel plans would require a travel agent (who could "see" flight schedules) to make flight, hotel and rental car reservations. Kitchen knew Schott's business travel needs/preferences and would save him, and later the rest of DIRS, hours booking travel for business meetings as well as the often much more complex arrangements for field work.

Kitchen became the face of DIRS all across campus. RIT's systems were set up to deal with faculty teaching undergraduate students. The master's degree programs were mostly set up to serve local employers with part-time students doing non-research-based thesis. The systems to support teaching of undergraduates also worked fine for these masters programs. Salaries, and where they came from, only changed annually, or at most quarterly. Purchasing was largely done quarterly for the next quarter. New accounts were rarely opened or closed. Staff salaries, position descriptions and career ladders were set up for administrative staff or stock clerks. They were not set up for research staff with credentials and salaries that made them look more like faculty. In order to be successful, DIRS had to use a different business model and different systems. However, DIRS was a tiny group in a giant organization and while a few senior people might want them to succeed, the rest of the organization had its own entrenched ways of doing business. Over and over in the early decades as DIRS grew and needed more or different things from the RIT systems, they were told we don't do that, you can't do that, or that will take months. Schott quickly learned to latch onto the few individuals whose response was closer to "we have never done that but let me figure out how we can". Whenever possible he would return to them over and over to widen the chinks in the administrative armor. More often than not DIRS just set up their own systems (accounting, time cards, petty cash, job descriptions, career ladders etc.) and did nearly everything with RIT through a host of one-time adjustments (charge backs) all of which were done manually in the early days. To move forward quickly, Schott was forced to adapt an attitude of just moving forward when personnel, payroll, accounting, human resources, purchasing, or grants and contracts said "no". Kitchen was left to help set up a DIRS' system that worked for DIRS, and then try to adapt it to RIT's cumbersome infrastructure (i.e., clean up Schott's mess). As a result, she ended up working all across the Institute's systems ranging from hand carrying proposals to be signed by the President's, VP's and Dean's offices and mailed that day, not in a week or two, to standing in line at the treasurer's windows with stacks of travel reimbursement and purchase receipts that hadn't gone through a handful of preapprovals, but had been paid in advance by DIRS. Kitchen was meticulous in keeping the books and paper trails and making sure the DIRS' accounts squared with the RIT accounts when the RIT accounts finely caught up months later. Because of her competence and intricate knowledge of the RIT systems (learned over the years of trying to force them to do things they weren't set up to do), she became well known and trusted by people across the Institute and at all levels of the administration. In many ways it helped that DIRS didn't officially exist. Schott, as a faculty member, in theory worked for the head of the department or Center, but Schott insisted over and over that the staff recognize that they worked for the research sponsors and the students and that the students realize they also worked for the research sponsors. The staff were RIT employees but they were paid from grants and contracts (and in practice worked for DIRS which didn't exist). DIRS had no budget from the Institute and showed up on none of the Institute's financial or personnel charts. Schott was hired to build a research enterprise and was pretty sure key people in the senior administration supported the idea of research, although he didn't meet with them regularly. No one had necessarily thought through all that meant in terms of infrastructure. His "I can't wait and it is far better to seek forgiveness than permission" approach alienated more than a few mid-level bureaucrats (particularly when he reminded them, that from his view, they worked for him and not the other way around). Luckily in most cases Kitchen figured out a way to work around, or between, the Institute's regulations and kept DIRS infrastructure moving. So, it is not surprising that people from all levels of the Institute showed up to wish Kitchen well when she retired in January of 2000.

By 2000, DIRS had regrouped and grown to two faculty, eight technical staff, and one administrative staff. The two-year 1998/2000 "annual report" lists over 50 students affiliated with DIRS (these were mostly M.S and Ph.D. students along with a few undergrads doing their senior capstone projects with DIRS). DIRS' contract volume had grown to about ¾ of a million dollars annually. As Schott reflected on where the end of the millennium had brought DIRS, he realized they were achieving the goal of being a research group playing a significant role on the national stage. This was exemplified in a visit to the lab in 1999 by Dr. Dan Goldin the NASA Administrator (see fig. 8-24). It was time to take stock and set a new goal. DIRS collectively set itself the goal of becoming the first-place government and industry labs would turn when looking for remote sensing research. They recognized trying to obtain this goal across the broad field of remote sensing was unrealistic and focused the goal to cover research into the science of remote sensing (i.e. the research that involved building the fundamental tools that would support a broad range of applications). This would continue the group's established focus on studying the science underlying the entire image chain, from the phenomenology/physics of the target/scene, through the illumination/radiation propagation, sensing, storage, processing and analysis. To accomplish this, the DIRS' team recognized they must become a bigger player, not for the sake of being bigger, but to increase their visibility. They also reaffirmed the mantra of under promising and over delivering which is what DIRS was built on and was why so much of DIRS' work came from returning sponsors.

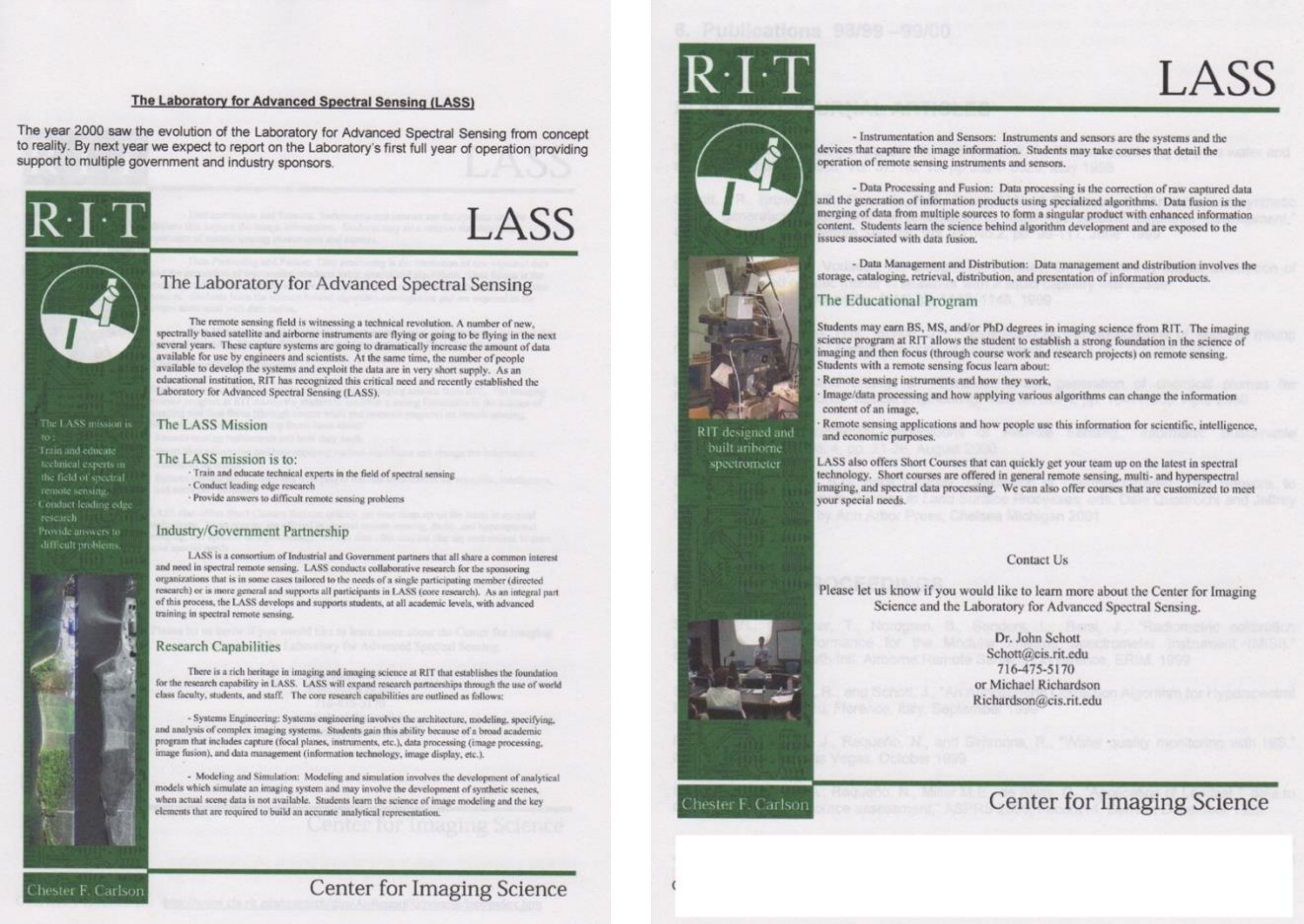


8-24. NASA Administrator, Dr. Dan Goldin and Schott discussing the DIRS MISI instrument during Goldin's visit.

9. Rapid Growth 2000 – 2005

Richardson was hired by CIS to grow research volume by helping faculty to make contacts and get proposals submitted and to manage the administrative side of larger research programs. Schott and Richardson were compatible and Richardson (having figured out that if he was to successfully grow research at CIS, he would have to focus on DIRS where there was a significant research base, i.e. something to sell) was soon working fulltime for DIRS. Richardson would quickly take over the administrative management of most of the DIRS projects leaving the faculty, and Schott in particular, to manage the science. This let Schott focus on what he loved, and freed up so much time, that Schott was willing and able to pursue more and larger programs. In 2000, Schott and Richardson dreamt up a rather unorthodox and far-reaching idea. The development by NASA and the defense/intelligence community of a few airborne spectral imaging test beds in the mid to late 1990's had whet the remote sensing communities' appetite for high dimensional data (many spectral bands – many sensing modalities). However, the field was so young that there were many unanswered questions concerning sensors, target/background phenomenology, data processing algorithms, and applications. The promise was enormous, but with so few sensors, most scenarios/sites had never been imaged even once. The requirements for achieving any level of exploitation performance were unknown (what bands, what spectral resolution, what signal-to-noise). Finally, the traditional algorithms could not be simply expanded to include more bands. Whole new algorithmic tools needed to be developed. Schott and Richardson recognized this was a huge undertaking. The large government labs and aerospace contractors would be looking to build new sensors and would prefer lucrative hardware contracts to much smaller more fundamental science studies. On the other hand, government and aerospace contractors needed better fundamental science knowledge and tools to effectively design and build these new sensors. The DIRS idea was to form a government-industry-university consortium to conduct some of the fundamental non-proprietary research interested parties needed. The government would benefit by having a better idea of where to invest more focused efforts. Industry would benefit by being able to focus more of their efforts on proprietary sensor designs based on better fundamental understanding and RIT would benefit by doing the research. In addition, all the players would benefit by all the students (future employees) who would move through the academic program and support the research. This all sounded feasible but historically these types of consortia were hard to set up and maintain because of real or perceived conflicts between government and industry and in particular, conflict between competing industrial players. Nevertheless, Schott and Richardson felt the nearly universal lack of background knowledge regarding high dimensional data in general, and hyperspectral (many spectral band) data in particular, made for a compelling argument. The sales argument for "why DIRS" was strengthened by the sizable number of spectral imaging programs DIRS had contributed to over the past decade and their experience building and operating an airborne imaging spectrometer.

Convinced they had the right idea at the right time and DIRS was the right place to make it happen, Schott and Richardson scheduled a trip to visit four potential team members. When they returned, they had four multi-year commitments for annual support of $75,000 or more from each member. These were not the usual "it sounds like a good idea, but we will have to talk it out amongst ourselves and kick it upstairs for further review". The response was "we want to be a part of the team and we are happy to sponsor a share of the research". To be clear, these were not cold calls, Schott or Richardson or both had a history with the potential members. In addition, they had visited a government agency first and secured their commitment. Most of the aerospace companies saw the chance to meet informally with government scientists and talk about where the field was going as an additional incentive to sign on. As a result, the Laboratory for Advanced Spectral Sensing (LASS) was formed with four founding members (the NRO, ITT, Boeing, and Kodak Commercial and Government Systems - formerly FSD). At this point, Schott and Richardson slowed down to give DIRS a chance to absorb the large



The Laboratory for Advanced Spectral Sensing (LASS)

The year 2000 saw the evolution of the Laboratory for Advanced Spectral Sensing from concept to reality. By next year we expect to report on the Laboratory's first full year of operation providing support to multiple government and industry sponsors.

R·I·T

LASS

The Laboratory for Advanced Spectral Sensing

The remote sensing field is witnessing a technical revolution. A number of new, spectrally based satellite and airborne instruments are flying or going to be flying in the next several years. These capture systems are going to dramatically increase the amount of data available for use by engineers and scientists. At the same time, the number of people available to develop the systems and exploit the data are in very short supply. As an educational institution, RIT has recognized this critical need and recently established the Laboratory for Advanced Spectral Sensing (LASS).

The LASS mission is to :
· Train and educate technical experts in the field of spectral remote sensing.
· Conduct leading edge research
· Provide answers to difficult problems.

The LASS Mission

The LASS mission is to:
· Train and educate technical experts in the field of spectral sensing
· Conduct leading edge research
· Provide answers to difficult remote sensing problems

Industry/Government Partnership

LASS is a consortium of Industrial and Government partners that all share a common interest and need in spectral remote sensing. LASS conducts collaborative research for the sponsoring organizations that is in some cases tailored to the needs of a single participating member (directed research) or is more general and supports all participants in LASS (core research). As an integral part of this process, the LASS develops and supports students, at all academic levels, with advanced training in spectral remote sensing.

Research Capabilities

There is a rich heritage in imaging and imaging science at RIT that establishes the foundation for the research capability in LASS. LASS will expand research partnerships through the use of world class faculty, students, and staff. The core research capabilities are outlined as follows:

- Systems Engineering: Systems engineering involves the architecture, modeling, specifying, and analysis of complex imaging systems. Students gain this ability because of a broad academic program that includes capture (focal planes, instruments, etc.), data processing (image processing, image fusion), and data management (information technology, image display, etc.).

- Modeling and Simulation: Modeling and simulation involves the development of analytical models which simulate an imaging system and may involve the development of synthetic scenes, when actual scene data is not available. Students learn the science of image modeling and the key elements that are required to build an accurate analytical representation.

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- Instrumentation and Sensors: Instruments and sensors are the systems and the devices that capture the image information. Students may take courses that detail the operation of remote sensing instruments and sensors.

- Data Processing and Fusion: Data processing is the correction of raw captured data and the generation of information products using specialized algorithms. Data fusion is the merging of data from multiple sources to form a singular product with enhanced information content. Students learn the science behind algorithm development and are exposed to the issues associated with data fusion.

- Data Management and Distribution: Data management and distribution involves the storage, cataloging, retrieval, distribution, and presentation of information products.

The Educational Program

Students may earn BS, MS, and/or PhD degrees in imaging science from RIT. The imaging science program at RIT allows the student to establish a strong foundation in the science of imaging and then focus (through course work and research projects) on remote sensing. Students with a remote sensing focus learn about:
· Remote sensing instruments and how they work,
· Image/data processing and how applying various algorithms can change the information content of an image,
· Remote sensing applications and how people use this information for scientific, intelligence, and economic purposes.

RIT designed and built ariborne spectrometer

LASS also offers Short Courses that can quickly get your team up on the latest in spectral technology. Short courses are offered in general remote sensing, multi- and hyperspectral imaging, and spectral data processing. We can also offer courses that are customized to meet your special needs.

Contact Us

Please let us know if you would like to learn more about the Center for Imaging Science and the Laboratory for Advanced Spectral Sensing.

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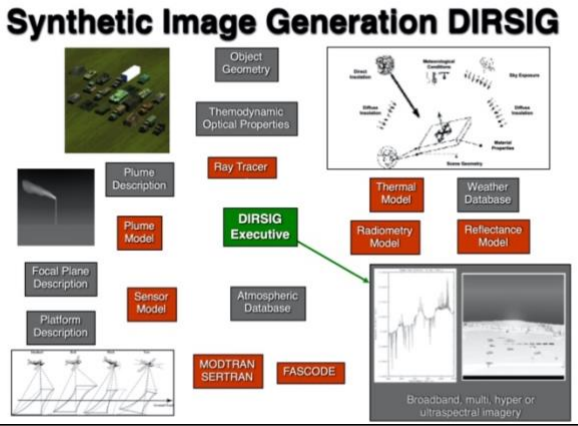
716-475-5170
or Michael Richardson
Richardson@cis.rit.edu

Chester F. Carlson

Center for Imaging Science

9-1. LASS brochure DIRS used to promote the new Laboratory for Advanced Spectral Sensing in the early 2000's.

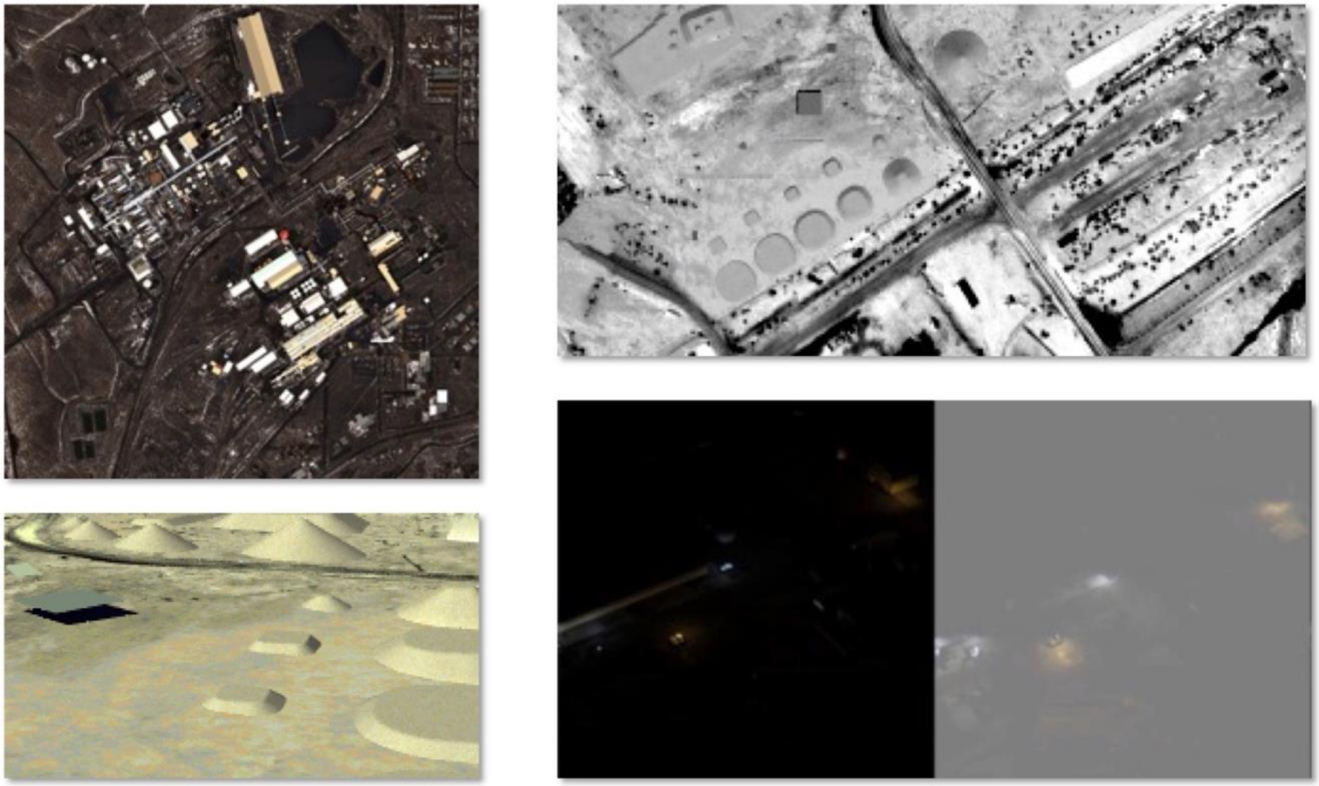
influx of new work. This didn't last long and by 2005 DOE's Los Alamos National Laboratory (DOE – LANL) and Lockheed Martin had also joined the LASS team. The LASS projects were typically multiyear with topics and funding allocation agreed to at an annual meeting and all results shared with all members and published in the open literature (see fig. 9-1). This gave LASS sponsors a couple years competitive head start on new science as they would see results at the semiannual meetings and publication of research results typically lagged by a year or more. In addition, some members funded additional projects of specific interest to them which could be kept confidential until published in theses or in the open literature (though this option of confidentiality was seldom exercised).



9-2. Flow chart showing some of the components of the DIRSIG model in the early 2000's.

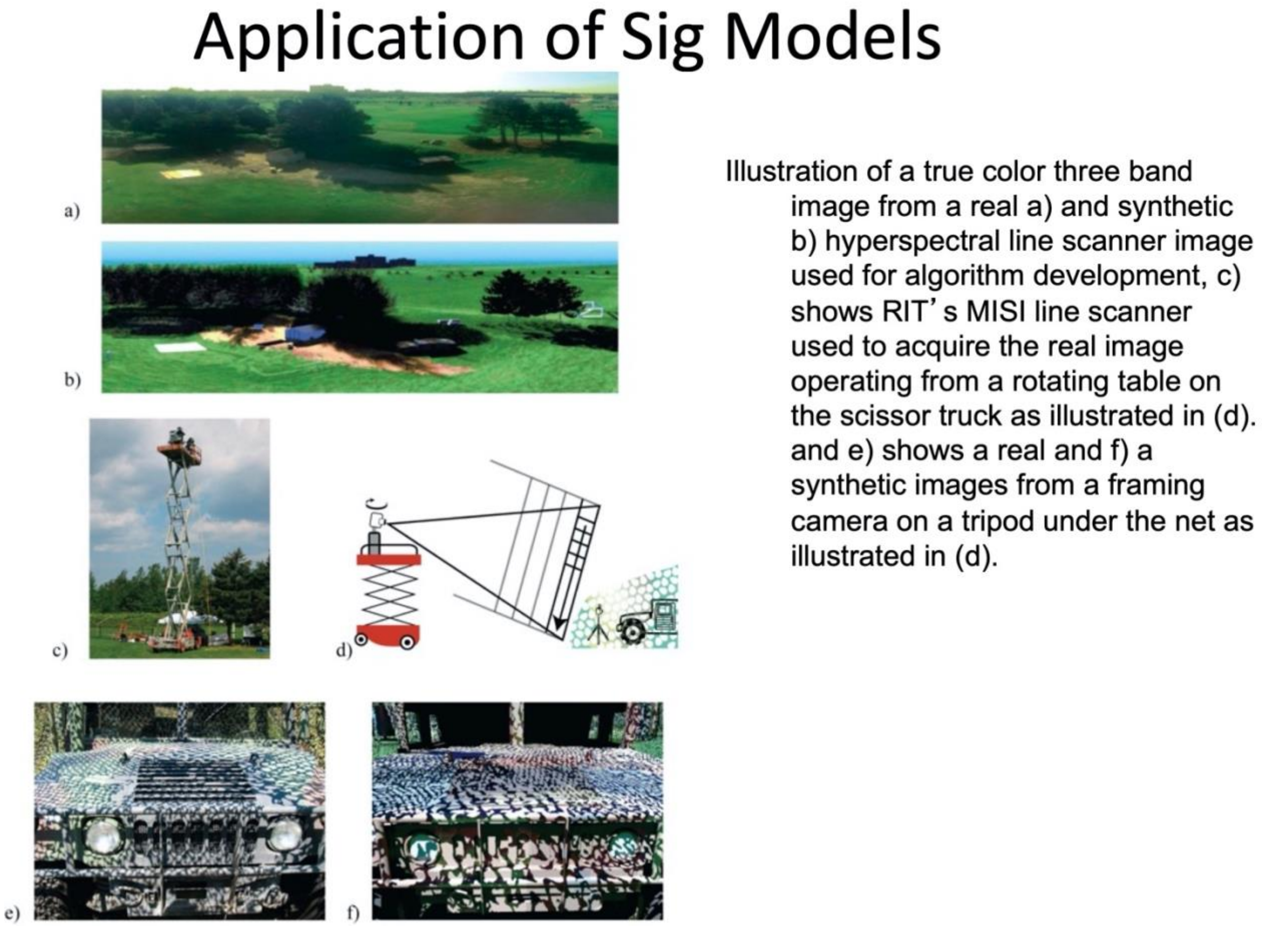
Under the LASS umbrella, DIRS took on a wide range of projects in the early 2000's with many of them linked somehow to the DIRSIG model (see fig. 9-2). Two large area scenes were built to support development and testing of image analysis algorithms by the wide array of DIRSIG users in government and industry. Up to this point, DIRSIG scenes had tended to be of very localized sites (e.g. a specific factory or hanger). Megascene I involved building a large section of Rochester in the DIRSIG environment suitable for imaging from the visible through the LWIR (see fig. 9-3), Megascene II was of a huge factory site in Trona, CA including the surrounding desert region (see fig. 9-4). Of course, if you've got megascenes you need a

9-3. True color rendering of a portion (approximately 20%) of the DIRSIG Megascene 1 (left) and zooms showing the detail present in the scene.



9-4. True color image of a portion of the DIRSIG Megascene 2 site (top left), DIRSIG image of a portion of the scene showing spoil piles (top right), detail of spoil piles (bottom left) and enhanced and original DIRSIG simulation of a "low light" image of a small section of the Megascene 2 site.

microscene to show off the detail that exists in all DIRSIG images. Consequently, a very detailed scene was imaged with the MISI instrument and created in DIRSIG (see fig. 9-5). As this work developed, improvements to properly model spatial-spectral texture were developed (see fig. 9-6) and implemented.



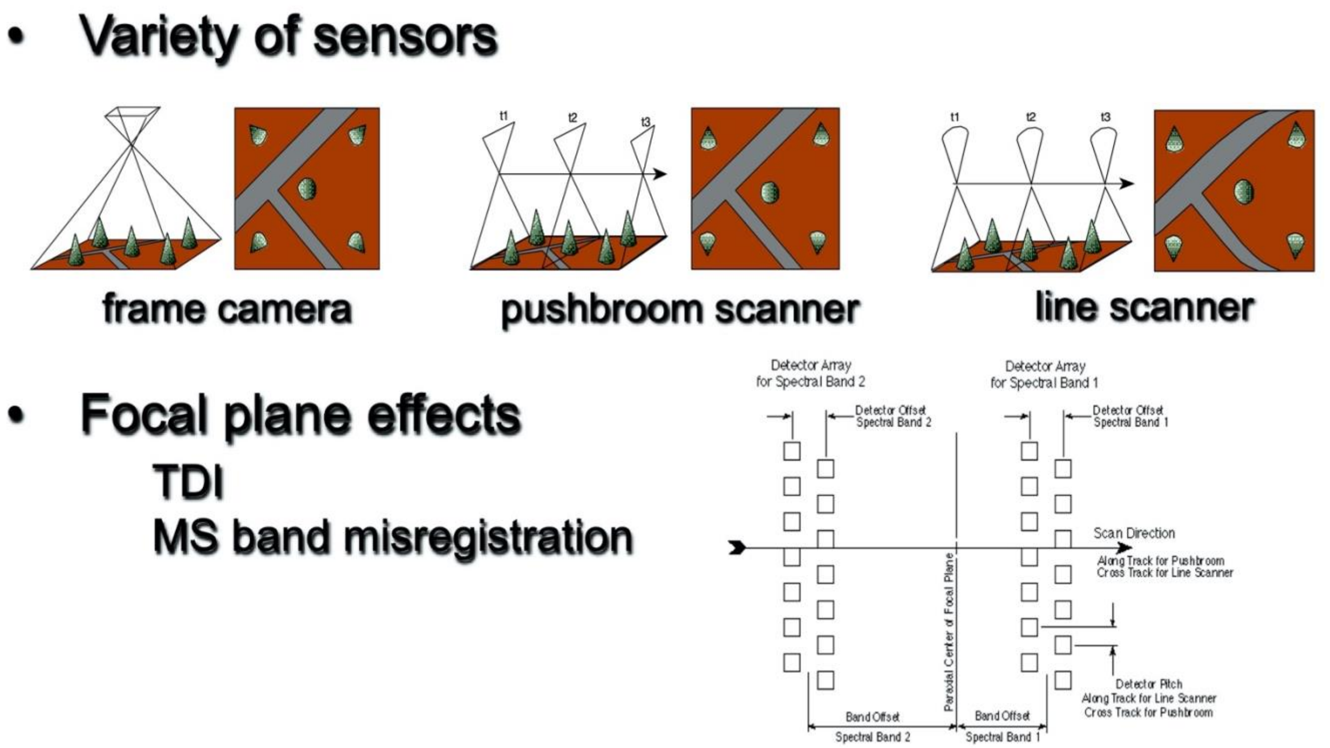
Application of Sig Models

Illustration of a true color three band image from a real a) and synthetic b) hyperspectral line scanner image used for algorithm development, c) shows RIT's MISI line scanner used to acquire the real image operating from a rotating table on the scissor truck as illustrated in (d). and e) shows a real and f) a synthetic images from a framing camera on a tripod under the net as illustrated in (d).

9-5. The DIRSIG micro-scene used a portion of the RIT campus that was imaged with MISI from a scissor jack as well as a framing camera under the camouflage net.

9-6. DIRSIG scenes showing spatial and spectrally correlated texture detail in targets and backgrounds.

Another LASS push was to build better sensor models into DIRSIG to allow simulation of the imaging geometry of a wide range of sensors (e.g. framing arrays, line scanners, and push-broom scanners (see fig. 9-7)). Other new scene development tools included properly accounting for the terrain elevation and path length effects the atmosphere induces on the sensor reaching radiance (see fig. 9-8) and beginning to incorporate the effects of participating media (e.g. water) to eventually allow littoral zone simulations (see fig. 9-9). Among the most fundamental changes begun during these years, as part of LASS, was adding new sensing modalities to DIRSIG scene and sensor models. LIDAR source, propagation and sensing models were added, as were polarimetric material properties, propagation and sensing (see fig.



- **Variety of sensors**

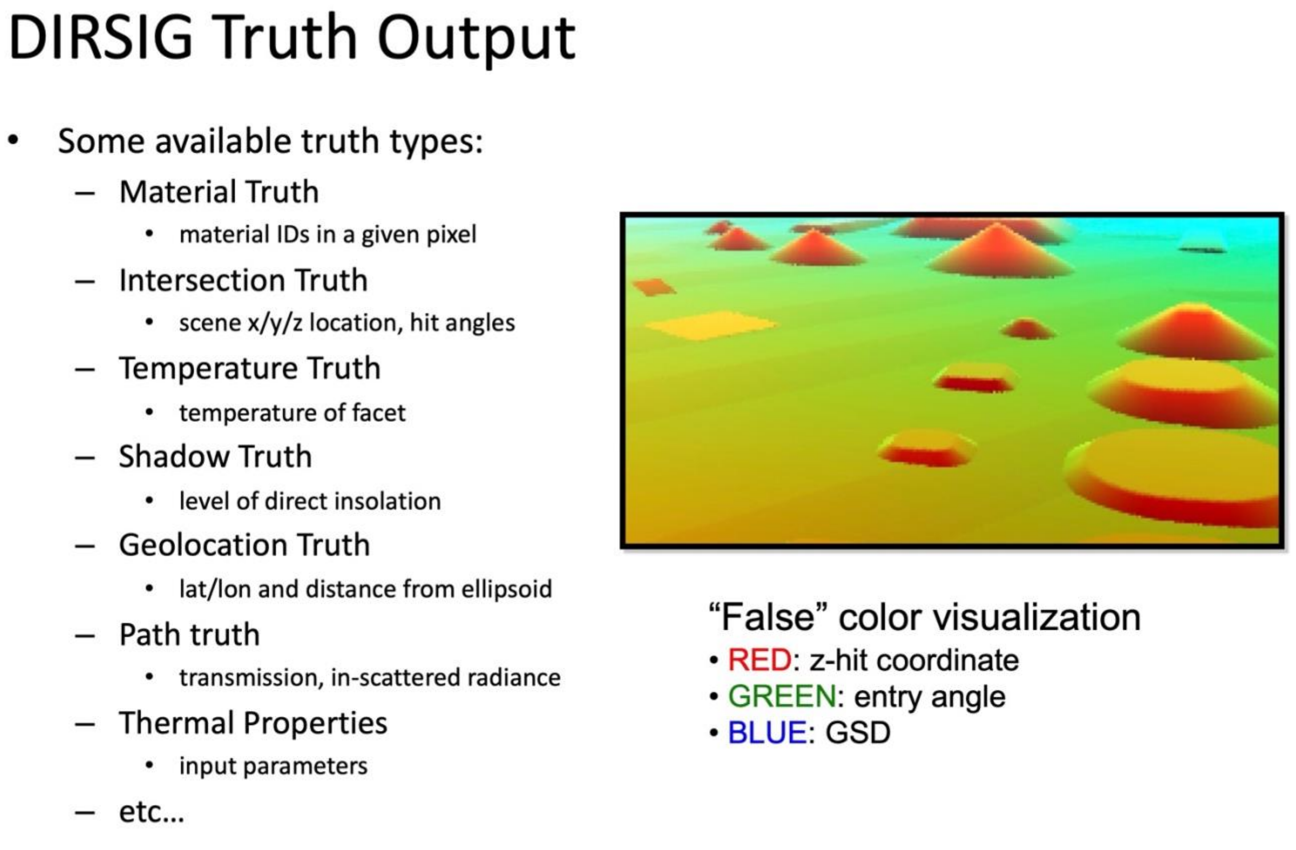
frame camera

pushbroom scanner

line scanner

- **Focal plane effects**
  - TDI
  - MS band misregistration

9-7. Illustration of the level of sensor geometric complexity that can be modeled with the DIRSIG sensor models.



DIRSIG Truth Output

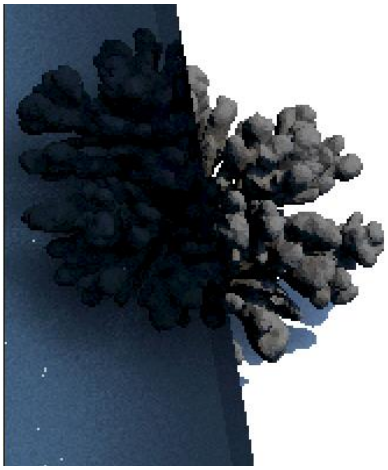
- Some available truth types:
  - Material Truth
    - material IDs in a given pixel
  - Intersection Truth
    - scene x/y/z location, hit angles
  - Temperature Truth
    - temperature of facet
  - Shadow Truth
    - level of direct insolation
  - Geolocation Truth
    - lat/lon and distance from ellipsoid
  - Path truth
    - transmission, in-scattered radiance
  - Thermal Properties
    - input parameters
  - etc…

"False" color visualization

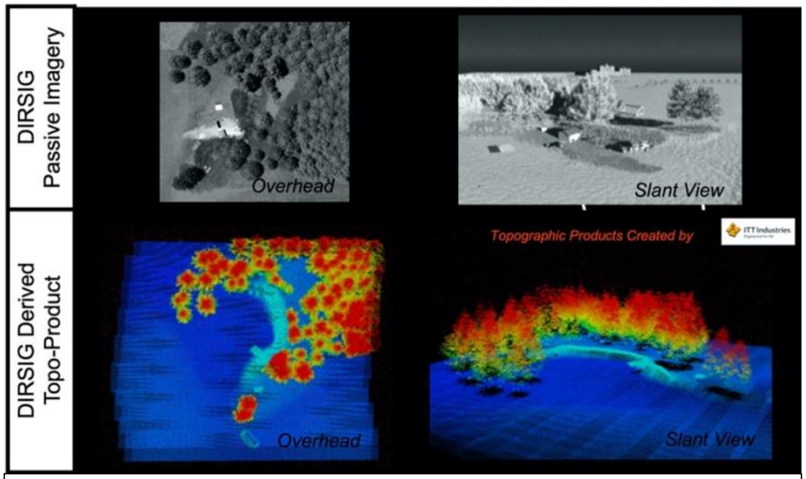
- RED: z-hit coordinate
- GREEN: entry angle
- BLUE: GSD

9-8. Illustration of "truth" data available from the DIRSIG model including elevation and distance from target.

9-10, and fig. 9-11). Early efforts to simulate sparse aperture sensors were also introduced (see fig. 9-



9-9. DIRSIG simulation of what a piece of coral would look like in a block of water (left) and not in the water (right) showing the effects of participating media being developed in DIRSIG in the early 2000's.

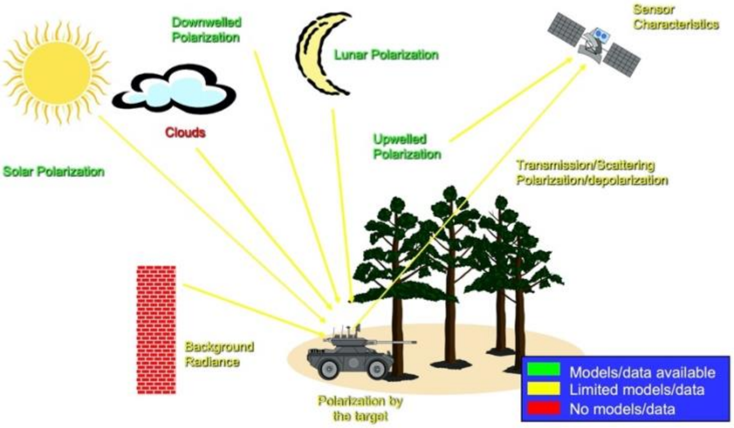


9-10. Illustration showing DIRSIG ability to model topographic LIDAR in the early 2000's.

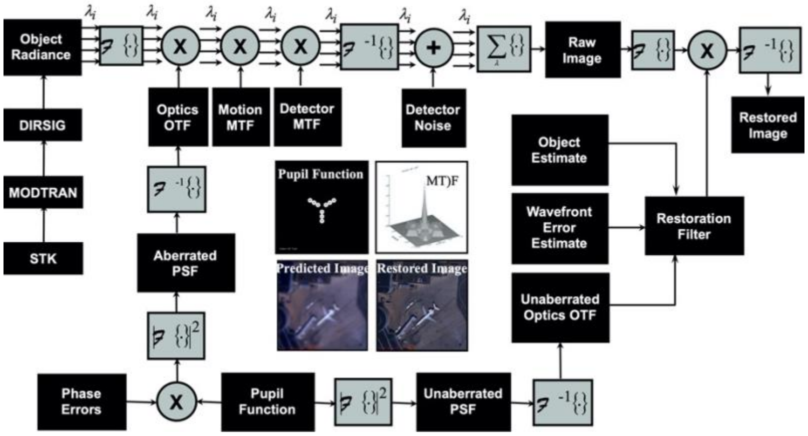
12) and the very first steps toward eventually adding synthetic aperture radar (SAR) to DIRSIG were explored (see fig. 9-13).

In addition to and in support of the DIRSIG activities, a major push to develop and operate a spectral measurement laboratory took place as part of LASS. This involved acquisition and operation of laboratory and field instruments to build spectral data bases of materials from the visible through the LWIR. On the algorithm side, efforts focused on development and testing of automatic image to image registration algorithms and a comparison of spectral target detection algorithms (see fig. 9-14, and fig. 9-15).

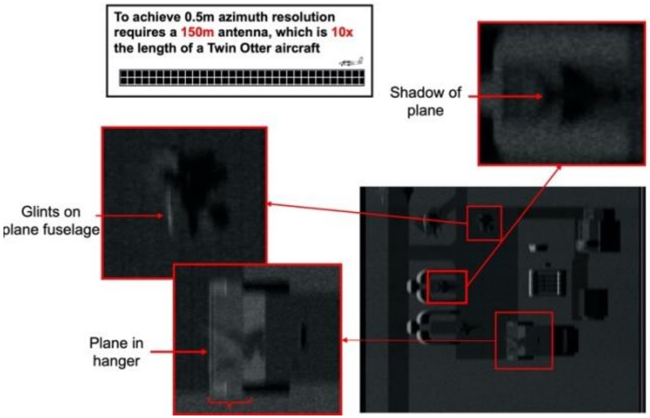
As the LASS activities were spinning up, Dr. Carl Salvaggio rejoined CIS as a faculty member and would soon become head of the DIRS Measurements and Experiments Group. To manage the large number of staff and students, DIRS set up a flexible internal structure to simplify day-to-day organization and management. In addition to the measurements group, Scott Brown headed up the Modeling and Simulation Group, Dr. David Messinger, who joined the DIRS staff in 2002, headed the Algorithms and Phenomenology Group (see fig. 9-16), and Dr. Vodacek headed the Fires Group. Cindy Schultz joined DIRS as the administrative assistant after Kitchen retired and quickly became a group resource and student confidant (see fig. 9-17).



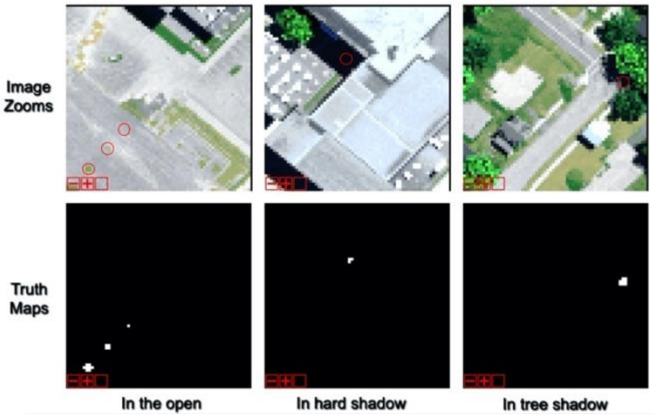
9-11. Illustration of some of the physics that had to be included in the DIRSIG polarimetric image models.



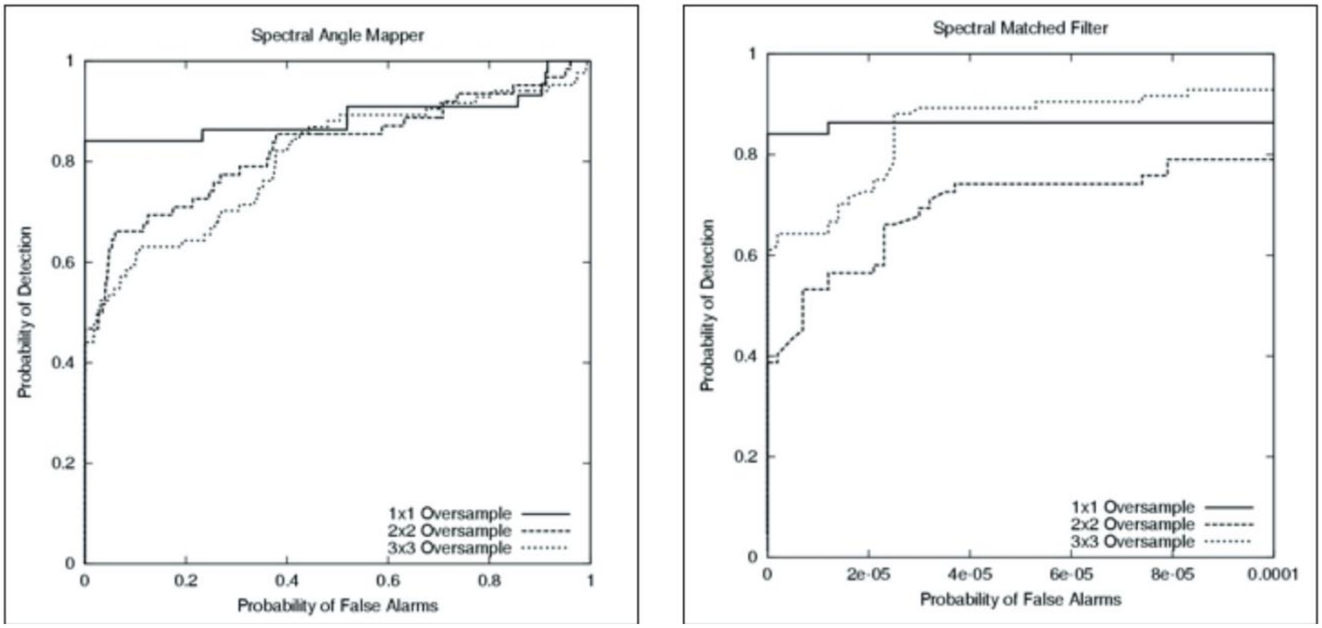
9-12. Illustration of the physics and data processing that was added to DIRSIG post processing to allow the full spectral simulation of the artifacts introduced using sparse aperture imaging systems.



9-13. Illustration of the way RADAR modeling that was initially added to DIRSIG in the early 2000's.



9-14. As DIRSIG became more sophisticated, it was increasingly used to test algorithms. In this illustration targets (circled in red) were placed in the open, in full shadow and in tree shadow to test the impact of shadows on a target detection algorithm with results shown at bottom.

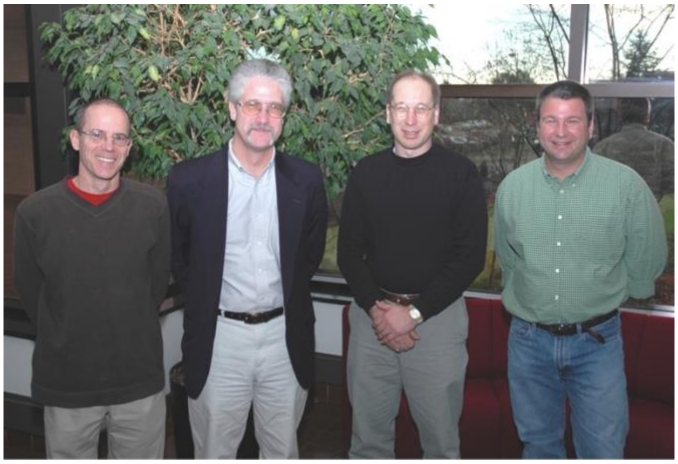


9-15. Receiver operator characteristic (ROC) curve showing the performance of a pair of target detection algorithms on various resolutions of DIRSIG images.

9-16. Dave Messinger in office in early 2000's.

9-17. Cindy Schultz at the top of staircase in CIS in early 2000's.

In 2004 Dr. John Kerekes became the fourth faculty member to join the DIRS group (see fig. 9-18). Dr. Kerekes had completed his Ph.D. at Purdue working in the Laboratory for Applications of Remote Sensing (LARS) group. He then worked for several years at the MIT Lincoln Labs. Not long after joining DIRS, Kerekes kicked off a multi-year project for AFRL looking at modeling scenes in support of multi-sensor analysis and developing spectral analysis



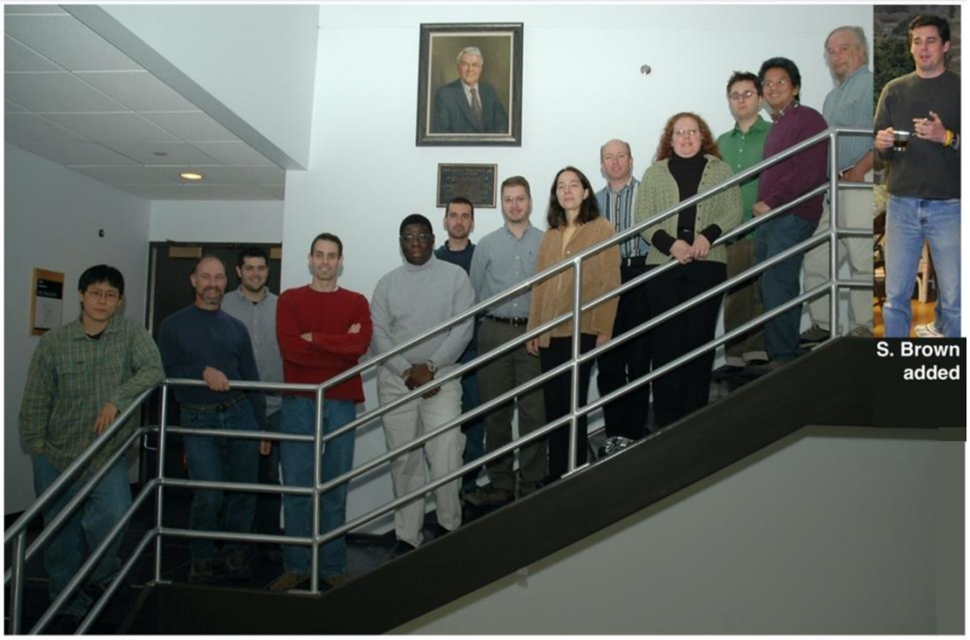
9-18. DIRS faculty 2004, Vodacek, Schott, Kerekes and Salvaggio.

techniques to track vehicles (see fig. 9-19). He also teamed with the CIS medical imaging group to assess the potential to use spectral sensing for medical diagnostic studies.

By 2005 there were 13 research staff and post-docs (see fig. 9-20), 4 faculty, an administrative assistant, and nearly 50 students (from high school interns to Ph.D. students) supporting DIRS projects.

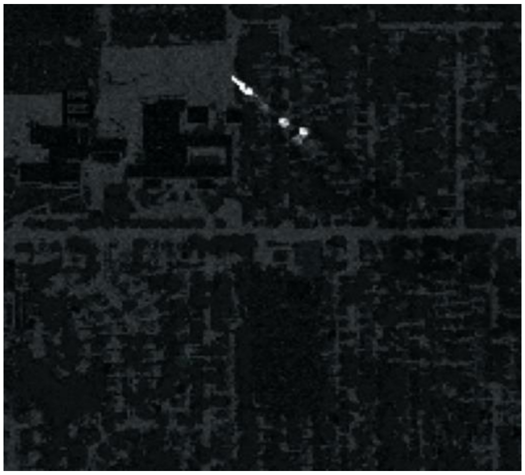
The growing number of faculty and staff were needed as DIRS would go on to be awarded several more major programs in the early 2000's. In 2001/2002 DIRS was awarded its largest single award to date in the form of a Multidisciplinary University Research Initiative (MURI) grant by the Office of Naval research (ONR). This was a 3-year grant (with 2 option years which DIRS would be awarded) exceeding $5,000,000. DIRS primed the effort with subcontracts to UC Irvine and Cornell University. The MURI grants are extremely competitive programs where proposals are solicited for particular research needed by DoD research organizations. Most years, when the request for proposals (RFPs) comes out, there is nothing close to what DIRS does. In 2000, Richardson and Schott

9-19. Vehicle tracking results from a test using the airborne MISI spectrometer over campus. True color image from the CIS roof (left), MISI image showing taget in oval (center) and detection results (right).

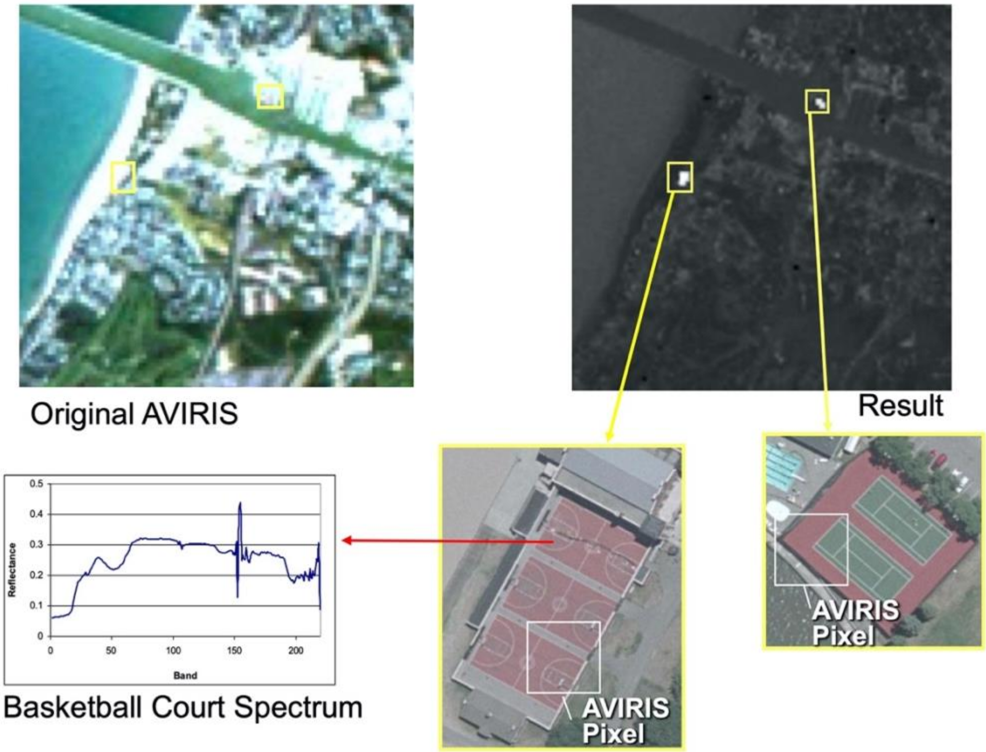


P. Lee, R. Kremens, T. Hattenberger, E. Ientilucci, A. Ononye, N. Sanders, D. Messinger, N. Raqueño, M. Richardson, C. Schultz, D. Pogorzala, R. Raqueño, T. Gallagher

9-20. Photo of DIRS staff 2003-2004 on CIS stairs with Scott Brown added.



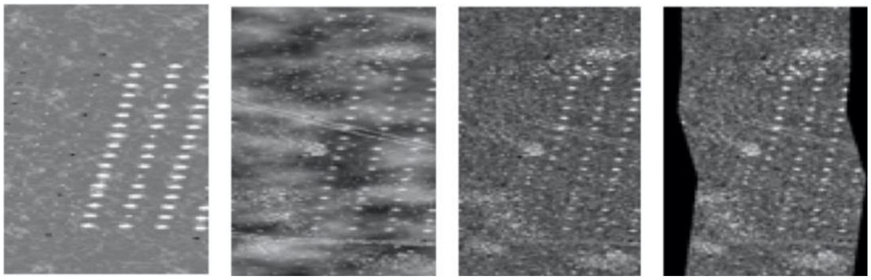
9-21. Target detection algorithm applied to a DIRSIG plume in a DIRSIG image.



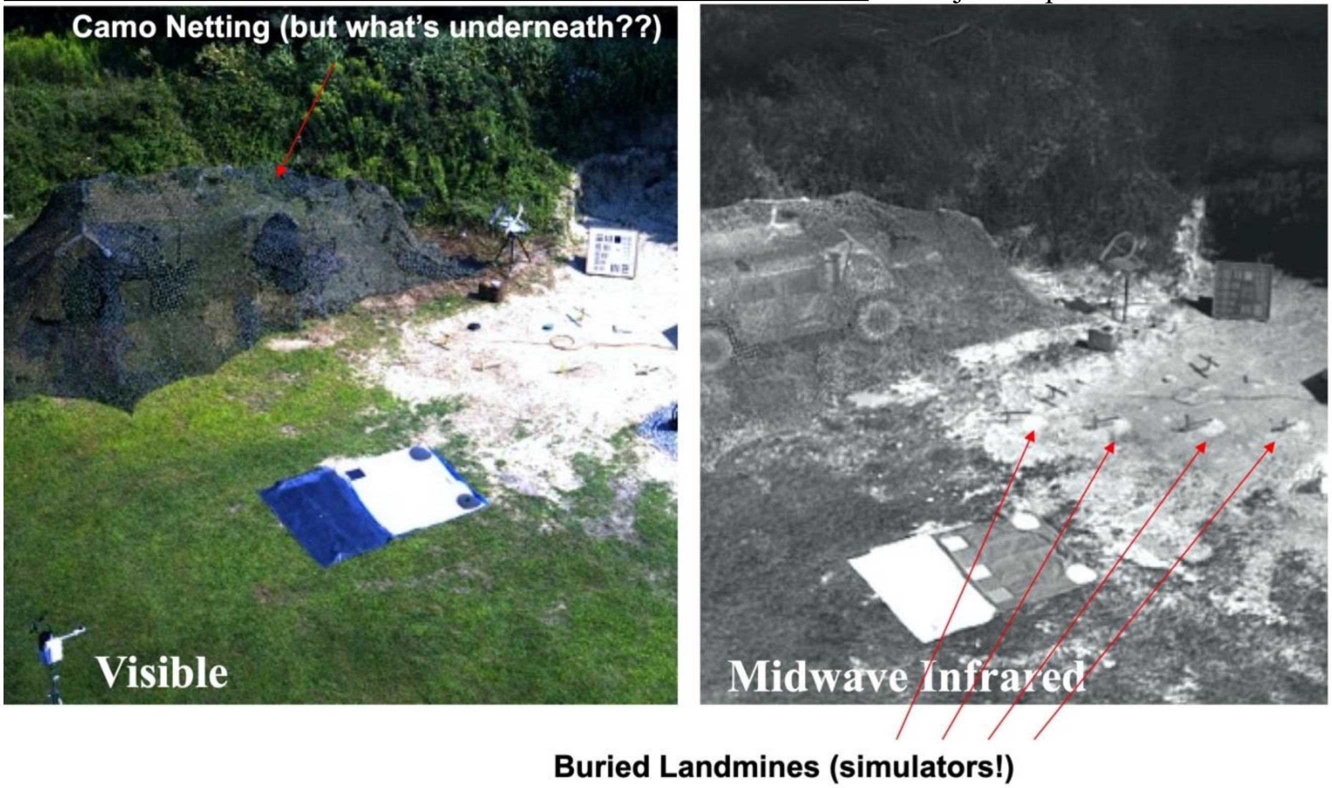
9-22. AVIRIS image of Lake Ontario shoreline (top left), invariant algorithm results (top right), spectrum of red paint supplied to the algorithm (bottom left), and aerial images showing the two targets detected and the size of an AVIRIS pixel indicating that the detections are subpixel.

read one topic in the RFP and agreed that it looked like the authors had been reading DIRS internal memos. The program was targeted at development of a new generation of physics-based algorithms to extract information from imaging spectrometer data. DIRS had for several years been working to improve our knowledge of the physics of remote sensing and incorporate that knowledge into models (DIRSIG) and algorithms. The ONR MURI project supported four thrusts at RIT that would mature over the next 5 years. The first, involving study of the littoral zone, would include major advances in DIRSIG's ability to model the air water interface, the transmission and scattering in the water due to the constituents in the water (chlorophyll, suspended solids, and yellowing organics) and reflection off the bottom. A second thrust was to develop ways to detect and identify the nature of gaseous effluents. This would include work in both ways to model effluents to help predict signatures (see fig. 9-21) and on LWIR spectral detection and identification algorithms. Two other thrusts included characterization of the atmosphere using imaging spectrometer data and development of physics-based models imbedded in target detection algorithms that were minimally impacted by the imaging conditions. These algorithms were based on the concept that by modeling all the ways a target could "look" the spectra could be converted into a new spectral space which was invariant to variations in illumination and atmospheric conditions. The resulting "physics-based" invariant algorithms are very powerful tools in target detection and land cover mapping (see fig. 9-22).

The next year, 2002/2003 Schott and Richardson were surprised to see another MURI RFP that spoke to DIRS capabilities. Deciding that leading two MURI's back-to-back was a stretch they choose to team as potential subcontractors on two other proposals. When the awards were announced the Army Research Office (ARO), who was the sponsor, had asked the two universities DIRS had teamed with to merge their teams leaving RIT a good share of the new grant. This effort was led by the Georgia Tech Research Institute (GTRI) with RIT and the University of Maryland as subcontractors. Its focus was on



9-23. Illustration showing the evolution of the DIRSIG land mine scene as more and more phenomenology was added to the model.

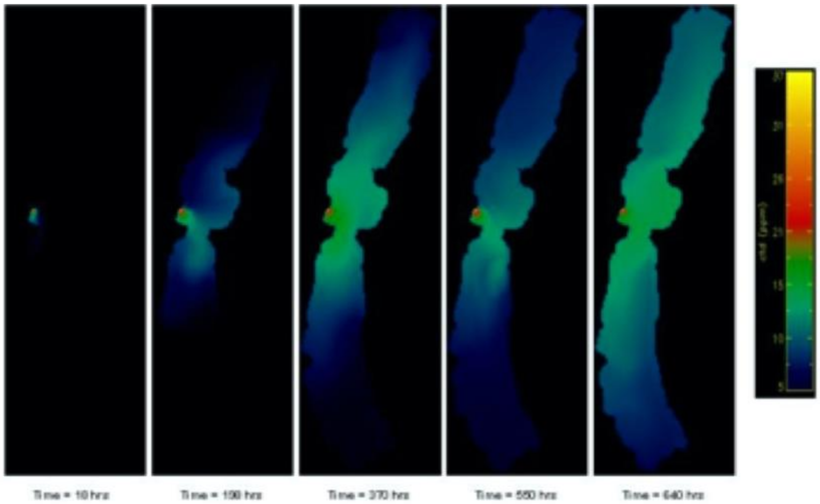


9-24. Illustration of the micro-scene to which buried land mine surrogates have been added (visible: left and mid-wave infrared: right).

the development of automatic target recognition algorithms using hyperspectral data. The targets of primary interest were buried land mines. DIRS' role was to employ DIRSIG to develop the synthetic images that would be used to train the algorithms (see fig. 9-23, and fig. 9-24). This was a major coup for DIRS as GTRI's scene simulation software had been a major DIRSIG competitor in the early days. For them to turn to DIRS for scene simulation on a major MURI spoke to how far DIRSIG had come in 15 years.

DIRS, in collaboration with the newly formed Laboratory for Imaging Algorithms and Systems (LIAS), also won a multi-year National Geospatial Intelligence Agency (NGA) University Research Initiative (NURI) in 2002/2003. LIAS was formed in 2001 from the airborne collection side of DIRS and the algorithm development team of CIS's airborne astronomy effort supporting NASA's SOFIA program. By 2009/2010 the remote sensing component of LIAS would merge back into DIRS. We will try to capture some of the LIAS story here. The NURI effort was aimed at developing hyperspectral algorithms and implementing them for operational use in a commercial software package (IDL-ENVI). The algorithms of interest were for sub-pixel target detection and detection and analysis of gaseous effluents. DIRS would focus on algorithm development and LIAS on recoding and implementation of the algorithms in IDL-ENVI.

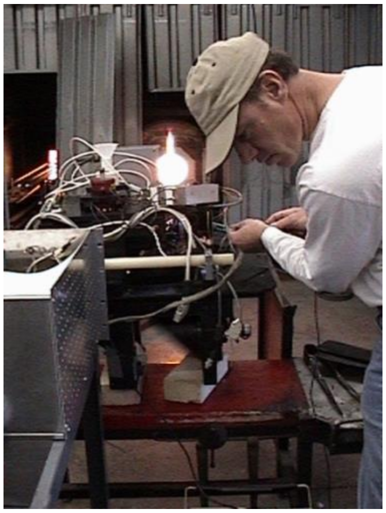
While the large FIRES, LASS, NRL-MURI, ARO-MURI, NURI, and NASA calibration programs dominated most of the activities in the early 2000s, other activities grew out of the new faculty's efforts. Vodacek added a USDA study to monitor water quality in the Conesus Lake watershed



An ALGE simulation of the fate of dissolved nutrients that are entering Conesus Lake from the small creek at Sandpoint. Nutrients from the stream distribute over most of the lake, but do tend to move in higher concentration to the north basin (top of image) where the outlet is located.

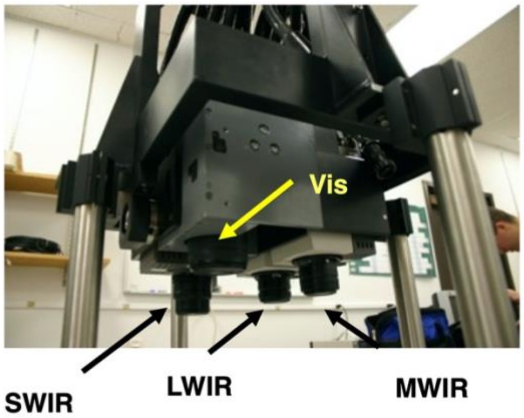
9-25. Illustration of the results of the ALGE hydrodynamic model showing dispersal of dissolved nutrients over time in Conesus Lake.

that involved hydrodynamic modeling of the Lake and mapping discharges into the Lake with the thermal bands of the MISI sensor (see fig. 9-25). Dr. Robert Kremens, who had joined the FIRES team as a research staff member, supported an NSF program targeted at real-time monitoring of forest fires that included development of field sensors (see fig. 9-26, and fig. 9-27) and development of a data integration system to merge ground and aerial data. Salvaggio started an effort working with General Dynamics for Wright Paterson AFB building on the LASS spectral library efforts to develop a spectral signatures database for the Intelligence community. Another project for Pictometry (an RIT spinoff that Steve Schultz of DIRS had helped to build) involved development of automated control point selection tools to allow automated registration of images.



9-26. Bob Kremens working on the MISI sensor in the lab.

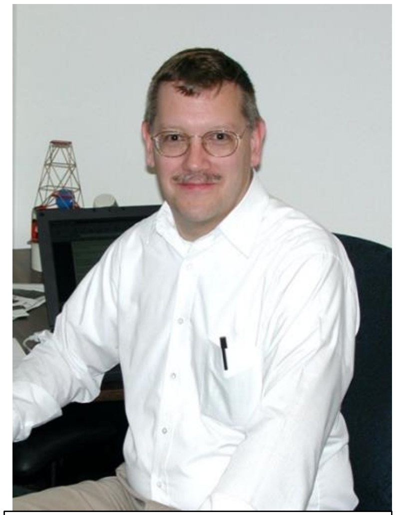
9-27. One of Kremens Fire sensors being tested.



9-28. The WASP sensor in the lab.

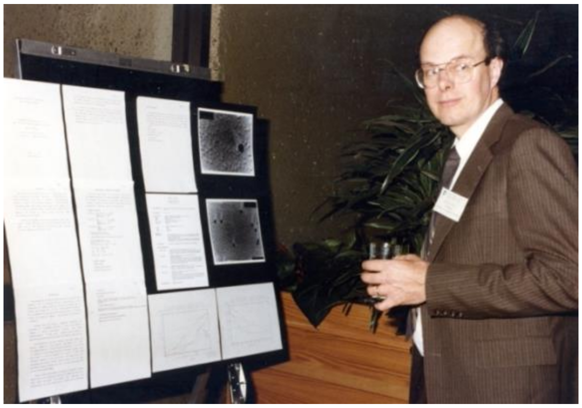
DIRS and LIAS jointly conducted several programs during this period, the most prominent one being the development of the Wildfire Airborne Sensor Program (WASP). This was a NASA-managed appropriation that was directed at building and test flying an airborne multicamera sensor suite to demonstrate the utility of multiwavelength sensing for detecting and mapping of wildfires. Over the early 2000's the RIT team, led by LIAS, acquired and integrated a four-camera sensor suite with data recording systems suitable for mounting in an aircraft camera hole. The system was then flown over a number of fires to help assess the utility of the various sensors (three band visible, shortwave infrared (SWIR), mid-wave infrared (MWIR) and Long-wave infrared (LWIR)). This was a massive design, build, integrate and test program that produced a camera suite that would support a number of future programs and is

9-29. Jason Faulrung in the plane with the WASP sensor system (left) and ground image of a forest fire (right).



9-30. Don McKeown in his office.

still in use today (see fig. 9-28, and fig. 9-29). To help manage the WASP program, LIAS brought Don McKeown from Kodak FSD on board (see fig. 9-30) as a distinguished researcher (i.e. the same role as Richardson held in DIRS) and Dr. Harvey Rhody, a long-term member of the CIS faculty and former head of Electrical Engineering to serve as the faculty lead (see fig. 9-31).



9-31. Harvey Rhody at an Industrial Associates meeting.

9-32. WASP Mega-Collect true color image and zoom showing targets deployed near a sewage treatment plant.

During this busy period DIRS also performed work for a range of other sponsors, including DARPA, the Director of Central Intelligence through post-doctoral awards, NRO, NASA (ISSI). NYS Cyber Security and Eastman Kodak. In addition, in June 2004 DIRS sponsored MegaCollect, an aerial and field collection program. This involved four airborne sensors on four aircraft (Compass VNIR-SWIR hyperspectral, SEBASS LWIR hyperspectral, MISI and WASP) as well as a host of field spectral measurements, deployed targets, water sampling and meteorological measurements (see fig. 9-32 , fig. 9-33, and fig. 9-34). The coverage included the DIRSIG

Megascene I so that simulation and actual data experiments could be conducted for years to come and these data were made widely available to the broader remote sensing community (see N Raqueño et al. 2005).

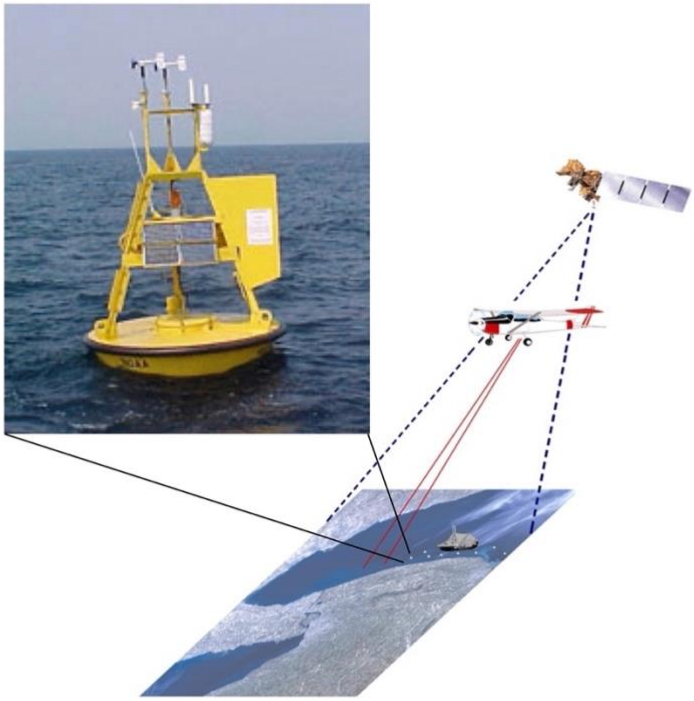
By 2005, DIRS had been transformed. With CIS faculty resistance to adding remote sensing faculty overcome, DIRS had four faculty and LIAS had another. The research staff had grown to 13 and contract volume had grown from roughly half a million dollars annually in the late 1990s, to over 2.5 million dollars annually in 2005. During the early 2000’s DIRS had fully implemented a matrix management system (with the help of and coordinated by Richardson) as it adapted to the growth in students, staff and contract volume. The lab appeared to be well on the way to achieving its goal of being the first choice of where potential sponsors were turning for research into the science of remote sensing.

9-33. Much of the DIRS ground truth team under the Compass platform after a tour during Mega-Collect.

9-34. Scott Brown and Nina Raqueño taking ground truth on Lake Ontario.

DIRS Contributions to the Remote Sensing Community

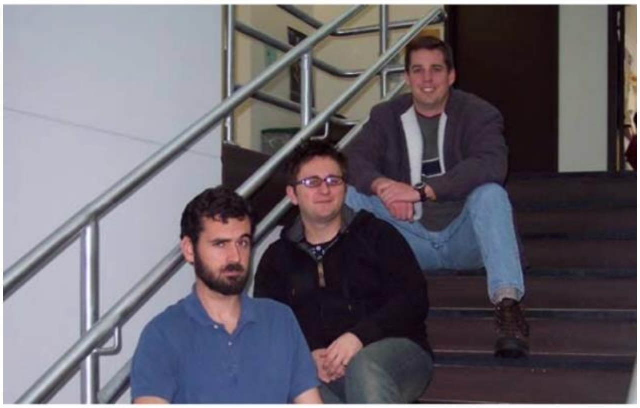
Building on the early work at Calspan on calibration and atmospheric compensation of aerial infrared line scanners and the HCMM satellites thermal calibration, DIRS has spent over four decades, developing, improving and implementing methods to calibrate overhead thermal imaging systems. Landsat's operational sensing in the thermal infrared began in 1982 with Landsat 4. DIRS has been part of the team calibrating all of the Landsat satellites since our early work on Landsat 4. Over the years our approach has evolved from occasional underflights with our airborne sensors and surface measurements from boats to the use of the NOAA fleet of moored buoys and cross calibration with other sensors. The use of the NOAA buoys was particularly important when NASA and the USGS turned operation of the Landsat program over to the commercial sector in the late 1980s and early 1990s and calibration was not a priority. Since no underflights or surface data were available, the ability to go back in time and calibrate the instruments using buoy data enabled DIRS to provide NASA Goddard the data needed to maintain the Landsat calibration record throughout its entire lifetime. Recently DIRS has developed a method to adjust the raw data from the Landsat 8 TIRS instrument for a stray light issue. For decades NASA JPL and DIRS have provided the vicarious calibration data (underflights, surface measurement, and buoy measurements) which when propagated to the sensor using atmospheric propagation models produce the well known "truth" radiance for the observed water targets. These data, coupled with the instrument data from the NASA Goddard team, enable NASA and USGS to adjust the Landsat calibration if necessary and maintain the Landsat archive of extremely well calibrated thermal data. More recently DIRS and NASA JPL have designed procedures that USGS has implemented to produce Land Surface Temperature (LST) data as a product enabled by this well calibrated Landsat data. It is exciting to think that DIRS has contributed in a major way to the calibration of all the thermal data available from the Landsat Instruments and now to the Landsat LST product.



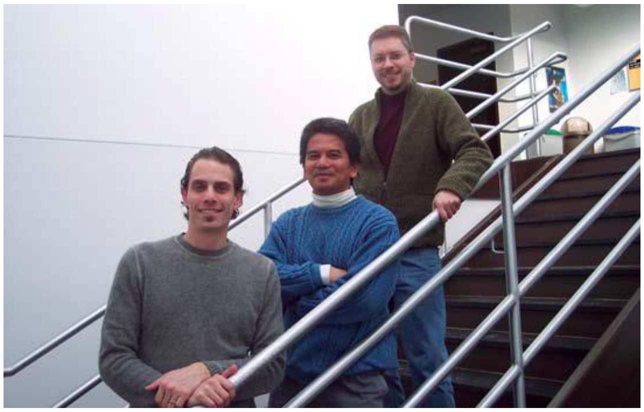
DIRS calibration of the thermal bands on Landsat 4, 5, 7, 8, and 9 and the development of the Landsat surface temperature product have taken advantage of aircraft underflights, surface measurements from boats, and extensive use of the NOAA fleet of moured buoys.

10. Adjusting the Business Model: 2005 – 2010

DIRS continued to heavily utilize a matrix managed approach with Richardson and McKeown helping to manage the matrix and faculty and senior staff serving as Principal Investigators (PIs). The PIs were supported by faculty, staff and students to get the research done. A loose structure developed across three broad research areas consisting of Modeling and Simulation (see fig. 10-1), Algorithms and Phenomenology (see fig. 10-2), and Measurements and Experiments (see fig. 10-3), although the matrix management approach let people work across these groups to meet any project needs. The number of PI's increased dramatically over this period with Jan van Aardt joining the faculty in 2008 and taking on the faculty leadership of LIAS (see fig. 10-4). In addition, by 2010 Dr. Emmet Ientilucci, Dr. Robert Kremens and Dr. David Messinger had all been promoted to research faculty roles with expectations of providing some of their own support and enabling them to supervise doctoral students. With nine faculty affiliated with DIRS (see fig. 10-5) the number and diversity of research programs grew rapidly during this period (30 – 40 projects are listed in each annual report with many annual reports accessible at the DIRS website) and to maintain readability only a very few will be highlighted here.



10-1. Modeling and Simulation Group 2007: Nick Sanders, David Pogorzala, and Scott Brown.

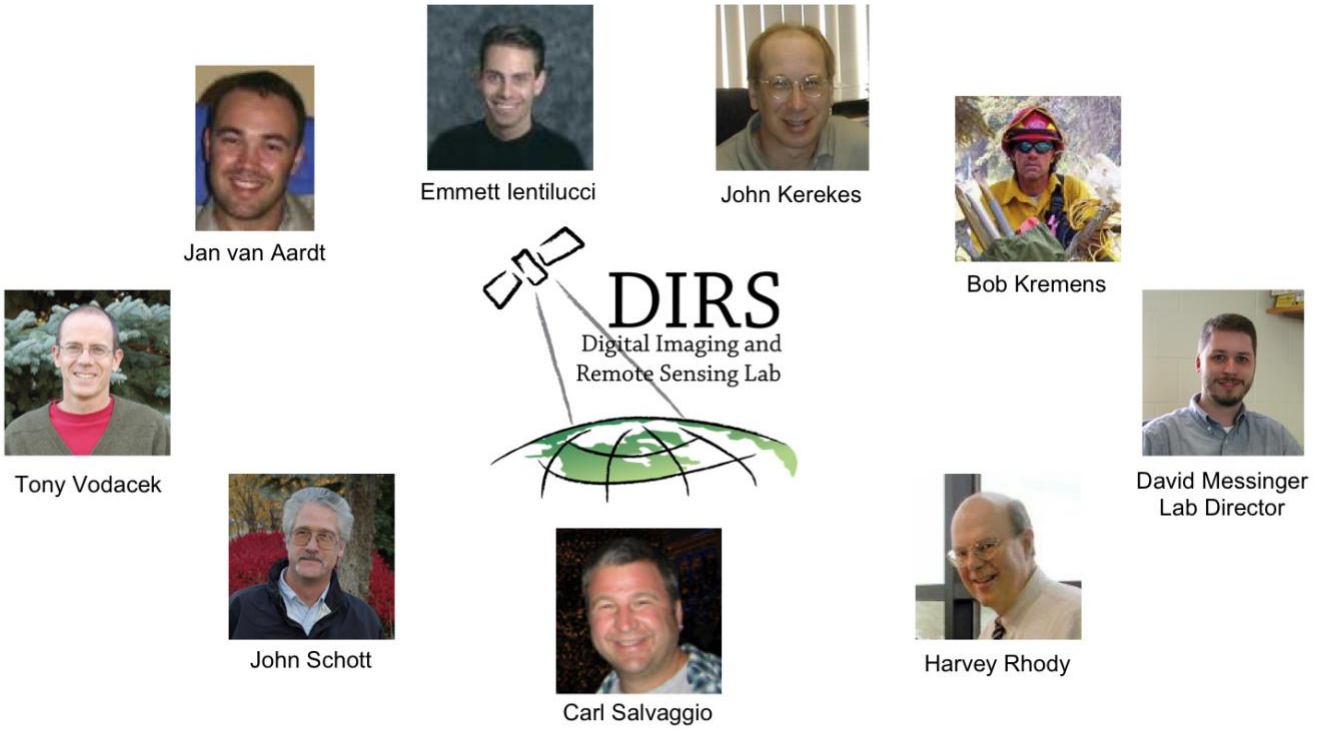


10-2. Algorithms and Phenomenology Group: Emmett Ientilucci, Rolando Raqueño, and David Messenger.

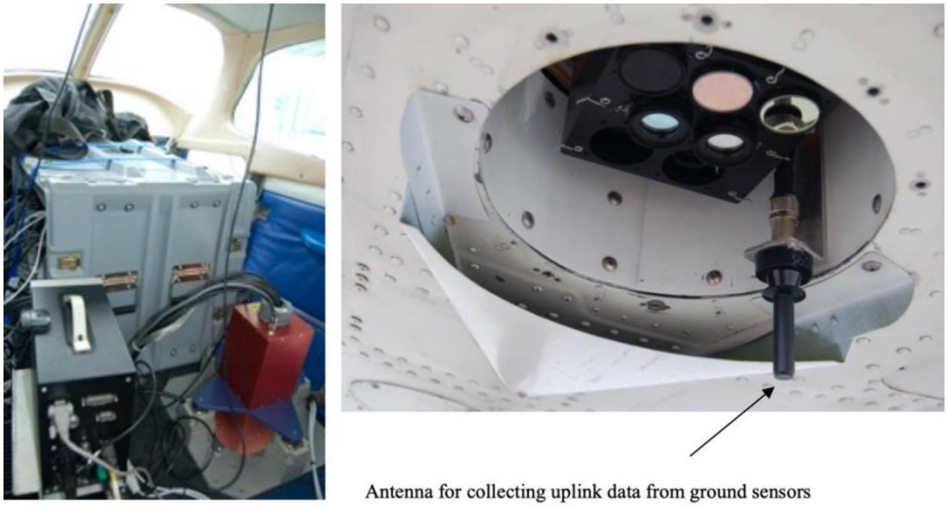
10-3. Measurements and Experiments Group: Michael Richardson and Nina Raqueño.

10-4. Jan vanAardt: LIAS faculty lead.

The Navy MURI, the Army MURI, LASS, NSF-FIRES and NASA Landsat continued into this period and were augmented by two more NURIs involving Rhody, Kerekes and Messinger. Salvaggio secured a string of programs supported by DoE Savannah River National Laboratory. DIRS and LIAS jointly supported a large NASA grant titled The Integrated Sensor System Initiative (ISSI) which included software and algorithm tasks as well as the development of the seven camera WASP-Lite systems designed for low cost multiband aerial data collection in light aircraft (see fig. 10-6). NASA also named Schott to the new Landsat Science Team, and in addition



10-5. DIRS faculty 2010.



10-6. WASP lite in plane. The red box with blue mounting fins is the camera package (left) and view of cameras from below the plane (right).

provided support for system engineering studies to assist in the development of Landsat 8. Kremens initiated a number of FIRE related studies. Ientilucci started programs for the NRL and AFRL. Vodacek started studies of Lake Kiva in Rwanda which would grow to a number of studies to support remote sensing in Rwanda. Kerekes initiated multiple studies for the AFRL sensor directorate, Messinger started programs for the Army Night Vision Lab and DoE's Pacific Northwest National Lab (PNNL), and van Aardt initiated a number of studies using ground and aerial LIDAR to study forest ecosystems.

Perhaps the highest visibility project during this period spun out of a 2004 NSF grant to establish the Information Products Laboratory for Emergency Response (IPLER), headed by van Aardt. Just as the IPLER team was beginning to assemble the collection (RIT's WASP camera system and a collaborator's airborne LIDAR), data processing, and air to ground communications systems that made up IPLER, the 2010 earthquake and subsequent disaster struck Haiti. LIAS/DIRS and a number of partners spent two weeks of intense Herculean effort responding to a call for help and getting a team to Haiti to conduct numerous over-flights, pipe the data back to RIT, process the data and make it available to first responders. The story is told in Appendix J of Schott (2019) with one of the first images to appear back at RIT (see fig. 10-7).

10-7. One of the first images to reach RIT campus collected by the RIT crew over Haiti and piped to RIT from Puerto Rico to be processed and disseminated (note: the SOS center).

10-8. Adam Goodenough at DIRS Christmas Party.

10-9. DIRSIG team: Rolando Raqueño, Scott Brown and Adam Goodenough.

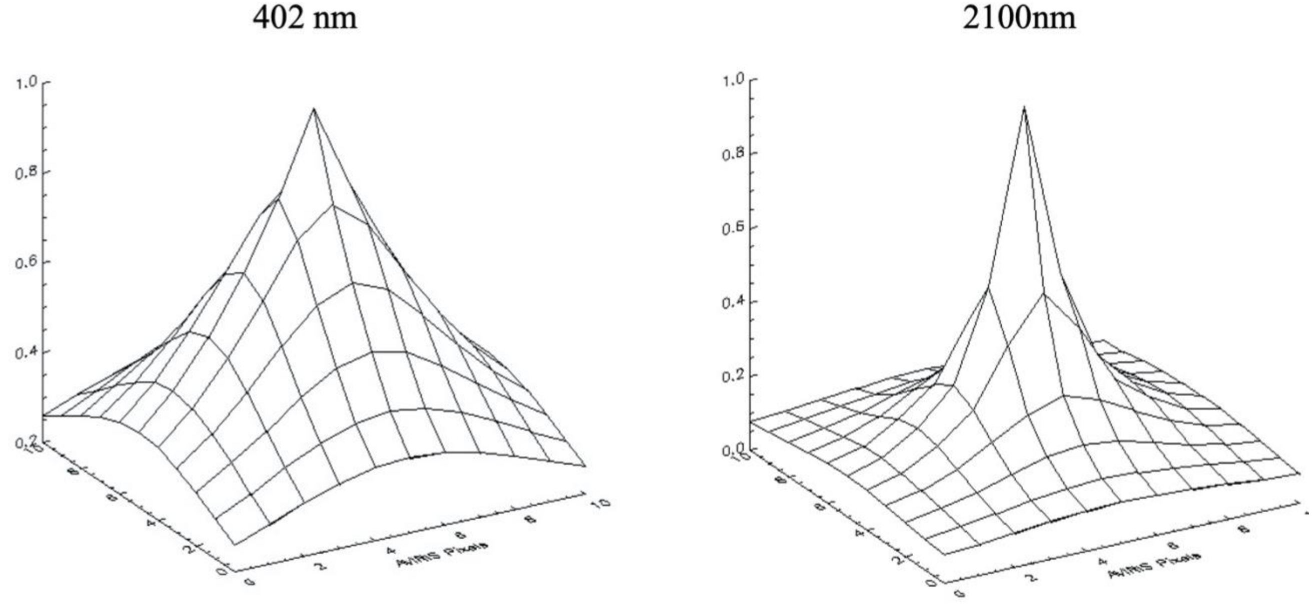
The simulation and modeling group led by Scott Brown began to play an outsized role in DIRS during this period. Brown finished his Ph.D. at SUNY Buffalo with DIRS support, Adam Goodenough, who had done his Ph.D. with Schott, joined the DIRSIG team along with one or two other research staff at any given time and became a major DIRSIG developer (see fig. 10-8). DIRSIG had become a major resource across the remote sensing community with hundreds of users at all the major national labs and aerospace centers. Within DIRS a large number of the research programs took advantage of DIRSIG to model phenomena, or sensors, or to simulate data to support algorithm development and testing. Brown and his team, in addition to supporting the research efforts, began to generate a steady income from training classes that helped pay for the ongoing maintenance and continuous upgrades needed to keep DIRSIG ahead of the competition (see fig. 10-9).

In 2007/2008 Schott, who had led DIRS since the early 1980's, took a sabbatical to work on a book on Polarimetric Remote Sensing. When he left, Messinger took over management of DIRS. Unbeknownst to Messinger, Schott had made a deal with Dr. Stefi Baum, who was then the Director of CIS, that if Messinger and the DIRS team were mutually satisfied with each other, Messinger would be asked to stay on as head of DIRS. Schott was ready to focus more on teaching and research for a few years. This worked out well for all concerned and Messinger stepped up. As part of this transition, Amanda Zeluff came on part-time as Schott's administrative assistant (see fig. 10-10). In addition, in the Spring of 2010 the LIAS remote sensing team merged back into DIRS by mutual agreement of both groups. This brought DIRS up to nine faculty (six tenured/tenure track and three research), sixteen technical staff, one and a half administrative staff and 30-plus graduate students (increasingly dominated by Ph.D. students) and a handful of B.S. students working on their capstone projects. Research volume had grown by another million dollars/year to about $3,700,000 in 2010. By this point DIRS was a large complex operation and one of the strongest remote sensing research centers in the country.

10-10. Monica Cook, Amanda Zeluff, Pam Schott, and John Schott at Holiday party.

DIRS Contributions to the Remote Sensing Community

DIRS helped introduce and promote the concept of physics based algorithms for analysis of remotely sensed data. One of DIRS first forays into physics based algorithms (before the term was used) was in the development of the pseudo invariant feature (PIF) algorithm. PIF used scene based statistics from multitemporal acquisitions of a site, coupled with physics driven constraints of the relationships between the statistics, to transform one scene to "look" as though it were imaged under the same illumination and atmospheric conditions as the other. Other algorithms used the Lowtran and later Modtran radiation propagation models to compensate thermal radiance at the sensor to thermal radiance at the ground and then to water surface temperature. Similar use of image data to constrain atmospheric parameters in radiative transfer models led to atmospheric compensation algorithms for visible through shortwave infrared imaging spectrometer data that eventually included corrections for surrounding pixels (adjacency effects). A major advancement in this physics based approach came with the application of physics based models to "train" hyperspectral target detection algorithms known as invariant algorithms (i.e. algorithms that were invariant to illumination and atmospheric variations). This work evolved to include methods to apply invariant algorithms to highly oblique images through very dense atmospheres.


402 nm

2100nm

Fractional scattering contribution in the 402 nm band (left) and the 2100 nm band (right) for AVIRIS sensor flown 60,000 feet and having 20 meter pixels viewed through a rural aerosol. Note the significant contribution from pixels even 5 pixels away in the blue (405 nm) and the significantly lower contribution in the shortwave infrared (2100 nm)

Modeling results from a study designed to develop a means to correct retrieved reflection spectra for errors introduced by the scattering of energy from surround pixels into the pixel of interest (i.e. adjacency effect).

11. A growing team: 2010 – 2015

The early 2010’s saw a number of role changes within DIRS. In 2011-2012 Schott would serve as acting director of CIS while Baum was on sabbatical. Then in 2013 he retired from teaching and went to a part-time position as a research faculty member to focus his last 4 years at RIT on his Landsat projects and on working with his last (7) doctoral students (one of whom was Carl Salvaggio’s son Phil). Phil would return to work with the DIRSIG team for a while a few years after graduation (see fig. 11-1, and fig. 11-2). Schott’s faculty position and the Wiedman Chair were filled by Dr. Charles (Chip) Bachman who joined DIRS from the Naval Research Lab where his work focused on instrumentation for measurement of the directional reflectance of materials (see fig. 11-3). Rhody, who had spent years in electrical engineering, then RITRC and finally CIS also retired in 2014. In 2014 Messinger was recruited to the CIS Director position when Baum took a position in Canada. He transitioned from research faculty to a tenure track faculty position. van Aardt became head of DIRS. Dr. Michael Gartley, one of Schott’s Ph.Ds from Kodak FSD, had been on the research staff for several years. He was promoted to research professor (see fig. 11-4). There were also two additions to the research staff. Dr. Aaron Gerace, who had studied with Schott, and Dr. Matt Montanero, who had studied with Salvaggio, joined the staff (see fig. 11-5). Gerace would initially support Schott’s wide range of Landsat programs as he began to establish his own programs. Montanaro had been working for NASA Goddard on the Landsat TIRS instrument and would continue that focus at DIRS upon his return.

11-1. Christmas at Schott’s. Schott and a very young Philip Salvaggio.

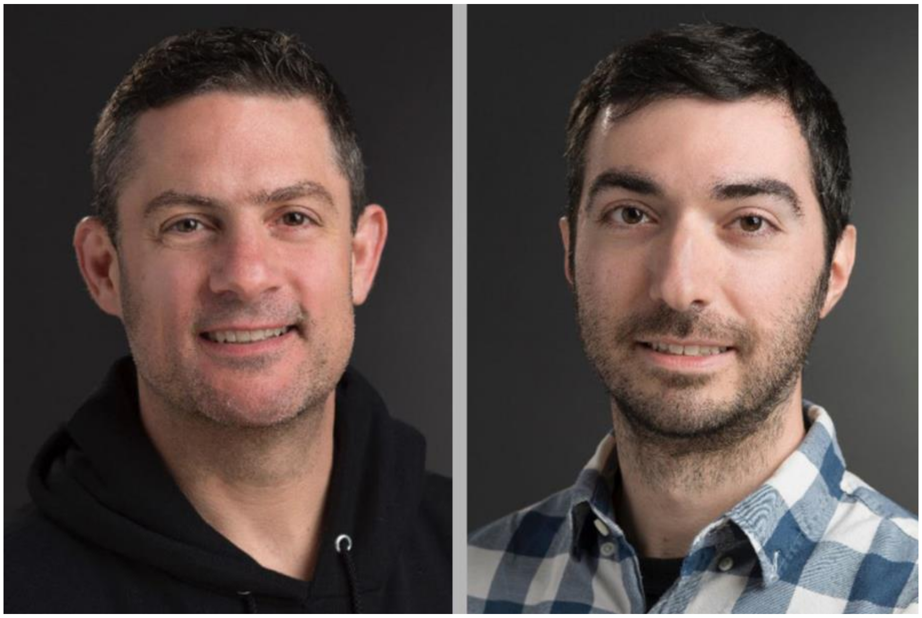
11-1. Dr. Schott’s last three doctoral students: Philip Salvaggio, Kelly Laraby and Raj Rengarajan at graduation.

11-3.Chip Bachman ready for a field campaign.

Research contract volume in DIRS peaked in the early part of this period at about $4 million/year and began a slow decline that finally turned around in 2018 and was nearly recovered by 2021. This decline through the mid 2010’s was not surprising as this period also saw a decline in federal funding for university R&D and DIRS was primarily funded by federal agencies. It also was a period where Schott was transitioning his work to other investigators and not seeking new work to supervise himself.

The grants during this period were so numerous, only some of the major thrusts will be mentioned here. At least 14 faculty or staff served as Principal Investigators in this era as many of the staff had matured to a point where they were seeking and securing some of their own funding and in some cases beginning to support other staff and students. What follows is just a small sampling of who was doing what during just this five-year span.

11-4. Mike Gartley setting up field instrument.



11-5. Aaron Gerace (left) and Matt Montanaro (right): pictures used to announce receipt of USGIF Academic Achievement Award (2019).

11-6.Robert Krzacek (left) and Carl Salvaggio as part of cleanup crew after DIRS holiday party.

Montanaro had support from NASA Goddard to work on building and testing the Landsat TIRS instrument and then for trying to characterize and compensate for a stray light issue after launch. Gerace worked with Schott on modeling the expected performance of Landsat 8 and understanding various issues post launch. He also started his own research, including a field collect and data analysis aimed at improving the understanding of overhead imaging of submerged targets for Goodrich. Robert Krzaczek, who joined DIRS as part of the LIAS repatriation, continued to support NASA's SOFIA program. He developed software to move data through the data processing system from the user's instrument and data acquisition request to delivery of processed data back to users (see fig. 11-6). Kremens had a number of projects on various aspects of forest fire research with an overarching theme of developing a better understanding of the poorly understood physics of forest fires. Gartley had several projects focused on pushing the limits of DIRSIG to look at complex concealed targets, improved polarimetric imaging and modeling of synthetic aperture radar (SAR) systems. The sponsors included AFRL, DoE-Sandia and Northrup Grumman. Ientilucci established a diverse sponsor base across an array of topics with many connected by the use of physics-based target detection algorithms. These sponsors included NGA, and a number of aerospace companies (SBIRs and STTRs). Brown usually had two or three people working with him on a wide assortment of DIRSIG related tasks. Brown led his team on a number of his own projects. These included improved plume modeling for Spectral Sciences and 3D model extraction for ESRI. The DIRSIG team also supported components of a huge fraction of DIRS projects that used, or sought to enhance DIRSIG capabilities. The modeling team also kicked off an internally funded major rewrite of DIRSIG to modernize and speed up the code. During this period Messinger established himself as a major RIT PI with multiple programs for NGA (NURI), NSF, DoE and NASA on topics including 3D scene construction, plume modeling and using remote sensing to study archeological sites. Bachman established himself with multiple programs funded by the Office of Naval Research (ONR) to study bidirectional reflectance distribution functions (BRDFs) for trafficability studies. This included work to build a field BRDF instrument which would become a major component of many DIRS field campaigns.

Van Aardt led the large IPLER project through completion in 2013 which included a number of flight programs and analysis efforts over hurricane induced flooded regions, analysis of imagery from the Fukushima, Japan nuclear disaster and improvements to flight and ground systems to demonstrate near real time down linking and map generation from aerial data. VanAardt also initiated a number of programs for NSF, NSF-NEON and NASA on the use of LIDAR and hyperspectral to characterize the structure of forests. This general topic would become a major thrust of vanAardt's future research. Vodacek continued to expand his work in Rwanda for the MacArthur Foundation studying the relationship between land use and water quality in Lake Kiva. He developed training programs for the Rwanda Ministry of Education on use of spatial/mapping science. He also led an AFOSR study aimed at developing methods to track vehicles/pedestrians from overhead imagery. Salvaggio ran a series of collection, modeling and analysis programs for DoE, as well as an Intelligence Community post-doc program. A theme across most of Salvaggio's efforts was improvement in modeling and analysis to better understand thermal infrared remotely sensed data. The success in winning and carrying out these efforts regularly reinforced DIRS commitment to staying involved in the hardware side of remote sensing. Many remote sensing groups had abandoned this area in favor of just processing image data. Kerekes ran a number of programs for sponsors such as AFOSR, AFRL, Pictometry and NASA. The topics included modeling multi-modal optical sensors, phenomenological studies to aid in tracking pedestrian dismounts from vehicles and 3D model extraction from multiple images. The NASA efforts involved studies of the physics of laser radiation interactions with ice and modeling in DIRSIG. This included modeling the laser, propagation, energy matter interaction, and return signal for NASA's ICESAT program. Although Schott retired from teaching in 2013, his research programs were unaffected. He continued some studies of the expected performance of exotic optical systems for LASS. Most of his attention focused on a large collection of long-term interrelated studies for NASA and USGS on calibration and analysis of Landsat data and DIRSIG modeling of the performance of current and proposed Landsat instruments.

The size and scope of DIRS in this era is captured in the 72-page 2013 DIRS annual report. It lists 9 faculty (6 tenure, 3 research), 13 research staff, 3 administrative staff (2 part-time), 25 Ph.D. students, 12 M.S. students, 8 B.S. students and nearly 30 different on-going research projects that are captured in short summaries. Most notably, over 75 publications are listed for that one-year period reflecting that Schott's unending admonition that "if you don't publish it, it didn't happen" had been taken to heart. He firmly believed that documenting DIRS work was important, not just for the visibility that academia promoted, but because if it wasn't published someone else would have to redo the work. No one else could build on your accomplishments or avoid your failures. This was the essence of research in the early years and in the hustle to do the work and chase the next project it was easily overlooked when everyone was so busy.

DIRS Contributions to the Remote Sensing Community

While DIRS has made many individual contributions to many other areas, we will close these vignettes by highlighting here one continuing, and somewhat unique, contribution in the area of instrumentation. Since its earliest days DIRS has endeavored to fly airborne and later drone based sensors. In some cases building the sensors from scratch (e.g. the Modular Imaging Spectrometer Instrument (MISI)) and in other cases integrating the sensors into custom packages (e.g. the Wildfire airborne Sensor Program (WASP) package and later WASPlite). Similarly, DIRS built laboratory and field instruments. These included thermal infrared emmisometers, field spectrometers, imaging elipsometers etc. The Fires program pointed out the need to better understand the physics of fires so DIRS built sensors to survive fires and to record the physics of forest fires. Later DIRS built bidirectional reflectance distribution function (BRDF) spectrometers for laboratory and field use (e.g. the goniometers in RITs GRIT lab). Another major effort has involved the deployment of ground based and aerial lidar systems to rigorously characterize forest ecosystems. Most recently DIRS has integrated and operates a host of drone based sensors and supporting field truth sensors. These instrument programs are of major value, not only for the instruments and the data they collect, but also because of the experience and insights they provide to the students who help design, build, operate, and maintain them. In an academic environment where many students spend nearly all their time only interacting with images on computers, it is critical that some universities take up the challenge to expose students to the physics and foibles of sensors and instrumentation. DIRS, from its earliest days, has accepted this challenge.

The RIT goniometer (GRIT) in the field. The GRIT instrument measures the spectral Bidirectional reflectance distribution function (BRDF) of natural surfaces at useful scales for supporting remote sensing science.

12. The Modern Era: 2015 – 2023

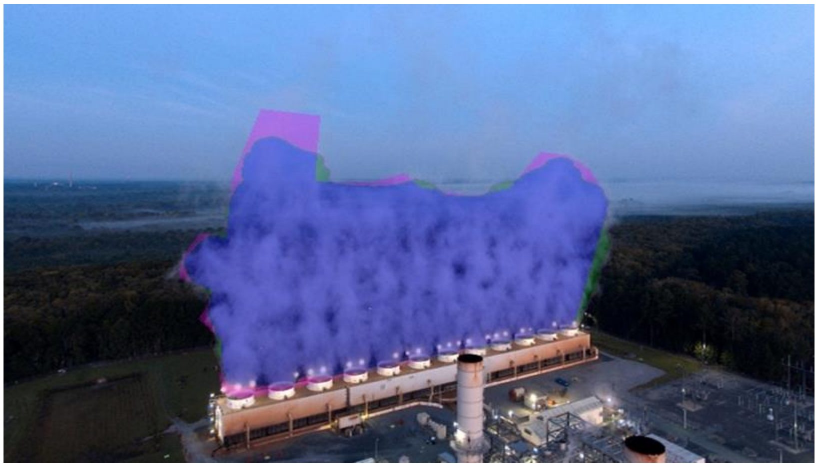
The last few years are way too fresh to treat as history so only a brief mention of a few projects will be included here along with the changes in major players.

The research during this period is well captured in the annual reports on the DIRS website (https://www.rit.edu/dirs/). They reflect a major thrust to add drone-based collection capabilities to the DIRS arsenal (see fig. 12-1). These capabilities allowed Salvaggio to lead a large program for the Savannah River National Laboratory. A machine learning-based model to segment condensed water vapor plumes from simultaneously collected RGB or greyscale imagery was developed. The model uses 18 months of imagery collected every 10 minutes to create "silhouettes" that are used in a space carving pipeline. The silhouettes produce metrically-accurate 3D volumetric reconstructions to assist with power plant production level estimates (see fig. 12-2, and fig. 12-3). For years van Aardt has been using ground and aerial LiDAR data to characterize the structure of forests. His ongoing work includes building detailed forest models in DIRSIG to better understand what can be learned from full waveform LiDAR scans of tree canopies (see fig. 12-4)

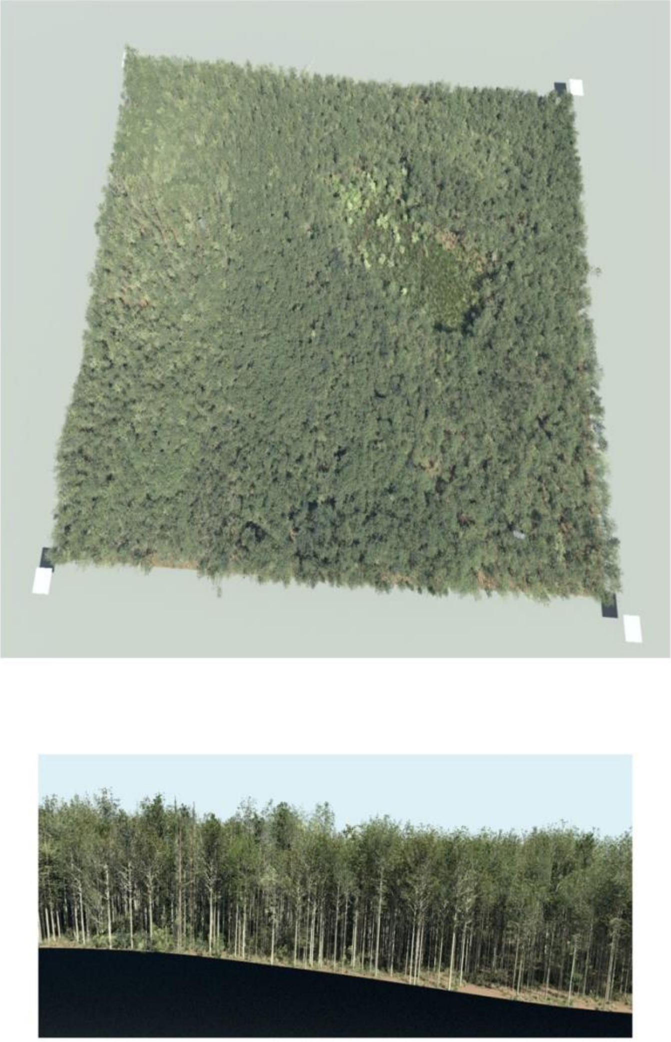
12-1. Carl Salvaggio in drone lab setting up six blade drone. Note fixed wing drones on cage wall.

12-2. Drone fleet with cooling towers in background.

In 2015/2016 Vodacek headed DIRS when VanAardt went on sabbatical. Then Kerekes took over for 2016 – 2018 followed by Salvaggio in 2018 – this writing (2023). In 2016 Cindy Schultz, who had taken over from Kitchen as DIRS' administrative assistant in 2001, died way too early. Cindy's always ready smile cheered countless students over the years and her loss was a blow to DIRS (see fig. 12-5). Colleen McMahon and Melanie Warren provide administrative support to DIRS today (see fig. 12-6, and fig. 12-7). In 2017 Richardson retired and would be replaced by Joseph Sirianni, who had done his M.S. with Schott and then spent many years in industry including a stint working for Salvaggio's company (see fig. 12-8). Ientilucci transitioned to tenure track faculty in 2018 after a national search. A long overdo national recognition was awarded to Scott Brown and the DIRSIG team including Adam Goodenough and Rolando Raqueno at the 2017 Geoint conference (see fig. 12-9). DIRSIG has become the dominant synthetic image generation tool supporting sensor design, algorithm development, algorithm training and phenomenology studies across the civil and defense/intelligence communities.



12-3. A 3-D volumetric reconstruction of cooling tower plumes created from color imagery collected by DIRS drone fleet from multitemporal imagery.



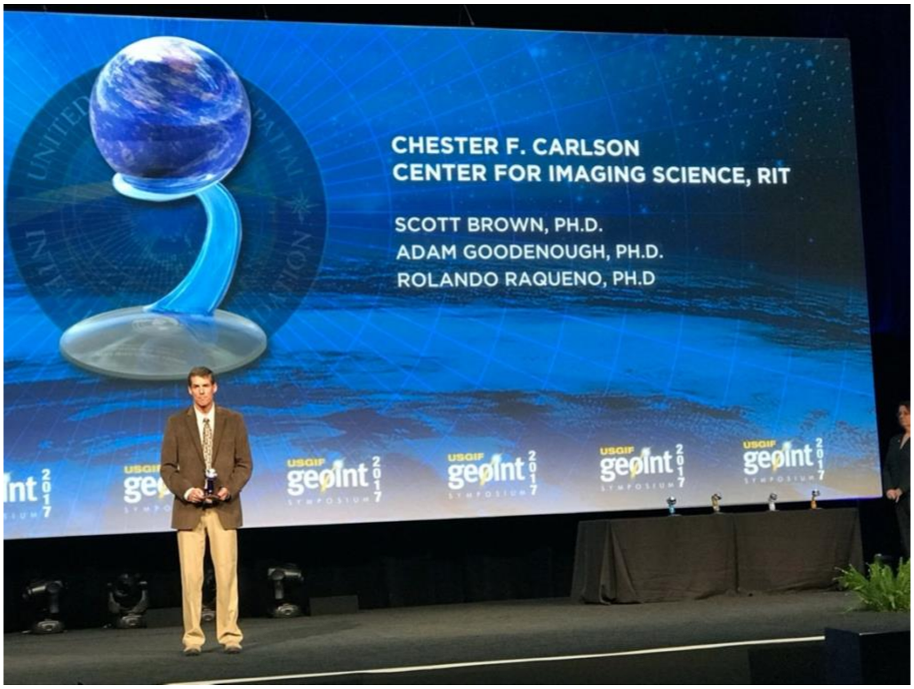
12-4. Overhead view of DIRSIG simulated forest scene and ground view of forest edge used in LIDAR studies.

12-5. Cindy Schultz at her desk with the smile that greeted so many students.

12-6. Colleen McMahon: DIRS Administrative Assistant.

12-7. Melanie Warren: DIRS Administrative Assistant making sure students get paid.

12-8. Joseph Sirianni: DIRS Associate Director.



12-9. Scott Brown on the stage at the GEOINT conference accepting the award for University Research for the DIRSIG team.

DIRS Contributions to the Remote Sensing Community

As colleagues in government, industry and other universities continue to try to recruit our graduates, it is clear that one of DIRS' greatest contributions is the students who have worked with us. Across the remote sensing community, they stand out from graduates from most other programs in their ability to see and address many aspects of a remote sensing problem. I'd like to say this ability to make meaningful contributions right out of university is due to the excellent training the DIRS faculty and staff provide through classroom courses and hands-on laboratory and field experience. I don't want to downplay that contribution and I think DIRS alone would produce good graduates. When I first considered joining RIT I thought that the Photo Science Department could produce some of the best remote sensing scientists. All they needed was some good remote sensing courses and some research experience. Over the years DIRS provided those courses and experience and helped shape the curriculum that grew into the Center for Imaging Science to produce not just good but great remote sensing scientists. This is largely due to the fundamental training in optics, linear systems, mathematics and imaging systems provided by the broader imaging science faculty. I've often said that what DIRS does is put the frosting on the cake, taking advantage of our colleagues' contributions to turn what could be good to great. For over four decades I have heard from the people our graduates work with and for how special they are in terms of their ability to make meaningful contributions. Our graduates I believe are our most lasting contribution and the one in which we take the most pride.

Designed by Freepik

Graduating students

13. The Many Faces of DIRS: 1980 – 2023

While DIRS is primarily a research group focusing on producing new science, it is also a community. At many times, and for many of those involved, it was very much a second family. Schott and his wife, Pam, enjoyed entertaining and nearly every holiday (Easter, Thanksgiving, St. Patrick's Day …) would see DIRS faculty, staff or students joining family around the Schott dinner table (see fig. 13-1). For larger St. Patrick's Day parties, the club house was the venue (see figs. 13-2- fig. 13-5). They also organized special dinners. These included dinners for the Air Force officers and families. Since the 1960's the US and Canadian Air Forces have been sending a continuous stream of officers to RIT to study for graduate degrees in photographic/imaging science. Since their careers would take most of them into reconnaissance, they gravitated toward DIRS for their research and became part of the DIRS extended family (see fig. 13-6). This group also included occasional Defense Mapping Agency (DMA) (later National Imaging and Mapping Agency (NIMA), then NGA) students. The CIA also sent two Officers in Residence in the late 1980's and early 1990's who, along with their families, became part of DIRS and the DIRS social scene. This sense of connectivity and extended family was capped off each year for decades with a Christmas party the Schott's hosted for DIRS faculty, staff, students and their families. In the early days this was at the Schott's home and later as DIRS grew, they had conveniently moved to a townhouse complex with a club house large enough to handle the nearly 100 guests. Pam

13-1. DIRS ST. Pat's dinner at the Schott's.

13-2. vanAardts and Nina at DIRS ST. Pat's at clubhouse.

13-3. Vodacek's and Kerekes' at DIRS St. Pat's at clubhouse.

13-4. North wall at DIRS St. Pat's at clubhouse

13-5. North wall at DIRS St. Pat’s at clubhouse

12-6. US and Canadian Air Force students in a rare in-uniform appearance.

Schott would prep for weeks to feed everyone and, after Richardson joined DIRS, Brenda

13-7. Brenda and Mike Richardson, a DIRS Christmas at the clubhouse.

13-8. Brown's, a DIRS Christmas at the clubhouse.

13-9. Ientilucci's and Pam a DIRS Christmas at the clubhouse.

Richardson would bake an array of treats to finish off the night (see figs 13-7, - fig. 13-14). Happily, DIRS continues this tradition with a holiday party. The holiday parties at Schott's were augmented with regular lunch time pizza or subs parties on campus to give the students an opportunity to socialize with faculty, staff and each other. In the summer this would extend to an occasional picnic lunch at Genesee Valley Park (see fig. 13-15) or at Schott's cottage (see fig. 13-16) and for many summers there was a regular volleyball game late in the afternoon one day a week (see fig. 13-17). It became a DIRS tradition

13-10. Joe K, Bernie Brouwer and Tim Gallagher, a DIRS Christmas at the clubhouse.

13-11. Salvaggio boys, Brown's and Ientilucci's at a DIRS Christmas party at the clubhouse.

13-12. Carolyn Kitchen and crew at the west table at a DIRS Christmas party.

13-13. Ed Przybylowicz as a DIRS Christmas party gets underway.

13-14. Families were always a major part of the Holiday parties.

13-15. The DIRS crew gathered for a photo op at one of the many picnics at Genesee Park.

13-16. Some of the DIRS crew at Schott's cottage.

13-17. Getting ready for volleyball.

13-18. DIRS crew and friends gather to celebrate Adam Goodenough's successful thesis defense (it was Good-Enough).

that the day of their theses defense the student organized a party and these were among the happiest parties (particularly for that student see fig. 13-18). In addition to the more social events, DIRS mixed business with pleasure every few years by holding faculty/staff retreats. These were often held off site with some of the most memorable in the dead of winter in front of a fireplace with sledding and chili afterwards when the families joined in (see fig. 13-19). These retreats were often targeted at long term planning. The DIRS group would spend much of a day taking stock of where they were and where they wanted to go. Should DIRS continue to stay in the expensive hardware business (yes was consistently the answer)? Should DIRS strive to grow and if so, how and in what direction

13-19. Food break at a DIRS winter planning retreat.

13-20. Summer high school interns collecting meteorological data on the North Range Lab on top of CIS building.

13-21. Julia Barsi on Genesee pier talking to students about water sampling.

13-22. Scott Brown and doctoral student Robin Burton at DIRS demo at Rochester Museum and Science Center (RMSC) open house.

13-23. Hot hands at DIRS thermal infrared camera demo at RMSC.

(more students?, more staff?, more faculty?, more applications?, more basic science?, more government funding?, more industry funding?). It was at these retreats that consensus was built around such goals as “becoming the first choice for sponsors looking to fund the science of remote sensing”. While these retreats had a business agenda, they also served to air any grievances and generally build camaraderie.

DIRS also took part in a range of outreach programs mostly coordinated by Nina Raqueño. These included; programs to introduce students to environmental data collection, imaging awareness days hosted by the Rochester Museum and Science Center, and high school summer internships (see figs. 13-20 - fig. 13-23). All these efforts were and continue to be aimed at helping the next generation see the excitement that the DIRS crew felt about science to possibly motivate them to pursue science-oriented studies and careers.

In all, hundreds of students have completed degrees while supporting DIRS’ research projects. Essentially all of them moved on to positions in the remote sensing community, often returning as collaborators or sponsors. Similarly, tens of research staff have moved through over the years. Some have stayed for decades and in a few cases moving on to faculty positions. Many research staff joined DIRS with degrees in physics or computer science and only stayed a few years to gain enough experience to make themselves attractive to the remote sensing community. This brief story can only capture and recognize a small sample of the faculty, staff and students who have passed through DIRS. Recognize, however, that there are many more contributors, each of whom helped DIRS move forward to become the major research center it is today.

14. Looking Back 1980 – 2023

I'll return the narrative here to the first person as it reflects some of my own thoughts on the lab and on the science.

When I think about some of the earliest days in this business it is amazing how hard we had to work to do things that are so simple today. Taking a measurement of the radiance or reflectance of a spot on the ground from a point on an image involved characterizing the nonlinear response of the film, taking a microdensitometric measurement of the density of film at the spot of interest, converting the density to an exposure, making many more measurements to characterize the atmosphere and the relationship between exposure in that image and reflectance on the ground and then on a calculator or primitive computer calculating a reflectance. Then we could measure another point, then another... Today the entire image exists in and can be displayed on a computer and in many cases can be delivered to a user already calibrated into ground leaving reflectance. If you wanted to study a location on the earth with any spatial detail you had to contract to have aerial imagery acquired often several times to get cloud free data and to see changes over time. Today satellites acquire almost weekly images of nearly anywhere on the globe with sample sizes of 10s of meters and images of almost anywhere have been acquired with a few meter sample sizes. Perhaps the most dramatic changes have been in the types of questions we are trying to answer about the earth. In the early days we were excited to accurately map large area land use (forest, pasture, agriculture, arid land, water etc.) with sample sizes of 10s of meters to 100s of meters. Today we are asking not only what is the plant or rock at scales of meters but what is its condition (health of crop, quality of water, amount of water in soil…), how is it changing at time scales of week to decades, what will the crop yield be etc. What is truly exciting about much of the work taking place today is that we are beginning to see the possibility to move these studies of the earth's surface from the domain of extremely well-trained remote sensing scientists, who might spend years studying a single site, to operational tools/systems that put this remote sensing knowledge in the hands of applications scientists and users (farmers, foresters, water quality managers, geopolitical decision makers, …) within actionable time frames. There are of course still many challenges and many unanswered questions. The approach DIRS has focused on of building tools to facilitate the broad application of remote sensing sciences to a range of applications is paying off in many areas and appears poised to contribute to many of the challenges facing earth resource managers.

It would have been hard to imagine in 1980 that one very young professor and a couple of graduate students could form a research group that would grow to be a significant player on the national stage and make major contributions to many aspects of remote sensing science. Early on DIRS was a major component of RIT's evolving steps towards becoming a research university. In the early days DIRS generated 25 to 50 percent of the small amount of institute wide overhead collected on research grants and contracts. DIRS helped, in many cases forced, the Institute to put in place the infrastructure needed to perform state of the art research including driving the push to add doctoral programs. Today, over 40 years later, RIT has claimed a place as a research university and research groups exist across the Institute with more springing up regularly. Yet even with all this growth across RIT, DIRS with its now 30 some faculty and staff and a similar number of students is still generating a significant percentage of the Institute's research overhead. More importantly, with 30-40 research programs active at any time, DIRS has and continues to support nearly every major player in the remote sensing research enterprise. This includes all branches of the military (ARO, NVL, AFOSR, NRL, ONR…), the intelligence community (CIA, NGA, DIA, NRO, DOE…), the civil government agencies (NASA, USGS, NSF, USDA, NYSERDA…), and the aerospace industries (Lockheed-Martin, Northrup Grumman, Ball, Boeing, General Dynamics, Eastman Kodak, Harris, Itek, Raytheon, Autometric…) that support them. This success was largely driven by a commitment to listen to and strive to understand sponsors problems and then to work with them to generate creative workable solutions. Often in academia faculty want to pursue their own research agenda. DIRS success is largely based on accepting a sponsor's problem as our own and trying to overdeliver on our research commitments.

14-1. An impromptu photo op of RIT faculty, staff and students at an SPIE conference.

One might think that a research lab was all about the research. When I look back it is at least as much about people. Nearly every research project had one or more students providing much and often most of the research. The new perspectives, energy and enthusiasm the students from high school interns to doctoral candidates and post-docs brought to problems reinvigorated the faculty and staff over and over. Many of the students spent years working closely with us and often became part of the family joining in holidays and outings. Several would go on to become research staff and a few would eventually join the faculty. For many the connection went way beyond the student years and former students became life-long friends and colleagues. Nearly all of the remote sensing graduates moved into their first jobs out of school in the remote sensing business. Most of them would stay within the remote sensing community for much if not all of their careers. Thus, the associations would continue at conferences and visits to aerospace companies and government facilities. Indeed, it was rare to take a business trip anywhere and not run into a CIS/DIRs connection (see fig. 14-1).

In some ways the student's success year after year may be one of the best measures of DIRS success. When I joined CIS in 1980 one of my concerns was that I did not want to be part of a program that did not prepare and place students in solid careers using the tools and skills for which they had trained. Leaving college with a physics degree in 1973 I was the only one of my classmates who took a job using my degree. A couple others went to graduate school for lack of career opportunities and nearly all the rest left physics behind. Thus, I tried to ensure that DIRS faculty/staff recognized that their educational mission went beyond getting students degrees and included getting them careers.

As I, and later DIRS, set and reset goals as each earlier goal was achieved we had moved on from starting a viable research group, to being a serious player, to playing at the national level, to being a major player at the national level, to seeking to be the first choice of sponsors looking for research into the science of remote sensing. Today DIRS stands as one of the largest and best academic centers (some would say "the best" which continues to be the DIRS' goal) in the world for remote sensing science. Early on DIRS became and remained the leading research lab at RIT. However, through all those early days I insisted that DIRS must look outside RIT to judge its performance. I encouraged the faculty and staff to look to the best scientists in their discipline and strive for their recognition and respect. This philosophy of judging DIRS’ progress by always looking outside the Institute drove DIRS to play and eventually excel on the world stage.

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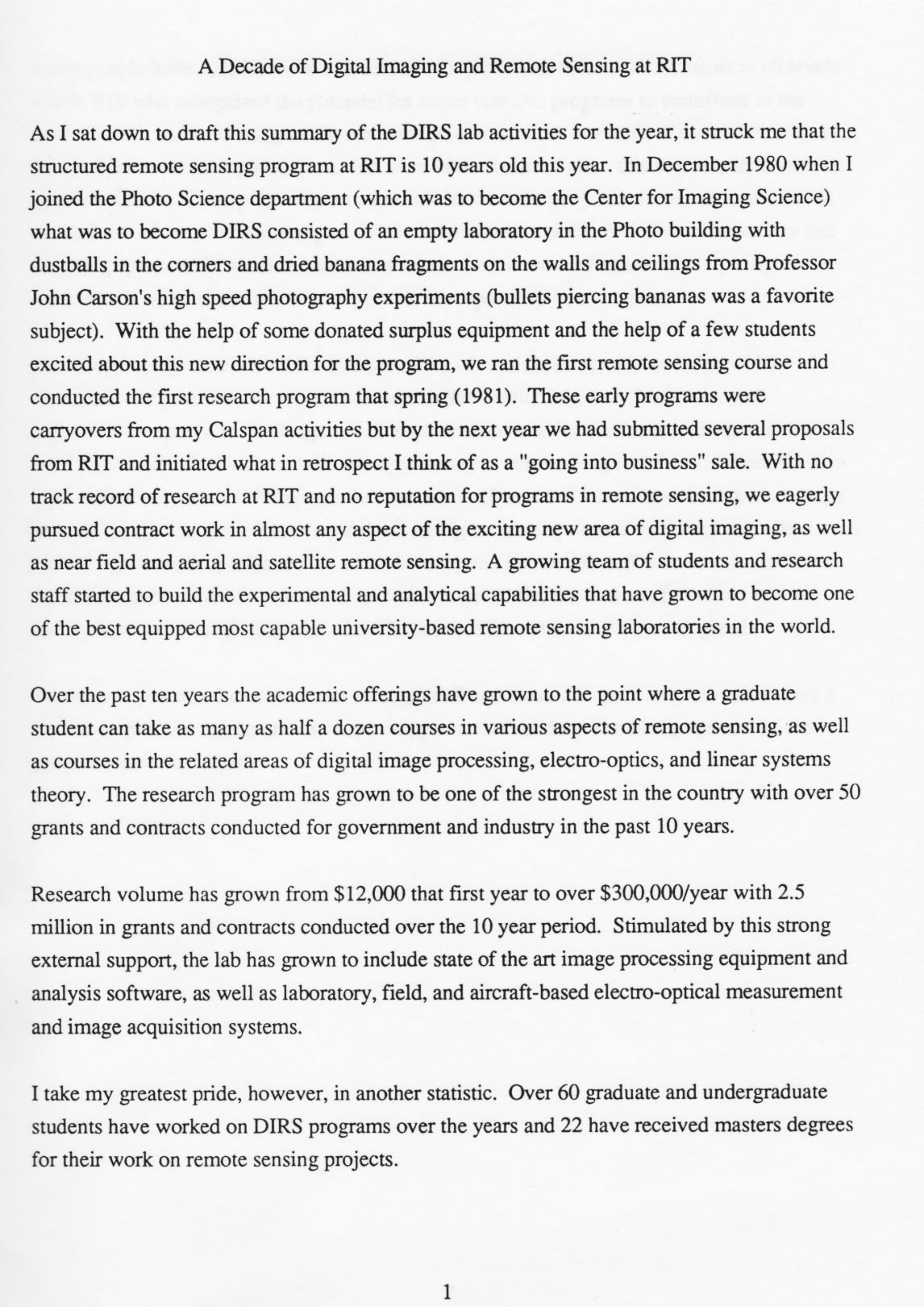
Appendix A
Introduction to 1990/1991 DIRS annual report



A Decade of Digital Imaging and Remote Sensing at RIT

As I sat down to draft this summary of the DIRS lab activities for the year, it struck me that the structured remote sensing program at RIT is 10 years old this year. In December 1980 when I joined the Photo Science department (which was to become the Center for Imaging Science) what was to become DIRS consisted of an empty laboratory in the Photo building with dustballs in the corners and dried banana fragments on the walls and ceilings from Professor John Carson's high speed photography experiments (bullets piercing bananas was a favorite subject). With the help of some donated surplus equipment and the help of a few students excited about this new direction for the program, we ran the first remote sensing course and conducted the first research program that spring (1981). These early programs were carryovers from my Calspan activities but by the next year we had submitted several proposals from RIT and initiated what in retrospect I think of as a "going into business" sale. With no track record of research at RIT and no reputation for programs in remote sensing, we eagerly pursued contract work in almost any aspect of the exciting new area of digital imaging, as well as near field and aerial and satellite remote sensing. A growing team of students and research staff started to build the experimental and analytical capabilities that have grown to become one of the best equipped most capable university-based remote sensing laboratories in the world.

Over the past ten years the academic offerings have grown to the point where a graduate student can take as many as half a dozen courses in various aspects of remote sensing, as well as courses in the related areas of digital image processing, electro-optics, and linear systems theory. The research program has grown to be one of the strongest in the country with over 50 grants and contracts conducted for government and industry in the past 10 years.

Research volume has grown from $12,000 that first year to over $300,000/year with 2.5 million in grants and contracts conducted over the 10 year period. Stimulated by this strong external support, the lab has grown to include state of the art image processing equipment and analysis software, as well as laboratory, field, and aircraft-based electro-optical measurement and image acquisition systems.

I take my greatest pride, however, in another statistic. Over 60 graduate and undergraduate students have worked on DIRS programs over the years and 22 have received masters degrees for their work on remote sensing projects.

Many people have contributed to this success. In particular, those administrators at all levels within RIT who recognized the potential for major research programs to contribute to the overall health and well-being of the academic programs at the Institute. Without their help in prying open, ever so slightly, doors that were often slammed shut, this task would have been insurmountable. Clearly the support and confidence in the programs from our sponsors has enabled the lab to grow and prosper. We believe that the number of follow-on contracts and recurring sponsorship which are the norm within the lab are a reflection of the quality of the work which we continue to strive to provide in response to your support.

Most importantly the current healthy state of the lab and the body of knowledge which represents our contribution over this decade are the result of the very hard work and enthusiastic response to challenge which have characterized the staff and students who have been part of the lab. I want to take this opportunity to acknowledge all those individuals who have collectively made this happen; the research staff, some of whom have been here through most of the decade and who have provided the rigorous analysis and continuity that allow us to tackle large complex problems, the administrative and secretarial staff who have insured that we always put our best face forward and most importantly, the students for whom it is all always new and through their shared excitement we are continuously re-energized.

To those of you who have been here through it all and those who may only have been here a quarter or two, my thanks and my hope that you have found the knowledge gained by the process worth the effort.