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Review / Synthèse

Josef Cihlar: a career of science and service to Canada and the world

Frank Ahern

Abstract. The academic world has a long-standing tradition to honour outstanding researchers and academics with a symposium. Josef Cihlar is certainly well deserving of this honour, and this special issue of the *Canadian Journal of Remote Sensing* serves to document the proceedings of the symposium held for Josef in October 2004. In this paper I review his career to highlight the contributions he has made to his department, Canada, and the world. These contributions include a very substantial addition to the scientific literature, including many papers published in the leading remote sensing journals. They also include critical contributions to the remote sensing programs of the Canada Centre for Remote Sensing and Canada. He has provided a fertile environment for research that has stimulated productive careers of numerous colleagues and younger scientists. Even more significantly, Josef Cihlar has provided influential leadership for the Canadian Global Change Program and the international effort to determine Earth's terrestrial carbon budget. The totality of these accomplishments amounts to a most remarkable career.

Résumé. Le milieu académique a une longue tradition d'honorer les chercheurs et les professeurs émérites par le biais d'un symposium. Josef Cihlar est certainement tout désigné pour cet honneur et ce numéro spécial du *Journal canadien de télédétection* se veut un témoignage en présentant les comptes rendus du symposium tenu pour Josef en octobre 2004. Dans cet article, nous passons en revue sa carrière afin de souligner les contributions qu'il a apportées à son ministère, au Canada et au monde. Ses réalisations incluent un apport très substantiel à la littérature scientifique, dont plusieurs articles publiés dans les revues de télédétection les plus prestigieuses. Elles incluent également des contributions critiques visant les programmes de télédétection du Centre canadien de télédétection et du Canada. Il a créé un environnement fertile pour la recherche qui a permis de stimuler la carrière productive de plusieurs collègues et jeunes chercheurs. Plus significativement, Josef Cihlar a fait preuve d'un leadership qui a su influencer le Programme canadien des changements à l'échelle du globe et l'effort international en vue de déterminer le bilan du carbone planétaire. L'ensemble de ces réalisations constitue l'assise d'une carrière remarquable.
[Traduit par la Rédaction]

Introduction

"Canada is a country made for remote sensing." So spoke Dr. Larry Morely, the driving force that brought the Canada Centre for Remote Sensing (CCRS) into being and led it as Director General during the initial years. The challenge of making remote sensing a reality for Canada brought out the best in a team of scientists, engineers, technicians, directors, and administrators. Over the next 25 years CCRS scientists and engineers were recognized around the world for their knowledge and innovation in data acquisition, data storage and processing, and the development and dissemination of practical applications of the emerging technology. Among many shining stars, the Sirius was Josef Cihlar (**Figure 1**).

A refugee to Canada after the 1968 Soviet invasion of Czechoslovakia, Josef completed a career of remarkable achievement and service in 2004. At the time of his retirement, he was so loved and respected by the scientists, technicians, and administrators who worked for him that they organized a workshop to honour him. This paper is the outgrowth of an invited oral presentation at that workshop. The intent is to provide a permanent written record of his exemplary career. Those who knew him and worked with him should enjoy having this memento. Those who come later can see what "aiming high" is all about.

Curriculum vitae

To provide a framework, I review Josef's life journey here in text and with the aid of a whimsical graphic (**Figure 2**).

Josef Cihlar was born in Kozmice, Czechoslovakia, on the 6th of October 1944 in a family that farmed for a living. Except for shortages, the war did not cause direct hardship to his family. After the war, the Communist Party took power in a bloodless coup in 1948, but again this did not affect the Cihlar family for several years. Josef enjoyed working on the farm and found a love for horses that has become an important part of his post-retirement activities.

Josef's village became a farming collective in 1956. Josef's horizons began to expand as he grew older. He studied at the University of Agriculture in Prague from 1962 to 1967,

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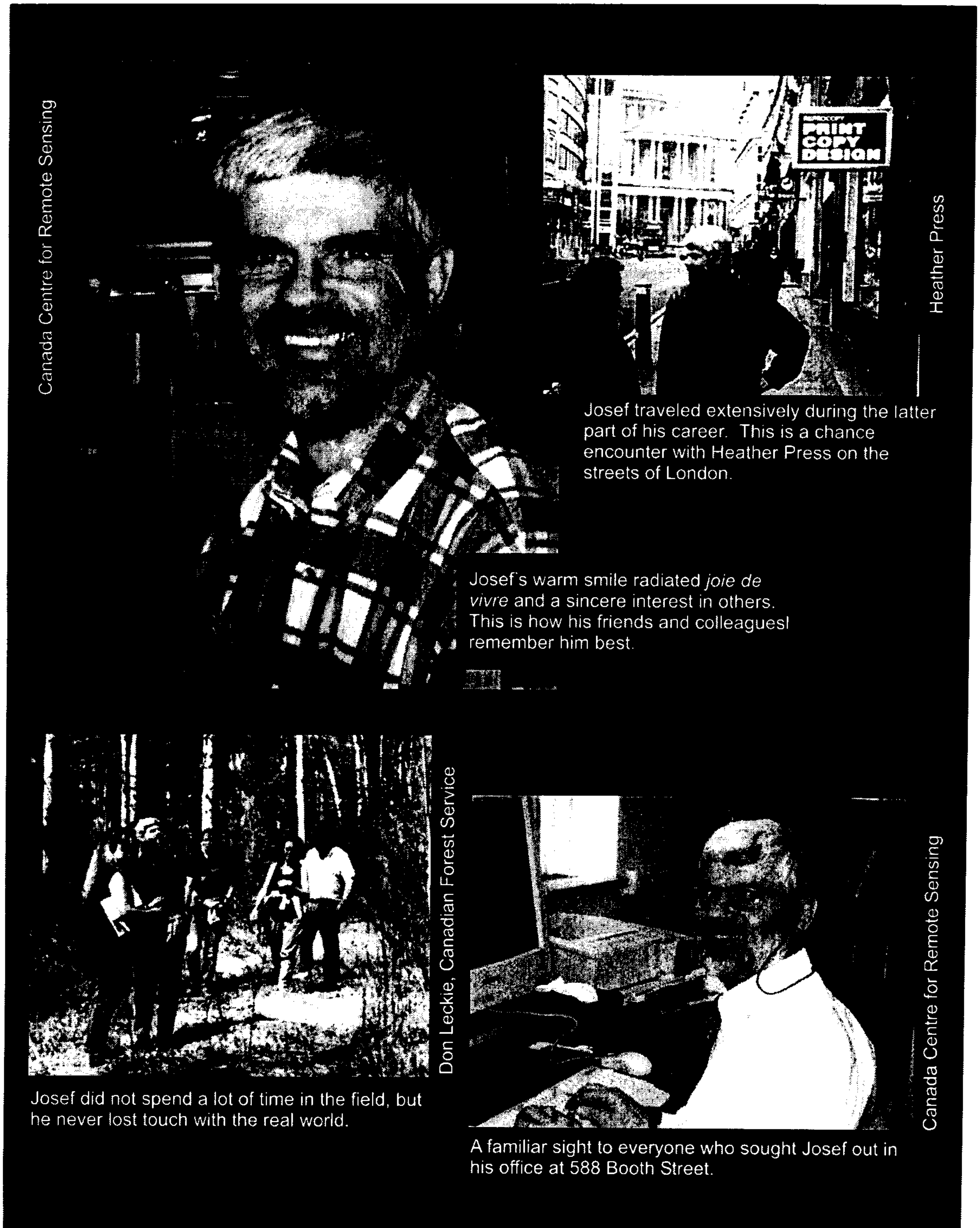

Josef traveled extensively during the latter part of his career. This is a chance encounter with Heather Press on the streets of London.

Josef's warm smile radiated *joie de vivre* and a sincere interest in others. This is how his friends and colleagues! remember him best.

Josef did not spend a lot of time in the field, but he never lost touch with the real world.

A familiar sight to everyone who sought Josef out in his office at 588 Booth Street.

Figure 1. Josef Cihlar.

receiving a B.Sc. in agricultural engineering, including a bachelor's thesis in soil water management and drainage. He completed 1 year of compulsory military service in August 1968, 2 weeks before the Soviet invasion. Before that cataclysmic event, he had been making plans to study overseas in an English-speaking country. His first choice was the University of Guelph. Josef obtained a student visa and moved to Canada just before studies in the West were forbidden by the increasingly pro-Soviet regime. He earned an M.Sc. degree in soil science under Richard Protz in 1971, exploring the use of colour aerial photography for soil mapping. Just before his graduation in 1971, he married Rosemary McCaw of Milford, Ontario.

The appeal of remote sensing became irresistible, and soil science remained the application that drove his interest. He chose the University of Kansas for doctoral studies because of its excellent program in radar, one of only two or three in the world at that time. He wanted to find out if radar could provide information on subsoil conditions, particularly soil moisture. Fawwaz Ulaby, an immigrant from Syria, had recently arrived at Kansas, beginning his ascent toward becoming a most prolific and respected academic in the field of microwave remote sensing. Josef gravitated to Ulaby as both a mentor and role model. He could not have picked a better person to emulate than this renowned leader and researcher. In 1975 Josef presented and defended his dissertation, "Soil moisture and temperature regimes and their importance to microwave remote sensing of soil water," and was awarded a Ph.D. in geography and remote sensing.

By the time he defended his dissertation, Josef had already accepted a job offer from the Applications Division of CCRS. Both he and Rosemary wanted to return to Canada.

It is worth noting that the CCRS of 1975 differed from many federal agencies that had research scientists on staff. While research scientists in many departments seemed to think that they were entitled to pursue pure research of their own choosing, that attitude was not highly regarded at CCRS. Research direction was strongly guided by senior management. Practical, operational use of the new technology was the priority, together with infrastructure that would support those applications, such as innovative sensors, efficient means for data processing, data storage, and data dissemination. Josef flourished in this climate.

Josef quickly began pursuing and publishing innovative research and working with users to get the results adopted operationally. He rapidly demonstrated interest and ability in leadership as well. He won a competition for head of the Applications Development Section in 1979, a position he held until 1991. Soon after taking on this new challenge, he assembled six teams to develop and implement remote sensing for agriculture, forestry, geology, hydrology, ice, and oceans. Each team was headed by a scientist who either was already producing world-class results or would soon begin to do so in the effective environment Josef and CCRS management provided. This was a "golden age" for the development of remote sensing technology in Canada. Many of the approaches developed at CCRS were world firsts. Many were adopted internationally, and CCRS earned a reputation abroad of providing excellent results on a modest budget.

During this time, Josef's management approach was to ensure that each of the six discipline leaders had adequate resources and was pursuing sensible goals on an ambitious timetable. This left him time to become involved in planning the RADARSAT mission, one of Canada's biggest space triumphs of the 20th century. From 1983 to 1985 Josef put a tremendous amount of time and energy toward defining the user requirements for RADARSAT data. He was instrumental in mobilizing the user community, many of whom initially viewed RADARSAT as a technology toy rather than a serious tool.

RADARSAT had been planned and justified almost entirely as a means to deliver ice imagery to support oil exploration and sovereignty in the Arctic. Under Josef's leadership many new applications were examined. Those that looked practical were pursued; those that did not were discarded. As oil prices declined during the early 1980s, RADARSAT required broader justification and support. Josef's applications group proposed numerous additional applications for RADARSAT (Cihlar et al., 1982).

As the 1980s drew to a close, Josef recognized the importance of climate change. The reception at CCRS of Josef's new obsession ranged from lukewarm acceptance to

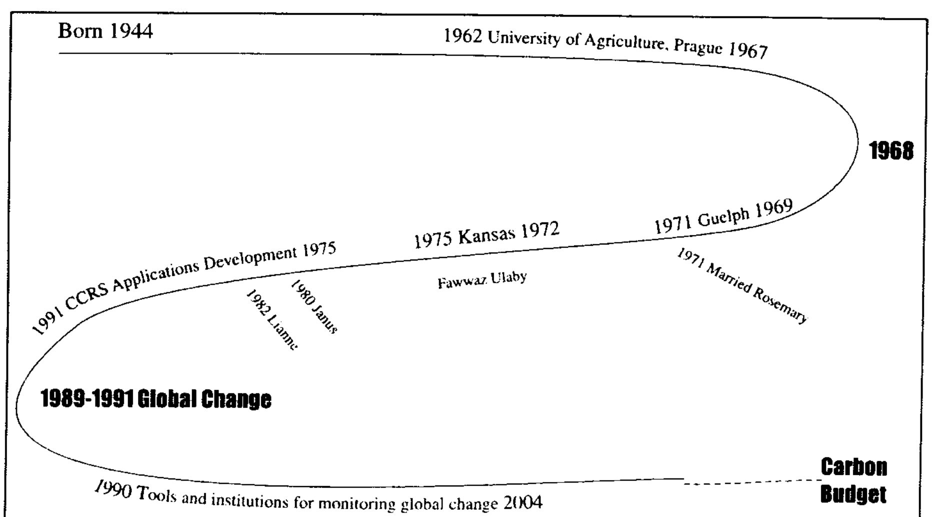

Figure 2. The life journey of Josef Cihlar. This figure summarizes the major events of Josef's life.

outright hostility. He turned to the Royal Society of Canada, found some support, and got a modest program underway (Cihlar et al., 1989). From that base he led or contributed substantially to several initiatives that linked remote sensing to climate change. His energy level was incredible, he began to make converts, and more substantial funding began to flow from several sources including CCRS, the Canadian Space Agency (CSA), and the National Aeronautics and Space Administration (NASA). By 1991 CCRS had a Global Monitoring Section with Josef as its head.

The new section needed new scientists. Josef became his own talent scout and soon landed bright, energetic, and devoted scientists from around the world, particularly China and Eastern Europe.

By the mid-1990s Josef was becoming a major international presence. I review that aspect of his career later in the paper. Suffice it to say that he made a major mark on a number of international endeavours that were aimed at monitoring global change.

At the time he announced his intention to retire in 2004, Josef was leading efforts that were making major advances on two fronts: to monitor the processes that determine Canada's carbon budget domestically, and to establish the institutions and methods to do the same on a global basis. This is why "carbon budget" is shown as the long-term objective in **Figure 2.** Many have wondered why Josef chose to retire when he was still going strong and the carbon budget objective was still not close at hand. For Josef, the joy of work came in pursuing the objective more than achieving it. He realized that he had reached a time for another turning point in his life, to find new objectives and pursue them with the same energy and determination.

Achievement and service

Scientific productivity

One simple measure of a scientist's research output is to count papers. By the end of 2004 Josef had published over 260 research papers, technical reports, or articles, including over 130 in refereed journals. It is even more instructive to read the titles, authors, and journals of his list of publications. The majority of his refereed publications appear in major national and international journals. Josef's coauthors include many well-known and respected Canadian and international scientists. The titles show perseverance toward clearly defined goals in a number of areas: heat loss from buildings, applications of microwave remote sensing, particularly of soil, and of course the terrestrial component of Earth's carbon budget. In the latter, Josef and his group had to develop a large amount of new methodology to use, calibrate, and correct continental datasets, particularly with the advanced very high resolution radiometer (AVHRR)[1] sensor. This work was just not getting done satisfactorily elsewhere, and Josef made sure it got done at CCRS. In so doing, his group developed a very solid scientific and technical foundation for subsequent global monitoring efforts.

What comes across in reading his list of publications is Josef's ability to assemble large, highly talented teams, keep them focused on a long-term goal, and keep them working harmoniously to achieve his vision. This is a common pattern of career progression for an outstanding scientist. It can produce an exponential growth, a chain reaction effect, which can be called the science cascade (see **Figure 3**). Josef produced two science cascades during his career, first through the applications development program of the 1980s, and subsequently through a larger cascade in the global change program of the 1990s. He was also very effective at partnering with other organizations.

Perhaps his most notable achievement was pioneering global change research in Canada. Josef realized that global climate change was going to be very important for the 21st century, before most others in Canada. He got a Canadian global change program up and running at CCRS despite a reception from most CCRS managers that was skeptical at best. His approach was one of persistent persuasion. According to one senior CCRS manager, he employed logic that could not be denied and was continually questing for more resources, but in a way that was patient rather than unpleasant. Compared to other seekers of support, he was more patient, more willing to listen and explain, and did not appear to be overstating his case.

Service to CCRS, Canada, and the world

The productivity discussed in the previous section, and the international leadership that went with it, alone would have been enough to propel Josef to the top of the research scientist category within the Government of Canada, but his career was distinguished even more by service to CCRS, Canada, and the world.

This characteristic first emerged in a 1979 review of the status of the usage of remote sensing for forestry, wildlife, wildlands, and biophysical inventory (Cihlar and Rubec, 1979). This led to a wider study of the status of remote sensing at the provincial level throughout Canada, recommendations to increase the transfer of remote sensing technology to the provinces (Cihlar, 1980), and ultimately the establishment of a

[1] This was the primary optical sensor on the National Oceanic and Atmospheric Administration (NOAA) polar-orbiting weather satellite series. Although the resolution might have been "very high" for a weather satellite, the 1.1 km resolution (at nadir) was very low compared with that of the optical sensors in general use by CCRS. AVHRR had the advantage of providing total coverage of all of Canada every day. Of course, much of Canada is covered with clouds every day. A technique developed and refined at CCRS, called compositing, picks the clearest pixels from images acquired over time periods of 7–10 days, producing a reasonably cloud free image of the country for that time interval. Although AVHRR data lack the spatial resolution of data from satellites like Landsat, they provide superior temporal resolution and spatial extent, and thus are very complementary to the higher resolution data. AVHRR data have now been superceded by data from more recent sensors, but the methods developed for AVHRR data can now be applied to the improved data from these newer sensors.

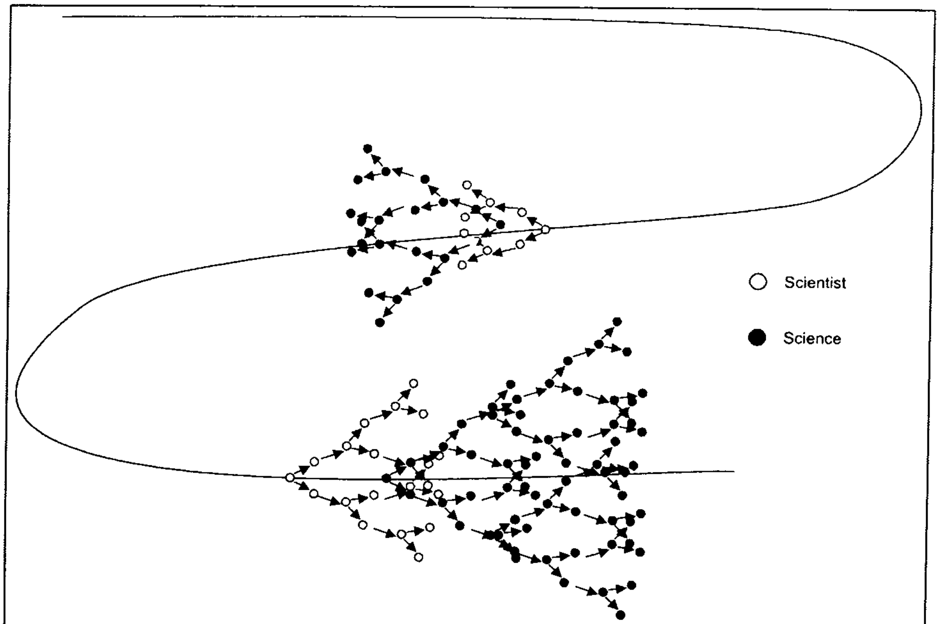

Figure 3. Two science cascades initiated by Josef Cihlar.

technology transfer section at CCRS. Josef was the originator of the concept that led to the technology transfer program at CCRS and provided management and leadership during its establishment phase.

Once the applications development effort was in the capable hands of the various discipline coordinators, Josef turned his attention to his first love: the application of synthetic aperture radar (SAR) data. The development of RADARSAT was making the transition to phase B, where credible practical applications for the data needed to be made. At the same time, the original justification for RADARSAT was becoming quite shaky.[2] Josef led a group that developed the user requirements for renewable land resources in Canada (i.e., agriculture, forestry, wetlands, rangeland). The report produced a very convincing case for the practical value of the C-HH SAR data proposed for RADARSAT for these applications. Josef then went on to lead the group that defined all of the applications of RADARSAT. The final RADARSAT phase B user requirements document produced under Josef's leadership appeared in 1985 (Cihlar et al., 1985).

Canadian Global Change Program

Josef's association with the Canadian Global Change Program began in 1988. Several visionary senior Canadian earth scientists had initiated the program under the auspices of the Royal Society of Canada. Josef's initial contribution was to ensure that the essential role of data from earth observation satellites was recognized (Cihlar et al., 1989). He also provided foresight into the types of data that would be required and the kinds of information to be derived from the data. One interesting project he initiated was the Canadian Global Change Encyclopedia (Cihlar et al., 1990). This was funded as part of Canada's activities under the International Space Year (1992) and attempted to demonstrate the value of multilayer continental and global datasets through a user-friendly data exploration software package.

His studies for the Canadian Global Change Program showed the magnitude of the task at hand. Although it was expected that much of the information could be derived from relatively coarse data, with 1 km resolution, the data volumes and data handling and processing requirements were immense, even with the technology on the horizon at that time. Undaunted, Josef set out to make it happen. The early 1990s showed a dramatic increase in the size and scope of Josef's research ambitions and the underpinning funding and infrastructure. He truly became a scientific entrepreneur during this time. When it became apparent that funding and other resources within CCRS could not expand enough to achieve his goals, Josef learned to tap numerous external sources, including Canada's Green Plan, CSA, the Royal Society of Canada, and NASA.

This quest for resources could have become all-consuming, but during this time Josef also proposed and executed the Northern Biosphere Observation and Modelling Experiment (NBIOME) (Cihlar et al., 1989; 1995; Cihlar, 1991).

NBIOME was an ambitious, but all-Canadian enterprise. Its objectives were as follows: (*i*) to investigate the effect of climate change on Canada's ecosystems, (*ii*) to map the land

[2] The original justification for RADARSAT was for ice mapping to support exploration and extraction of oil from Canada's High Arctic. In the early 1980s the price of oil began to stabilize and then fell, making this justification much less tenable.

cover of Canada, (*iii*) to look for evidence of land cover change, (*iv*) to model the carbon budget of Canada, and (*v*) to model ecosystem change.

It was apparent that a program of national scope and ambitious objectives would best be carried out by engaging scientists from other departments and from Canadian universities. Josef convened several workshops, and a science plan was developed. The actual execution took several years and involved scientists from CCRS, the Canadian Forest Service, and other organizations.

Shortly after NBIOME got underway, Josef was instrumental in helping to formulate and initiate a NASA-sponsored project called BOREAS, after the god of the north wind. BOREAS was a new undertaking for CCRS and Canada. It was a Canadian response to a new way of doing science at NASA. NASA was developing an Earth Observation System (EOS) to provide essential data for climate change studies. EOS became a billion-dollar program. Millions of dollars were available for one component, called Earth Systems Science. In essence, NASA intended to understand how the major earth systems function using an engineering approach. The complex systems were broken into simpler components that were given names, together with lists of input and output variables. They were interconnected with appropriate lines, creating massive, complicated "wiring diagrams". The role of terrestrial ecosystems in the global climate system became a priority at NASA and in the international scientific community, the latter initially clustered around the International Satellite Land Surface Climatology Project.

Among of the first systems to come under NASA's scrutiny were the carbon and water cycles because of their importance in the exchange of energy and in determining the concentration of CO_2, CH_4, and other greenhouse gasses in Earth's atmosphere. NASA's approach was to invite teams of forefront scientists to long, intense, 3- to 5-day workshops to hammer out a program plan. The program would draw the wiring diagrams, determine which boxes were well understood and which needed more study, determine how to create computer models of the entire system, and determine how to use space technology (and other technologies if necessary) to obtain the data to make the model work. NASA quickly learned that major aspects of how Earth functions were not really well known. Being NASA, they did not let that stop them. They chose major areas of uncertainty and invited more forefront scientists to more gruelling workshops to make plans for massive studies to determine how Earth works. One of the first of these massive studies was the Boreal Ecosystem–Atmosphere Study (BOREAS) (Sellers et al., 1995). BOREAS was an effort to determine how the boreal forest functions within the global climate system, and Canada was chosen as the study site. Numerous Canadian scientists were invited to the initial workshops, but NASA was prepared to do BOREAS in Canada with minimal Canadian participation if necessary.

Fortunately for Canada, and for NASA, several senior Canadian scientists, including Josef, recommended that Canada should participate in BOREAS in a major way. They realized that BOREAS represented a unique opportunity for Canada and Canadian scientists to increase scientific understanding of a major Canadian biome that is important both ecologically and economically. At Josef's suggestion, CCRS agreed to support establishment of a BOREAS Secretariat in his section. In Canada, as in NASA, BOREAS consisted of substantial forefront research together with a large amount of backbreaking work. The BOREAS Secretariat helped ensure that Canadian scientists would have an opportunity to participate significantly in the forefront research. The BOREAS Secretariat also facilitated fieldwork in Canada by scientific teams from outside the country. Josef served as the Canadian coordinator for BOREAS from 1992 to 1996.

During the early stages of NBIOME and BOREAS, Josef needed to populate his new section with research scientists eager and able to take on these new challenges. Josef attracted some remarkable young talent from China and Eastern Europe in these years just following the Tiananmen Square massacre and the breakup of the Soviet Union. Both NBIOME and BOREAS moved forward. NBIOME began to lay the groundwork for processing AVHRR data at a nationwide scale. BOREAS validated NASA's engineering systems approach to modelling Earth, leading to an even larger project with Brazil in the Amazon. It was a training ground for many young scientists and developed scientific methodology that continues to produce the knowledge necessary to model Earth's complex systems.

At the same time a lot of the basic infrastructure to acquire and handle the needed datasets had to be developed, essentially from scratch. At the time Josef began to discern the need for national, continental, and global datasets, CCRS had very little capability of using 1 km resolution data; except for the Crop Information System,[3] all of the data acquired, processed, and archived by CCRS ranged in resolution from 30 m (Landsat) to 1 m (Multidetector Electro-optical Imaging Sensor, MEIS). These high-resolution images were processed as individual multispectral images. Very little capability existed to handle multi-image datasets. Therefore, in addition to leading efforts to understand the functioning of the boreal forest and other Canadian ecosystems, Josef's section led the development of the basic infrastructure needed to observe Canada as a biophysical entity. These developments included the following: (*i*) the capability to acquire and archive 1.1 km AVHRR data for all of Canada on a daily basis; (*ii*) a facility to produce composite images by extracting the clearest (most cloud free) pixels, based on an earlier system developed for the Crop Information System (Adair et al., 2002; Cihlar et al., 2002); (*iii*) a number of techniques to reduce the effects of residual cloud and haze contamination (Cihlar and Howarth, 1994);

[3] The Crop Information System, developed for the Canadian Wheat Board, used daily imagery from the AVHRR sensor on the NOAA weather satellites to provide information on the growing conditions in the Canadian Prairies.

(*iv*) methods to correct for variations in illumination and viewing geometry inherent in the data (Cihlar and Huang, 1994; Cihlar et al., 1994; Wu et al., 1995; Li et al., 1996); (*v*) significant developments in automated land cover classification for both coarse-resolution (~1 km) and fine-resolution (~25 m) data (Cihlar et al., 1996; 1997; 1998; Beaubien et al., 1999), innovations that decreased the amount of intervention required by expert interpreters, a prerequisite for classification of large areas in a consistent way; and (*v*) methods for combining coarse- and fine-resolution data.

By 1995 Josef had assembled a large and productive research group. It was exceptional in its enthusiasm for hard work and single-minded pursuit of the goals that Josef had established years earlier. Once the basic infrastructure began to be available, the research team began to turn its efforts toward demonstrating the kinds of data products that were necessary for climate change research. In most cases these were produced for all of Canada at 1 km resolution and were done in a way that could be turned into routine production with little modification. The highlights include the following: (*i*) annual maps of the area burned by large forest fires using AVHRR data (Li et al., 2000); (*ii*) the leaf area index for Canada's vegetation at 10-day intervals throughout the growing season (Chen and Cihlar, 1998); (*iii*) the amount of photosynthetically active radiation falling on Canada's vegetation, and the fraction of that radiation that was absorbed, at 10-day intervals throughout the growing season (Li et al., 1997); (*iv*) the land surface temperature; (*v*) measures of vegetation productivity (Liu et al., 2000); and (*vi*) maps of net primary productivity and net ecosystem productivity (Liu et al., 2002).

The final two products are essential inputs into calculations of Canada's carbon budget that use biophysical process modelling. They require most of the earlier products in the list, which in turn require the basic infrastructure described earlier.

In addition to producing these products, Josef's group devoted considerable effort to validating the outputs of each step along the way, so credible error estimates were available. These showed that some of the errors were larger than desired, and the products have been criticized for this shortcoming. This is the way science progresses, however: to reach far, go as far as possible, and then make refinements to improve the weak links.

In short, Josef led a prolonged, well-focused effort that produced and validated an entire system for deriving critical carbon-budget variables from daily coarse-resolution data, starting nearly from scratch.

The international arena

In 1988 Josef jumped into the international arena by becoming active in the International Geosphere–Biosphere Programme (IGBP), a massive international program designed to deliver a rapid expansion in knowledge of the interactions between the biosphere and the geosphere (all nonliving parts of Earth). His influence quickly expanded. Not only was he a knowledgeable and convincing proponent for his ideas concerning effective use of space observations in IGBP, but he was also willing to take on a large amount of the hard, unglamorous work. He helped organize and lead workshops of experts, chaired plenary and breakout sessions, helped achieve consensus, and typically contributed much more than his share of writing up reports after the meetings.

The international arena is a complex playing field with real and imaginary components, where only the insightful can distinguish the real from the imaginary. It is populated with large numbers of organizations and initiatives, always named with acronyms, and even larger numbers of participating individuals. There are many big egos and rigid institutions. To make a meaningful contribution requires intelligence, a great memory, diplomacy, determination, and lots of hard work.

Figure 4 is a roadmap to help follow and appreciate Josef's international contributions. These began in 1988 when he initially co-proposed a global land cover mapping initiative based on 1 km resolution satellite data from the AVHRR sensor. In 1990 he joined the IGBP Land Cover Change working group and helped define the data processing methodology and the validation strategy. This initiative finally reached fruition in 1999 when the first land cover map of the entire Earth was released, at 1 km resolution.

While IGBP emphasized actual science, Josef realized that a lasting contribution required efforts to develop international institutions and policies to ensure that effective observations would be made and the appropriate information products would be derived from these observations. One of the outgrowths of the 1992 Earth Summit in Rio de Janeiro was an initiative designed to lead toward coordinated global observations of the environment. Three observing systems were proposed, called the Global Terrestrial Observing System (GTOS), the Global

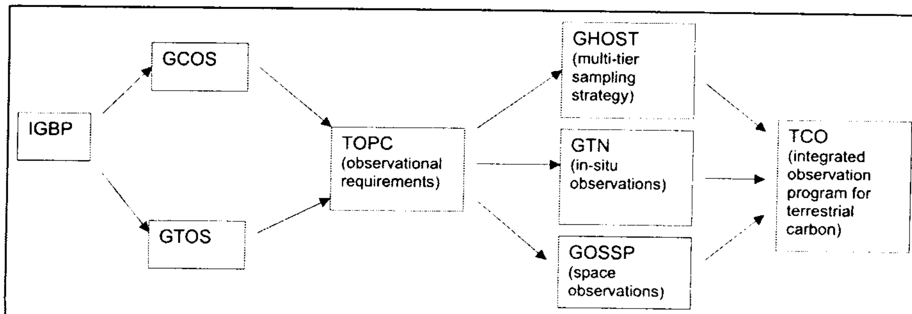

Figure 4. Flow chart of Josef Cihlar's international activities.

Climate Observing System (GCOS), and the Global Ocean Observing System (GOOS). Josef became a member of the Canadian GCOS task force in 1994 and played a leading role in defining observational requirements. There was a lot of commonality between the observational requirements for GCOS and those of GTOS, so a joint panel called the Terrestrial Observation Panel for Climate (TOPC) was formed to determine the observational requirements and propose means to achieve them. Josef became its chairman from 1995 to 2001. During this time, multiple meetings in far-flung places resulted in (*i*) an innovative multi-tier sampling strategy to collect the required observations from ground to space, called GHOST; (*ii*) much more detailed definitions of the observations needed from space through a panel called the Global Observing Systems Space Panel (GOSSP); and (*iii*) a similar definition of in situ observations through development of the Global Terrestrial Network (GTN) concept.[4]

The primary aim of these efforts was to provide the information needed to determine the natural and anthropogenic effects on terrestrial ecosystems, including the impact of climate change. When GCOS and GTOS became members of the International Global Observing Strategy Partnership (IGOS-P), TOPC proposed to develop a terrestrial carbon "theme" in 1999. Following IGOS-P approval, Josef played a major role in an international effort to plan and implement the Terrestrial Carbon Observation (TCO) initiative. This work carried on through 2002 and resulted in two benchmark reports that illuminated the path forward to achieve the observations and modelling needed for a reliable terrestrial carbon budget. As a result of this work, the Conference of the Parties of the Climate Change Convention is actually addressing issues related to climate observation, capacity, and requirements, and the international community has made a commitment to a sustained international program of Earth observation and data through the international Group on Earth Observation.

Thus Josef made multiple, major contributions to the international effort to understand the terrestrial carbon cycle. Under its EOS program, NASA is beginning to produce products to support carbon budget studies that are reminiscent of the products produced for Canada by Josef's group in the 1990s. An international consortium has produced a global land cover map that improves significantly upon the initial land cover map produced by the IGBP. International institutions endorse these efforts and embrace their findings. Gradually, a well-supported international capability to monitor Earth's most important processes is being built. These institutions and the infrastructure will help ensure that political decisions that influence the future health of our planet are made with open information that is based on the best possible science. Josef Cihlar can be proud of his contribution to this effort.

Personal characteristics

In reviewing Josef's career, one cannot help but ponder the personal characteristics that underpinned his remarkable career. To approach this subject, the author interviewed many of Josef's coworkers, fellow scientists and engineers within CCRS and beyond, and some of his managers. The following personal characteristics were mentioned time and again: (*i*) vision; (*ii*) hard work (Josef is legendary for his ability to work hard and seems to enjoy it immensely); (*iii*) people management (the teams he has assembled work very well together; he encourages diverse points of view but makes sure there are no interpersonal conflicts); (*iv*) focus (he is able to keep the big picture and all the details clearly in focus at all times; one scientist who worked with him early in his career said "He drew a lot of charts and crazy network diagrams"); (*v*) a charismatic leader who was able to draw out the best from everyone; and (*vi*) a very honest person.

It is also illuminating to provide some insightful quotations from these interviews: "He is very determined, sometimes to a fault. He is always convinced that his way is best. His team was also convinced, which sometimes made it hard for outsiders to work with his team." "He is able to achieve his objectives despite others with their own agendas." "He is able to put science into a practical policy context." "He has a challenging mind." "He pushes the envelope of technical capabilities; the results are not always correct, but they are always thought-provoking." "He has little time for small talk." "He is a good diplomat." "He is a good scientific entrepreneur without being unpleasant. He was able to assemble resources by producing compelling arguments and chipping away at management bit by bit." "His memory is rather scary at times. He can suggest something to one of his scientists and then inquire 6 months later how it worked out, often to the person's embarrassment." "He is tough, yet fair." "He leads people to work to their full potential."

Conclusion

The period between 1972 and 2000 will be remembered as the time when remote sensing took off. The discipline progressed from promise to practicality. The Canada Centre for Remote Sensing (CCRS) played a major role in that progression, primarily because of the corporate culture, which encouraged ambitious undertakings by both scientists and engineers, constrained only by clearly articulated goals, modest but not parsimonious budgets, and a sense of accountability to the Canadian taxpayer. In this fertile environment, numerous scientists and engineers were able to produce remarkable achievements through their dedicated, consistently superior work. Among this creative lot, Josef Cihlar stands out for his scientific achievements, his truly significant institution-building contributions for Canada and the international

[4] It is useful to note that this planning led to concrete action. For example, two GTN networks were established during Josef's tenure, one for glaciers and one for permafrost.

community, and his personal characteristics of foresight, leadership, hard work, and persuasiveness. It is a fitting tribute that his research group volunteered to honour him with a workshop in his name, and the *Canadian Journal of Remote Sensing* produced this special issue as a lasting, written record of his career and accomplishments.

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