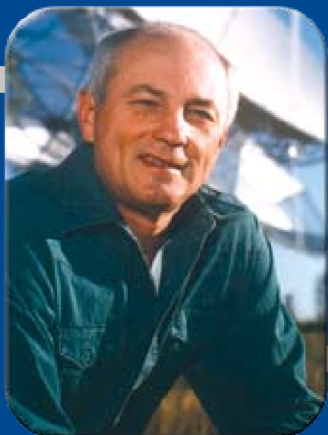
CIRA

Cooperative Institute for Research in the Atmosphere



25 Years

Pioneering Innovative Research Collaborations and Partnerships (1980 - 2005)

Many thanks are due to CIRA staff – both past and present – whose contributions culminated in this important publication. Names have been included where appropriate; however, much gratitude is extended in particular to Ms. Linda Meyer.

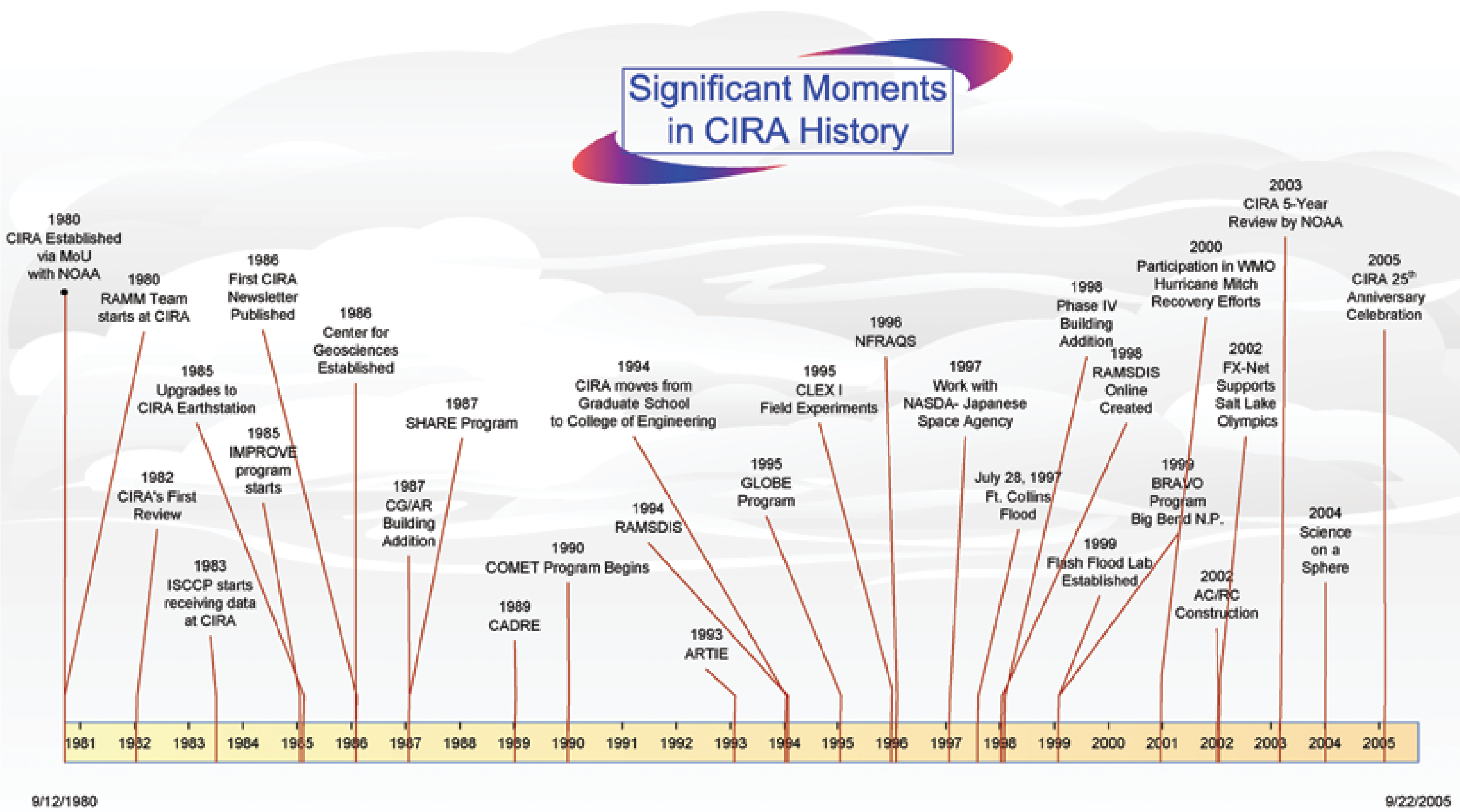
As an historian at Colorado State University, Ms. Meyer had the challenging task of sorting through CIRA's collection of past annual reports, magazines, newspaper articles and other information to document the history of CIRA. In addition, she spent several hours interviewing Dr. Vonder Haar, CIRA's founder, for this effort and to include as part of the University's oral history project.

Further thanks go to Deputy Director Ken Eis, for his invaluable contributions; Associate Director Cliff Matsumoto, for his assistance in gathering the "Boulder story;" Laura Grames for her efforts in collecting images and editing the book; Joanne DiVico for helping Ms. Meyers and others in gathering CIRA's historical archive; Renate Brummer and Don Reinke for their creativity in gathering presentations for the CIRA 25th Anniversary event (much of which ended up in this book); Maureen Murray for the cover design; and all the individual contributors to the content herein.

The CIRA story is, of course, about more than the innovative research and ground-breaking science which has flourished at the Institute. The real story is in the people: Dr. Thomas H. Vonder Haar, his vision to contribute to our understandings of the atmosphere and our Earth, and all those who have lent their imaginations to the success of the Cooperative Institute for Research in the Atmosphere.

– Mary McInnis-Efaw
CIRA Manager and Contributing Editor

Table of Contents



CHAPTER 1: *An Historical Overview*

During the early autumn of 1976, the faculty from the Department of Atmospheric Science at Colorado State University (CSU) gathered for their annual mountain retreat near the city of Fort Collins. With technological advances had come new questions. The solutions to scientific problems had become increasingly complex, and researchers felt a growing awareness of the need for collaboration and interdisciplinary studies. One successful partnership, the Cooperative Institute for Research in the Environmental Sciences (CIRES), had been established nine years earlier by an agreement between the National Oceanic and Atmospheric Administration (NOAA) and the University of Colorado in nearby Boulder. As a growing number of CSU Atmospheric Science faculty members desired to collaborate in research with their colleagues at NOAA, the model represented by CIRES held promise. Thus during the faculty discussions at the retreat, the idea to create a cooperative research institute for the study of atmospheric topics at CSU gradually took shape.


MAILGRAM SERVICE CENTER
MIDDLETOWN, VA. 22645

western union Mailgram

COLORADO STATE UNIVERSITY J COBB
DEPT OF ATMOSPHERIC SCIENCE
FT COLLINS CO 80523

THIS MAILGRAM IS A CONFIRMATION COPY OF THE FOLLOWING MESSAGE:

3034918566 NL TDMT FT COLLINS CO 26 09-15 0435P EST
PMS EARL G DROESSLER DIRECTOR OF UNIVERSITY AFFAIRS, DLR
UNITED STATES DEPARMENT OF COMMERCE NATIONAL OCEANIC AND ATMOSPHERIC
ADMINISTRATION
WASHINGTON DC 20230
ALL SIGNATURES HAVE BEEN COLLECTED AND THE CIRA IS NOW OFFICIAL.
THANKS AGAIN FOR YOUR GUIDANCE. PLEASE CALL WHEN CONVENIENT TO
DISCUSS THE DETAILS. BEST REGARDS
VONDERHAAR

1640 EST

MGMCOMP MGM

Original mailgram confirming the formation of CIRA, September 1980.

The CSU Department of Atmospheric Science was established in 1962 under the direction of Professor Herbert R. Riehl, a noted tropical meteorologist from the University of Chicago. Riehl was offered a faculty position at CSU to participate in an atmospheric science graduate program within the department of Civil Engineering. After encouraging several colleagues from Chicago to join him, Riehl convinced the university to establish an independent department of Atmospheric Science in the College of Engineering. A very successful research program with funding from contracts and grants allowed the eight-member department to move into a new atmospheric science building on the foothills campus in 1967. Two years later, Dr. Riehl stepped down as department head to devote his full attention to research and teaching, and Dr. Elmar R. Reiter accepted responsibility for leading the department.

Thomas H. Vonder Haar came to CSU in 1970. After earning his Ph.D. in meteorology at the University of Wisconsin in 1968, Vonder Haar continued post-doctoral work there at the Space Science and Engineering Center under the tutelage of Professor Verner Suomi, a leader in the emerging field of satellite meteorology. Vonder Haar became involved in research for NASA and for the U.S. Weather Bureau (precursor of NOAA), and developed successful

Thus during the faculty discussions at the retreat, the idea to create a cooperative research institute for the study of atmospheric topics at CSU gradually took shape.

working relationships with numerous government scientists. While participating in a 1965 meeting at the National Center for Atmospheric Research (NCAR) in Boulder, he was impressed by the opportunities available for meteorological research in Colorado. A colleague from Wisconsin, Stephen K. Cox, was hired by CSU as an assistant professor in the Atmospheric Science Department in 1969. After hearing of a job opening there for a climatologist, Vonder Haar joined Cox on the faculty at CSU a year later.

When Dr. Reiter resigned as head of the Atmospheric Science Department late in 1973, none of the senior faculty had an interest in running the department, and they encouraged young associate professor Vonder Haar to apply for the position. Dr. Vonder Haar's national and international connections would enhance the department's visibility, and the selection committee chose him over the external candidates to fill the vacancy. One of his earliest duties as department head involved hiring Colorado's first state climatologist in 1974. The stage had been set by former department head Elmar R. Reiter, Professor Lewis O. Grant, and Engineering College Dean Lionel V. Baldwin to persuade the state legislature to create the position and affiliate it with the Department of Atmospheric Science at CSU. Following their successful efforts, Dr. Vonder Haar hired Thomas B. McKee to fill the post. Dr. McKee had received his Ph.D. from CSU in 1972, and returned to Colorado in 1974 from an assistant professorship at the University of Virginia.

The Atmospheric Science Department was rebuilding at this time, as some senior faculty approached retirement age and others left for new opportunities, among them Dr. Riehl, who accepted a professorship at the University of Berlin and returned to his native Germany. During his ten years as department head, Vonder Haar would hire seven new faculty members, five of whom would ultimately become involved with the cooperative institute envisioned by the Atmospheric Science faculty at their 1976 retreat.

In the meantime, Dr. Vonder Haar had developed a working relationship with Joseph O. Fletcher, a senior scientist who became deputy director of the Environmental Research Laboratories (ERL) at NOAA. In line with the growing federal interest in tapping the resources of academic institutions, Fletcher had embarked on an active campaign to recruit universities to join NOAA in forming cooperative research institutes. In May 1977, Fletcher made a direct appeal to Vonder Haar and CSU. Fletcher encouraged Vonder Haar's interest in creating a similar institute and provided him with a copy of the cooperative agreement between NOAA and the University of Miami.

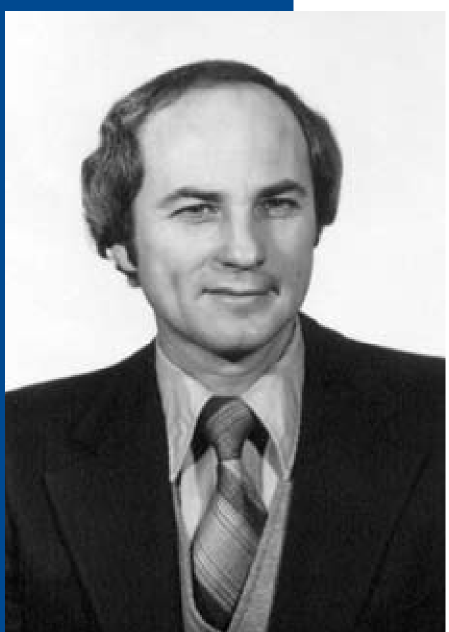
By November 1977, following additional discussions with Deputy Director Fletcher about the cooperative institute concept, Dr. Vonder Haar prepared a draft Memorandum of Agreement to submit to Fletcher for review. In his cover letter, Vonder Haar cited examples of the productive results achieved in prior short-term collaborations between CSU researchers in the Department of Atmospheric Science and their counterparts at NOAA/ERL. Emphasizing the importance of ongoing studies to enhance resources for predicting the weather, Vonder Haar described how a move from such short-term collaborations to mutually-beneficial long-term research projects could move the science forward. CSU offered the only Atmospheric Science Department in the state of Colorado, therefore the University represented the best logical choice for a partnership with NOAA.

A severe drought in the late 1970s led to a heightened interest on the part

CIRA is the second oldest NOAA cooperative institute.

CIRA's close relationship with NOAA via PROFS and FSL, and its satellite theme area, go back to its inception.

of the Colorado legislature in funding a weather modification program. This was an initiative designed to increase the winter snow pack in the mountains which would, in turn, result in increased spring runoff to counteract the effects of the drought. Weather modification would become one of the major research themes proposed for the new cooperative institute. Other themes included global climate dynamics, local area weather forecasting and evaluation, and VISSR Atmospheric Sounder (VAS) research, which endeavored to exploit a new system aboard the GOES-4 (Geostationary Operational Environmental Satellite) in addressing meteorological issues.



Dr. Vonder Haar, circa 1980

Deputy Director Fletcher responded to the initial memorandum of agreement in January 1978. The revised draft he returned to Dr. Vonder Haar included suggestions for an external advisory board and clarifications concerning the particulars of the agreement between NOAA and CSU. He invited Vonder Haar's response and continued progress toward completion. However, in the ensuing months, plans for the cooperative institute were put on hold due to a shift in NOAA management. Later, in a January 1979 memo to NOAA managers, NOAA Administrator Richard A. Frank outlined a federal strategy for expanding relations between academic institutions and NOAA research facilities. This included plans for additional cooperative agreements, and the appointment of a new director of university relations at NOAA, Earl G. Droessler. Taking advantage of the renewed interest at NOAA, and with the support of Engineering College Dean Lionel Baldwin, the timing was ideal for Dr. Vonder Haar to move ahead with the plans for the cooperative institute.

On September 12, 1980, Acting CSU President Charles O. Neidt signed the official Memorandum of Understanding with NOAA, and the Cooperative Institute for Research in the Atmosphere (CIRA) was formally established. The stated purposes of CIRA were:

1. To improve the effectiveness of research and graduate-level teaching through close collaboration of the two parent organizations.
2. To serve as a focal point for cooperation in specified research programs by scientists from Colorado, the Nation, and other countries.
3. To train personnel for research in the atmospheric sciences, and to accumulate experience with multifaceted research programs.

The Memorandum stressed that although the majority of CSU participation in CIRA would come through the Department of Atmospheric Science, other departments would also be involved. Initially, these included Agricultural and Chemical Engineering, Civil Engineering, Computer Science, Earth Resources, Economics, Electrical Engineering, and Statistics. NOAA's participation in the institute would come primarily through personnel from ERL and NESS (the National Environmental Satellite Service).

According to the framework provided in the agreement, the personnel of CIRA would consist of Fellows, Visiting Fellows, Research Associates, and support staff. CIRA Fellows might be CSU faculty and staff assigned by the Director of CIRA and approved by NOAA, or they could be NOAA researchers assigned by the NOAA administrator and approved by CIRA (on behalf of CSU). The CIRA Advisory Council, consisting of three NOAA Fellows, two CSU Fellows, and the Director of CIRA (a CSU Fellow), would be responsible

FLASHBACK: CIRA newsletter, Volume 14: Fall, 2000

NOAA Collaborations

Starting in the early 1990s, the ranks of CIRA staff members in Boulder – primarily at the Forecast Systems Lab (FSL, now known as ESRL/GSD) – steadily grew. From approximately 20 people in 1993, CIRA's presence in Boulder peaked near 70 members in 1997. CIRA personnel now populate six of the seven Lab divisions. They are an integral part of virtually all major projects at FSL – from data assimilation and mesoscale model development to high performance computing and 3D visualization. They form the core of the development effort for the internationally acclaimed GLOBE program and the NWS award-winning AWIPS program. They provide cutting-edge technological expertise in wavelet transform techniques for satellite image compression and dissemination as well as gridded model output fields over the Internet. They are vital to the development and maintenance of realtime meteorological data acquisition and processing systems within the FSL Central Facility. CIRA personnel also contribute to research efforts within NOAA's Environmental Technology Lab and the NESDIS National Geophysical Data Center.

– Cliff Matsumoto

for advising the Director on issues regarding cooperation between CSU and NOAA, maintenance of high scientific standards at CIRA, appointment of Visiting Fellows, and adoption and modification of CIRA by-laws. In addition to the Advisory Council, an external CIRA Advisory Board comprised of CSU and NOAA leaders would review and approve the policies, research themes and priorities of CIRA, make recommendations for the CIRA Directorship, prepare a biennial evaluation of CIRA and review the CIRA budget. The Advisory Board membership included the Director of NOAA University Affairs, the Director of ERL, the Director of Research at NESS, the CSU Vice President for Research, the Dean of the College of Engineering and the Head of the Atmospheric Science Department. The Director of CIRA would serve as a non-voting member.

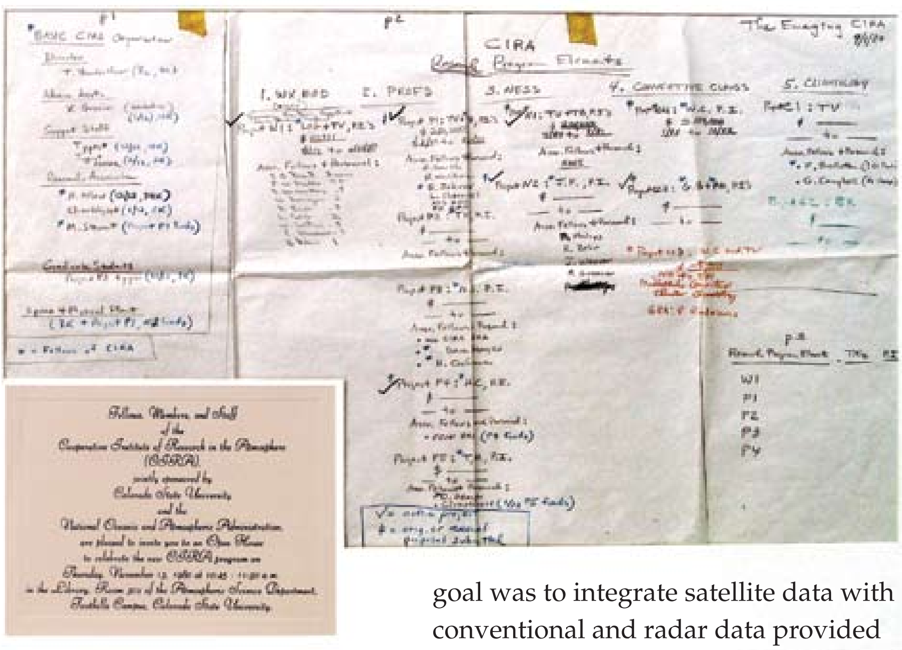
The first CSU Atmospheric Science Department faculty members honored for their work as CIRA Fellows were Lewis O. Grant, Thomas B. McKee, and Peter C. Sinclair. They were joined by Thomas A. Brubaker of the Electrical Engineering Department, Harold C. Cochrane (Economics), Paul W. Mielke, Jr. (Statistics), and Glenn W. Brier, a senior research associate in Atmospheric Science. The initial NOAA Fellows were Ron L. Alberty (ERL), Donald W. Beran (ERL), and James F. W. Purdom (NESS). The first Research Associates of CIRA included D. Neil Allen, Michael Goggin, Melanie A. Kruidenier, and Ronald F. Wachtman from the Atmospheric Science Department, as well as NOAA scientists Robert N. Green (NESS), Robert Lipschutz (ERL), Roger Phillips (NESS), John F. Weaver (NESS), Herb Winston (ERL), and Raymond M. Zehr (NESS). In addition, G. Garrett Campbell and Donald W. Hillger, both graduates of the CSU Atmospheric Science Ph.D. program, joined the initial group of CIRA Research Associates.

Once the institute was launched on paper and staffed with outstanding Fellows and Research Associates, the members of the newly-formed institute did not have to wait long for a designated facility in which to work. The CSU Research Foundation provided land for the new CIRA building adjoining the grounds of the Atmospheric Science building on the foothills campus,

CIRA's multi-disciplinary approach to research was part of its birth. Its first Fellows included an economist, electrical engineer, and statistician.

and NOAA contributed funds for the construction. The facility was completed quickly, and in October 1981, fifteen CIRA researchers and staff moved in to their new quarters.

The plan behind the creation of CIRA always included an intention to coordinate with other joint research programs already underway. For example, an ongoing effort between CSU and NESS involved the future use of satellite data by NOAA. Specifically, the goal was to integrate satellite data with conventional and radar data provided by a new Doppler radar facility that was to be built in the Boulder/Denver area. CIRA supported the Prototype Regional Observing and Forecasting Service (PROFS) through the collection and integration of satellite data and development of "visualization" and "nowcasting" capabilities. The "nowcast" products displayed the data in a manner which allowed weather events to be studied in a real-time environment. PROFS and CSU researchers also devised techniques for utilizing radar to complement the acquisition of satellite data, and their recommendations would later be implemented in the NEXt generation of RADar (NEXRAD). Dr. Thomas Brubaker from the Electrical Engineering Department and Dr. Vonder Haar led much of the advanced engineering and digital technology for this research.



Dr. Vonder Haar's original sketch for CIRA and the invitation for CIRA's first Open House, 1980.

Another early CIRA priority involved participation in the International Satellite Cloud Climatology Project (ISCCP), part of a World Meteorological Organization program to collect and process satellite data worldwide. The aim was to increase international knowledge of the impact of clouds on weather and climate. CIRA began receiving data for this project from the GOES-6 satellite in July 1983, and continued collection from later GOES satellites as well as from Meteosat 3 and INSAT. This project continues in 2006 and thus has become the longest continuous research project at CIRA.

As part of the NOAA contribution to CIRA, five NESS employees relocated to Fort Collins from Washington, D.C. in the fall of 1980. (By 1984, NESS had changed its name to NESDIS, the National Environmental Satellite, Data and Information Service.) These federal scientists, James F. W. Purdom, Robert N. Green, Roger Phillips, John F. Weaver, and Raymond N. Zehr, became the first members of the Regional and Mesoscale Meteorology (RAMM) Branch of the NESS Applications Laboratory at CSU. Their initial work with other research associates at CIRA involved utilizing satellite data to better understand the development of severe or convective weather, and this focus soon broadened to include tropical storms and mesoscale modeling of the atmosphere. An important outreach role of the RAMM Branch has involved the training of National Weather Service and other meteorologists in the application of satellite data to weather analysis.

Within a year of its inception, the advisory board was taking another look at CIRA's stated research themes and the advisability of seeking sources of funding outside of CSU and NOAA. At the annual meeting held in December 1981, the board expressed concern about the theme of weather modification research, which was not supported by the new Reagan administration. In response, it was suggested that the work identified as weather modification be described by another label. This was accomplished gradually over the next few years, and the weather modification theme evolved into "applied cloud physics." Also, board members felt that the theme area of VISSR Atmospheric Sounder research needed a broader title. The board changed this theme to "application of satellite observations" at their next meeting in September 1982. Another possible theme related to a project sponsored by the National Park Service (NPS) concerning atmospheric visibility. This project represented the first infusion of outside funds into CIRA. At the 1982 meeting, the advisory board voted to establish a fifth theme of "air quality," which would include the NPS study and might attract additional funding from energy development companies involved with oil shale activities in Colorado.

In December 1982, CIRA received very positive marks in its first biennial review. The institute was rated highly in its current status, progress, and plans for the future. One reviewer commented that CIRA had enhanced the effectiveness of research and graduate level teaching by providing opportunities for scientists from NESS to assist in thesis studies and serve as co-advisors for CSU graduate students in the atmospheric sciences. The NESS researchers also benefited from increased interaction with members of the academic community at CSU. The only area regarded as needing improvement was the visiting scientists program, which was subject to budget limitations. CIRA made plans to overcome this deficiency and increase its scholarly interaction through additional visiting scientists. Dr. Michael Yeh from the University of Utah received the first visiting fellowship in 1981, and the recipients of the 1982-1983 fellowships were Dr. Alberto Mugnai from Italy and Dr. Ytzhaq Mahrer from Israel.

At their April 1984 meeting, the CIRA advisory board discussed the possibility of adopting two additional research themes. The need to understand the physical forms of water vapor, cloud forms and ice particles in climate emerged as a potential theme under the rubric "atmospheric radiation." Coincidentally, CSU had just hired a noted radiation theorist, Dr. Graeme L. Stephens, so the theme area held particular promise. Also, five data streams were available for research in agricultural yield forecasts, which could be especially useful to both local and international interests, leading to the proposal of a theme of "agricultural applications." Ultimately, concern over declining budgets and the desire not to over-extend CIRA resulted in the decision to table these candidate themes until the following year.

Construction on the CIRA facility began in the summer of 1981.

Another topic of discussion at the 1984 board meeting concerned the problem of space. In less than 3 years and with the expansion of the computer resources area, CIRA had already outgrown its new building. Additional federal funding for Phase II of the

"CIRA Village" was not available, and the possibility of using one of the nearby solar research houses was dismissed as unfeasible, since the current occupants of the houses were unlikely to leave. Another potential source of building funds came via the National Park Service, in

First Atmospheric Sciences satellite dishes at CSU, 1978.

CIRA's exploitation of satellite data was only limited by the state-of-the-art in computer technology.

exchange for space at the facility for Park Service employees affiliated with CIRA. In 1985, Dr. Vonder Haar showed design plans to the board for a new CIRA addition, should funding become available. CSU Vice President for Research Judson Harper suggested that the board make a request through the dean of the College of Engineering for CSU to fund the building addition, in view of the increasing level of research.

The expansion of computer resources which contributed to CIRA's overcrowding was accelerated by the 1985 upgrade of the CIRA weather satellite earthstation data collection system with VAX equipment manufactured by the Digital Equipment Corporation (DEC). Since 1977, the CSU departments of Atmospheric Science (Vonder Haar and colleagues) and Electrical Engineering (Brubaker and colleagues) had managed one of only three satellite earthstations in the United States. This upgrade would allow CIRA to continue to receive transmissions from the newest NOAA satellites, since the federal government planned to change the method used to transmit data to weather stations in 1986. The new system included three VAX-11/750 computers, six microVAX-based intelligent workstations, VAX-cluster hardware, an Ethernet interface, peripherals and supporting software. The graphics capabilities of the system would permit a sophisticated visual display of cloud formations, hurricanes and other weather phenomena. In addition to upgrading CIRA's weather satellite earth-station system, the new equipment facilitated the establishment of a real-time weather data lab and support of the Colorado Climate Data Center, directed by State Climatologist Thomas McKee.

Another project initiated in 1985, the Interagency Monitoring of PROtected Visual Environments (IMPROVE), a national monitoring network developed by CIRA in partnership with the National Park Service, would make a significant CIRA contribution to air quality research. The IMPROVE program established current visibility conditions, tracked changes in visibility and determined the causes of visibility impairment in the national parks and wilderness areas (designated Class I areas by the 1977 Clean Air Act). The network, through collecting and analyzing aerosol samples, would soon establish that all Class I areas in the United States are subject to impaired visibility from environmental pollution.

Following a gradual increase in funding of CIRA projects by agencies other than NOAA, the university and CIRA received a windfall by winning the 1986 University Research Initiative grant competition sponsored by the Department of Defense in support of scientific inquiry relevant to military needs. The five-year, $11.5 million award, the largest single grant received by CSU up to that time, allowed for the construction of an addition to CIRA to house the new Center for Geosciences/Atmospheric Research (CG/AR). This addition was completed by the following May and dedicated June 5, 1987. Research areas during the first phase of the project from 1986 to 1992 involved satellite, radar and lidar remote sensing, atmospheric and hydrological modeling, boundary layer studies, climatic geomorphology, and information extraction and visualization. The six principal investigators for the project reflected its multidisciplinary nature: Thomas Vonder Haar, Thomas McKee and Roger Pielke of the Atmospheric Science Department, V.N. Bringi and Thomas Brubaker from Electrical Engineering, and Daryl B. Simons of Civil Engineering. In addition to the departments of the principal investigators, the Earth Resources, Psychology, Physics, and Mathematics departments participated in the grant.

Another significant milestone in 1986 would be the publication of the first edition of the CIRA newsletter. The idea for a newsletter, to be published in the spring and fall of each year, had been approved at the advisory council meeting in September 1985. CIRA Deputy Director Roger Pielke served as the first editor. The newsletter assisted the institute in informing the scientific community of CIRA's ongoing research, personnel changes and special events.


CIRA Newsletter

September 1986 — Volume 1, Number 2

CIRA to Administer New Center for Geosciences

R. A. Pielke Deputy Director, CIRA

The technical components of the Center are in Atmospheric and Surface Remote and In-situ Sensing; Atmospheric Modeling of Meteorological Parameters and Dispersion; Hydrology including Hydrologic Modeling; and Geoscience Information Extraction.

A Center for Geosciences supported by the U. S. Army Research Office is being established within CIRA at Col-

A new building is being constructed on the CSU Foothills Campus as part of the CIRA facilities to house the Center and host visiting scientists. CSU faculty and research staff will also make short- and long-term visits to Army research facilities. A Research Coordinator is to be appointed within CIRA to assist with day-to-day activities among the Center's scientific investigators and with visiting Army scientists.

"CIRA Research Facility and Army Center for Geo-

CIRA was able to use a hardware simulator to develop a GOES/GVAR earth station for the first time. CIRA captured the first transmitted data in 1994.

FLASHBACK: CIRA newsletter, Volume 8: Fall, 1993

GVAR Development at CIRA

NOAA is scheduled to launch the next generation geostationary weather satellite (GOES-I) in 1994. GOES-I will have many new improvements. It will be 3-axis stabilized, as opposed to the current spin-scan stabilized system, allowing for more accurate geo-location of earth images. In addition, the satellite will have a new scanning mechanism that will allow for more frequent and flexible imaging. The scanner will also operate at a higher spatial, temporal and thermal resolution.

Along with these system improvements, GOES-I will use a new data transmission format, called GOES VARiable (GVAR). This change will require a significant modification to CIRA's existing ingest hardware and software. CIRA engineers have finished the initial system design for the improved GVAR system, and have made significant progress in implementing a two-year development effort. Ingest software will be written to be more machine independent where possible, allowing ingest processing to be moved to less expensive and more efficient processors. The raw image data format will be designed so that all imagery can be processed on a wider range of host systems.

– Donald Reinke and Duane Whitcomb

CIRA has a long history of training NWS and foreign meteorologists in how to use satellite data.

The Software Help in Applications, Research and Education (SHARE) Program, an international outreach program for technology transfer to developing countries, was initiated in 1987 by the World Meteorological Organization (WMO) and funded by the United Nations Development Program, the WMO Voluntary Cooperation Program, and NOAA. Colorado State University and CIRA provided support in the form of equipment, facilities and tuition assistance.

In addition, CIRA developed data handling and display programs and hosted a two-week session for the international SHARE team members in September 1988.

D. Neil Allen served as the initial SHARE program manager at CIRA, and was succeeded five years later by William S. Davis. Through the SHARE fellowship program, visiting scientists from developing nations gained experience in telecommunications and weather data handling, learning how computers could assist them in processing observations from weather reporting stations throughout the world. In 1990, SHARE software developed at CIRA was successfully installed in meteorological centers in Bangladesh, Pakistan, Sri Lanka, and Fiji. After personnel in these countries received training in the use of the software, SHARE workshops provided participants with opportunities for productive interaction with other meteorologists from their region of the world.

A new research theme, dealing with the economic and societal aspects of weather and climate, was adopted by CIRA in 1987. Collaborations in this area culminated with the selection of Chris Adams as the recipient of the 1996 National Weather Service (NWS) Modernization Award. He had led efforts to incorporate social science research on individual and community hazards warning response into NWS operations.

The next few years saw an increase in CIRA interaction with the Forecast Systems Laboratory (FSL). Don Hillger's work with the clustering of satellite data was incorporated into PROFS studies, and in response to a request for additional NWS forecaster training, Paul Menzel and Jim Purdom visited each forecast center, providing seminars in Boulder, Norman and Kansas City.

During the summer of 1992, CIRA received a gift which would provide a vastly increased amount of weather data for its research programs. The GTE Corporation donated a five thousand pound, seven-meter diameter satellite dish to CSU, but there was one catch – the dish was mounted at the top of a thirteen-story building in Marina del Ray, California, and CSU would have to come and pick it up. At a cost of $25,000 for a dismantling crew, helicopter and rental truck, CIRA's new satellite dish was installed by the end of August. The dish gave CIRA access to a communications satellite which broadcast data from a NOAA earthstation in Virginia, which in turn collected data from weather satellites over Europe and in polar orbits.

In November, 1992 an agreement was completed between CIRA's RAMM Branch and the NWS Forecast Office in Cheyenne, Wyoming to establish a formal working arrangement for the two-way transfer of ideas, research and technology between the two organizations. Named the Applied Research and Technology Interchange Effort (ARTIE), this program held its first seminar on the topic of severe weather forecasting in Cheyenne the following April. ARTIE goals included enhancing the ability of operational meteorologists and forecasters to utilize satellite data and new technologies in their work, as well as assisting weather researchers to better understand the forecast office environment and its operational requirements. ARTIE would also allow forecasters and researchers to undertake joint local research projects and to develop computer based satellite analysis techniques and systems applications. As an example of cooperative efforts between research and operations, a computer-based expert system for severe storm forecasting was developed and field-tested at the Cheyenne Weather Service Forecast Office.

The year 1994 would be significant for CIRA in a number of ways. In February, a university reorganization plan moved CIRA from its affiliation with the Graduate School to make the institute part of the College of Engineering. In April 1994, GOES-I (the first of NOAA's next generation of geostationary satellites) was launched and began service. CIRA, one of the first research organizations capable of handling GOES-I imagery, modified its earthstation ingest hardware and software to be able to read and decode the new GOES VARiable (GVAR) data transmission format.

On Earth Day, April 22, 1994, Vice President Al Gore announced a new environmental awareness program based on ideas outlined in his book, *Earth in the Balance: Ecology and the Human Spirit*, encouraging participation by schools in America. One year later, the Global Learning and Observations to Benefit the Environment Program (GLOBE) became operational, with 450 U.S. schools registered to participate and many educational institutions in other countries expressing an interest in the program. Schoolchildren participate by conducting local measurements of air temperature, precipitation, surface water pH and temperature, and soil moisture. Added to their observations of clouds, land cover, and vegetation, this data is shared with the world via the Internet. The Environmental Research Laboratories of NOAA assisted in the development and implementation of GLOBE, and CIRA staff members supported the program through maintenance and enhancement of the GLOBE Web server, real-time data acquisition system, and central database. During the next ten years, the GLOBE program would expand to involve more than 16,000 schools in 108 countries. GLOBE program manager Renate Brummer joined CIRA in 1995 and served as such during its first 10 years.

In late 1994, a second Department of Defense grant to CG/AR of $4.3 million provided continued weather and hydrological research support at CIRA. Part of this grant funded the Cloud Layer Experiment (CLEX), a field program designed to collect observational data to better understand the factors involved in the formation, maintenance, and dissipation of complex and multi-layer cloud systems. Aircraft measurements of cloud properties and airborne radar cloud images would be compared to remotely sensed algorithms for cloud liquid water and water vapor. The first in a series of experiments (CLEX-1) collected data during the last two weeks of June, 1996.

The years after 1995 brought the development of the RAMM Advanced Meteorological Satellite Demonstration

DOD funding since the late 1980s has allowed CIRA to work on many "dual-use" research areas of interest to NOAA and the DOD.

VAX units in the CIRA computer room.

NFRAQS was one of CIRA's only non-federally funded activities. It represented a highly successful partnership of state and private enterprises.

and Interpretation System workstations (RAMSDIS). These personal computer-based, satellite ingest and display systems were deployed to seventy NWS forecast offices around the United States. Each system was tailored for a specific geographic region. Computer-based learning modules were designed by RAMM team members to run on the RAMSDIS workstations and provide GOES imagery tutorials on-site at NWS forecast offices. These modules were also made available to others via the Internet. A modified version of RAMSDIS, which soon became known as "Tropical RAMSDIS," was developed by Ray Zehr (RAMM) and Kevin Schrab (CIRA Research Associate). Tropical RAMSDIS utilizes high resolution geostationary satellite images to follow individual hurricanes, typhoons, and tropical storms through their entire lifetime.

The Northern Front Range Air Quality Study (NFRAQS), a one-year, $2.5 million project initiated by CSU, authorized by state legislation, and supported by industry and trade groups, began sampling airborne pollutants in early 1996. Dr. Douglas R. Lawson of CIRA served as the Technical Project Manager for the study, which was designed to address three policy-driven objectives: 1) identify the sources of airborne carbonaceous particles, which comprised fifty percent of the fine particles in the Denver "brown cloud"; 2) understand the relative importance of ammonia, nitrogen oxide and sulfur dioxide emissions in formation of secondary particles; and 3) perform source apportionment of ammonium nitrate and ammonium sulfate aerosols along the Northern Front Range of Colorado.

The year 1998 brought additional RAMM Branch activities, with the introduction of RAMSDIS Online. The Virtual Institute for Satellite Integration Training (VISIT) program was also created in 1998. Funded by NESDIS and the National Weather Service (NWS), VISIT served to provide distance learning to operational weather forecasters and accelerate the transfer of research results based on atmospheric sensing data into NWS operations. A software package, VISITview, was developed at the Cooperative Institute for Meteorological Satellite Studies (CIMSS) to meet the specific distance learning requirements of VISIT. This software, utilized with a telephone conference call, made teletraining sessions available to NWS offices. VISIT staff include personnel from CIMSS, the NWS training division, NESDIS, and CIRA.

In July 1998 the third phase of CIRA's Department of Defense-sponsored research received funding. A CG/AR grant of $6.8 million over three years would focus primarily upon atmospheric phenomena. Specific topics of study included developing advanced data assimilation techniques to join forecast models and satellite data, providing cloud drift winds derived from satellite data to initialize forecast models, deriving aerosol properties from satellite data, providing high-resolution measurements of the stable boundary layer, and developing more sophisticated models to predict flash floods.

Other 1998 highlights included a new wing added to the CIRA complex, with teleconferencing capability to help implement virtual laboratory functions such as the VISIT program and the Flash Flood Laboratory. With the launch of the NOAA 15 satellite in 1998, CIRA began developing products from a new instrument called the Advanced Microwave Sounding Unit (AMSU). Working closely with the NESDIS/RAMM team, products such as total precipitable water, instantaneous rain rate, cloud liquid water, and snow cover were made available interactively and in real-time. Finally, in December 1998, NASA awarded $145 million in funding to the CloudSat

FLASHBACK: CIRA newsletter, Volume 17: Spring, 2002

ATS and CIRA Meet in the Middle: New Research Facility Underway

The Department of Atmospheric Science (ATS) and CIRA agreed to construct an addition to the existing Atmospheric Science Building in support of their collaborative research programs. The unique location of the ATS/CIRA Research Center (ACRC) has presented some construction challenges. Since the facilities are situated on the knob of a hill overlooking the city of Fort Collins, strong winds are not uncommon. As a result, a fully enclosed walkway between the new building and CIRA would be cost prohibitive. However, landscape elements such as trees and bushes will be strategically located around the area to temper the force of the winds. In addition, concrete caissons which extend below the building and several yards into the ground will provide extra structural support against high winds.

Currently scheduled for occupancy in mid to late April 2002, the new facility will provide research space for atmospheric scientists, post-docs, graduate students, support staff, and visiting scientists from all regions of the globe. Among the agencies supporting the research are the National Oceanic and Atmospheric Administration (NOAA), the Department of Defense (DoD), and the National Aeronautics and Space Administration (NASA). Some of the research teams planning to occupy the facility upon its completion include CEAS and CloudSat, both headed by Dr. Graeme Stephens (ATS); the CloudSat Data Processing Laboratory, headed by Dr. Thomas Vonder Haar (CIRA); the Global Precipitation Mission (GPM), headed by Dr. Chris Kummerow (ATS); and the Center for Geosciences and Atmospheric Research (CG/AR), headed by Dr. Vonder Haar. Special capabilities within the new addition include an integrated classroom/lab with the capacity for lidar observations, a dedicated multi-circuit computer room for CloudSat data processing, a temperature and humidity controlled underground tape storage room, and high band width Internet computer connections throughout the facility. It will also improve collaborative research activities with NOAA since it will contain visiting scientist rooms, classrooms with remote sensing ports, and GOES Earthstation ingest equipment. Designed by Aller-Lingle Architects P.C., the new facility is scheduled to be dedicated in early July 2002 to coincide with the 40th anniversary celebration of the Atmospheric Science Department.

– Dave Cismoski and Mary McInnis-Efaw

project headed by principal investigator Graeme Stephens.

By 1999, the DEC VAX and PDP mini-frames installed in 1985 to perform satellite data collection tasks were replaced by a new Windows NT data collection platform (architecture and engineering performed by Michael Hiatt). The new Windows operating system could run on inexpensive Intel personal computer hardware, greatly reducing the costs of satellite data collection without sacrificing performance. CIRA engineers developed two network monitoring software tools, the Data Collection Monitor and the Ingest Monitor, to automatically notify the staff in the event of satellite transmission problems, telemetry or hardware failures and software issues. Archived GOES, AVHRR, and Meteosat images from the previous two months were made available for display via the CIRA web page.

The devastating Fort Collins flood of July 28, 1997 brought the impact of unusually heavy precipitation into

GVAR Development at CIRA

NOAA is scheduled to launch the next generation geostationary weather satellite (GOES-I) in 1994. GOES-I will have many new improvements. It will be 3-axis stabilized, as opposed to the current spin-scan stabilized system, allowing for more accurate geo-location of earth images. In addition, the satellite will have a new scanning mechanism that will allow for more frequent and flexible imaging. The scanner will also operate at a higher spatial, temporal, and thermal resolution.

Along with these system improvements, GOES-I will use a new data transmission format, called GOES VARiable (GVAR). This change will require a significant modification to CIRA's existing ingest hardware and software. CIRA engineers have finished the initial system design for the improved GVAR system, and have made significant progress in implementing a two-year development effort. Ingest software will be written to be more machine independent where possible, allowing ingest processing to be moved to less expensive and more efficient processors. The raw image data format will be designed so that all imagery can be processed on a wider range of host systems.

– D. Reinke and D. Whitcomb

FX-NET development allowed low-end users with limited bandwidth to benefit from the latest in satellite analysis technologies.

sharp focus for residents of northern Colorado. To address the physical and social problems created by such disasters, CSU created the interdisciplinary Flash Flood Laboratory in 1999. CIRA invited geographer Eve C. Gruntfest to work as a senior fellow for six months in assisting atmospheric scientist Kenneth E. Eis and sociologist Christopher R. Adams to establish the program. The goals of the Flash Flood Laboratory included increased scientific understanding of the atmospheric, hydrologic, geographic, and social factors contributing to disastrous flash floods and improved ability to predict them, as well as more effective public education, warning, and support tools for government preparedness and response teams.

From July to October, 1999, the Big Bend Regional Aerosol and Visibility Observational Study (BRAVO) was conducted in Big Bend National Park, on the Texas/Mexico national border. Researchers studied the sources of haze in the park; these included natural emissions such as windblown dust as well as industrial power plants and refineries in Texas and Mexico.

During the late 1990s, a group of researchers from the Boulder division of CIRA developed an innovation which would offer valuable service during the 2002 Winter Olympics held in Salt Lake City. FX-Net, a PC workstation which could provide Internet access to basic meteorological analysis and forecast products, available through the

FLASHBACK: CIRA newsletter, Volume 21: Spring, 2004

Water Vapor Variability on Timescales from Days to Decades

Water vapor is Earth's most important variable greenhouse gas. The NASA Water Vapor Project (NVAP) is a NASA Pathfinder project designed to measure via satellite the distribution of global water vapor on a daily basis. The Climate Data Records (CDRs) developed by NVAP have given us an increasing ability to monitor Earth's water vapor fluctuations on a variety of timescales. Fronts, hurricanes, and droughts are captured in NVAP, as well as longer-term variability such as El Niño episodes and volcanic eruptions. A key question related to global climate change is: Will the amount of water vapor in the atmosphere increase if Earth warms? This could provide positive feedback in greenhouse warming versus that due to CO2 alone.

The NVAP dataset now covers the period 1988-2001. It was processed for NASA by the Science and Technology Corporation, METSAT Division. They have provided the entire dataset to CIRA for scientific analysis. NVAP data is used by researchers worldwide. NVAP is a relative of other long-term, satellite-based, global climate datasets created for the Global Energy and Water Cycle Experiment (GEWEX). Examples of these are the International Satellite Cloud Climatology Project (ISCCP), the Global Precipitation Climatology Project (GPCP), and the Global Aerosol Climatology Project (GACP). These types of datasets have played a fundamental role in understanding Earth's climate and assessing the results from general circulation models.

CIRA scientists have played a key role in the development of the NVAP dataset and its scientific application. CIRA-affiliated researchers past and present who have worked on NVAP include Dave Randel, Tom Greenwald, Johnny Luo, Darren McKague, Garrett Campbell, Ben Ruston, Cindy Combs, and Don Reinke.

– John Forsythe and Thomas Vonder Haar

Advanced Weather Interactive Processing System (AWIPS) used in all NWS forecast offices in the U.S., provided a familiar tool at a relatively low cost to forecasters. Developed to meet the meteorological workstation needs of research and teaching facilities, fire weather forecasters and remote weather service offices, FX-Net was first installed in 1999 at Plymouth State College in New Hampshire. Following the training offered by CIRA's FX-Net developers to private forecaster teams working for the local Salt Lake City television station, the support provided by the FX-Net platform for weather forecasts at the five outdoor venues was a resounding success during the 2002 Winter Games.

As CIRA moved forward into the new millennium, the growth of its research programs once again necessitated the construction of additional workspace. CIRA entered into an agreement with the Department of Atmospheric Science (ATS) to construct an addition to the existing Atmospheric Science Building to house their continually expanding research programs. With added support from the Vice President for Research and Information Technology, the Provost, and the College of Engineering, the new 14,000-plus square-foot facility would provide the space needed by both the Department and the Institute. At a cost of $2.4 million, the project included such features as a second-story bridge to the ATS building and a covered walkway to the CIRA building. Official opening ceremonies were held on July 10, 2002.

As its first quarter-century comes to a close, CIRA's research scientists routinely employ advanced technologies unimaginable to the Fellows and Research Associates of 1980. In 2004, Science on a Sphere™ (SOS) was conceived by Dr. Alexander MacDonald, head of NOAA's Forecast Systems Laboratory (FSL) in response to NOAA's cross-cutting priorities of environmental literacy, outreach, and education. The NOAA SOS project displays and animates global datasets in a spatially accurate and visually compelling way on a 6-foot spherical screen. CIRA provides key technical support to the project, especially pertaining to research into new visualizations and effective user interfaces for the system. SOS continues in use at the Science Fiction Museum in Seattle, and this year SOS was installed in its first permanent science museum location at the Nauticus Museum in Norfolk, VA. In addition to engaging three-dimensional representations of the Earth's weather, climate, and geology as if they were viewed from space, other popular displays include massive, churning solar flares of the Sun, geological objects on the surface of Mars, the cloudy atmosphere of Jupiter and a full set of Jupiter's Galilean satellites.

With tasks ranging from collecting weather data and measuring atmospheric aerosols, to training weather forecasters and providing worldwide interactive access to weather observations, CIRA continues its mission to conduct research in the atmospheric sciences that will be of benefit not only to the scientific community, the state, and the nation, but also to all the people of the world.

CHAPTER 2: *Climate Research*

The application of satellite data to climate research represents the longest lived project in CIRA. ISCCP is still an active program after 23 years of constant funding.

Regional and global climate studies were already underway in the Department of Atmospheric Science and the Colorado Climate Center at CSU when CIRA was formed in 1980. Since NOAA had become the lead agency in the U.S. Climate Program, it was natural that climate activities and research would grow as part of the CSU and NOAA collaboration under CIRA.

The Colorado Climate Center had been formed in 1974 to host the office of the state climatologist and carry out regional studies. This special center of the Department of Atmospheric Science filled an important need for the State of Colorado and served as a focal point for the collection of Colorado weather and climate data across the state, as well as analyses of the impact on the state and its many climate user groups.

Professor Tom McKee had been hired to serve as both a regular faculty member in the department and as the first Colorado state climatologist. In 1979, the U.S. had completed a major international global weather experiment. A number of CSU faculty participated in the planning, data gathering, and analysis of the project including Professors Cox and Vonder Haar. This later provided a very rich dataset for the study of global weather forecasting as well as for climate studies. Shortly after the formation of CIRA in 1980, Dr. Vonder Haar and Dr. Garrett Campbell worked with the international climate research program to establish the International Satellite Cloud Climatology Project (ISCCP). This project began collecting data in 1983 under a collaborative NOAA/CSU funding through CIRA. It continues through the present time and ranks as the longest lasting single project at CIRA and one of the longest lasting in the entire University. Along with international collaborators, CSU scientists, staff and students have contributed to several hundred scientific publications based upon the world-wide cloud data collected under the ISCCP.

During the 1980s and 1990s and continuing in some ways into the present, the NOAA Office of Global Programs (OGP)/CSU faculty student research through CIRA contributed to the Tropical Ocean and Global Atmosphere Experiment (TOGA), the Global Energy and Water Cycle Experiment (GEWEX), studies of both the summer and winter monsoons, and other studies. In addition, CIRA scientists collaborated with CSU colleagues in the College of Natural Resources and the Natural Resources Ecology Laboratory (NREL) on land surface and carbon cycle research related to the U.S. Climate Program.

Our climate dynamics research theme under CIRA has had, as noted above, a special observational and analysis component emphasis. CIRA reports during the past 20 years provide evidence of many scientific contributions made toward understanding the physical basis of climate change and the important global and regional processes and interactions that formed part of the Earth Atmosphere Cyrosphere-Biosphere-Hydrosphere System.

One related observational example, carried out with the collaboration and support of NASA, was the Earth Radiation Budget Experiment (ERBE). The concept was developed at CSU, NOAA/NESDIS, and the NASA Research Centers at Goddard Space Flight

Centers and Langley Research Center. This experiment consisted of Earth Radiation Budget measuring instruments on NOAA 9 and 10 satellites, and on the special shuttle-launched ERBS satellite built by Ball Aerospace in Boulder, Colorado. Professor Vonder Haar served as the project scientist for the ERBE during its conceptual development stages. The first of three satellites was launched in October 1984, and the data collected led to numerous science papers and a better understanding of the energy exchange between earth and space, as well as the impact of clouds on earth's climate system. Many scientists participated through NASA science teams and several CSU students used the data in their research. It is worth noting that the relatively simple instrument designed at CSU continued operating on the ERBS satellite from 1984 into the 2005 period, making it one of the longest lasting earth observing instruments in the history of the U.S. space program.

ISCCP at CIRA, 1983 to Present

As noted earlier, the idea for the International Satellite Cloud Climatology Project was initiated by Vonder Haar and Paltridge in 1979, but CIRA actually started collecting GOES 6 data in July of 1983. In the 1980s, ISCCP was quite an ambitious computer project involving the processing of more than 1 gigabyte of data per day. Students, programmers and researchers were involved in the day-to-day task of mounting data tapes and quality controlling the data.

In the early days, it was often necessary to reposition the receiving antenna in order to track the satellite. A mobile backup antenna was cobbled together by mounting a surplus radar dish on a dump truck. It was then possible to re-orient the antenna by driving the truck or tilting the bed. Although this worked, fortunately the 15-meter dish was reliable, and the back-up was not often needed.

As ISCCP continued, the U.S. received a variety of geosynchronous satellite views of western North America. Thanks to the efforts of Don Reinke, the 10 C band antenna was installed and used to collect Meteosat 3 data for ISCCP and now is used to collect data from AVHRR. Data has been collected for ISCCP from GOES 7, 8, 9, 10 and 12. CIRA scientists also worked with the National Center for Atmospheric Research (NCAR) to prepare some INSAT data for ISCCP.

With advances in computer technology and stability of the satellites, ISCCP data is now processed with relative ease. The project has progressed to enable the study of many cloud process and allow a search for systematic changes in the clouds over time.

Those primarily responsible for ISCCP over the years were G. Garrett Campbell, Bill Davis, Kelly Dean, Tom Vonder Haar and Dave Watson. The engineers maintaining the ground station included Mike Hiatt, Karll Renken, Mark Whitcomb and Duane Witcomb. Thanks are due to NOAA for funding CIRA as part of this international effort.

CIRA's trademark satellite farm.

CHANCES Global Satellite Database

In 1994, a small Fort Collins company called Metsat Inc. set up a cooperative agreement with CIRA to build a unique global satellite database named the Climatological and Historical Analysis of Cloud for Environmental Simulations (CHANCES). The project required the generation of a one-year, global, 5-km spatial and 1-hour temporal coverage database of satellite imagery from every available meteorological satellite. This was a unique effort that no one had attempted before this time. In order to build this database, CIRA agreed to collect all of the necessary satellite imagery and develop software to merge the imagery into a seamless global database. The timing for the project was ideal, because small computer workstations were, for the first time, able to handle the memory and processing requirements of merging global satellite data at such a high time and space resolution. In addition, CIRA was able to install a 7-meter communications antenna to downlink Meteosat and AVHRR data, and the NOAA Snow and Ice Data Center had begun to archive digital DMSP data. This confluence of technology and data availability allowed CIRA and Metsat to complete the project. Within 18 months they had built the first global database at the 1-hr and 5-km resolution. This database has not been improved upon in the succeeding 11 years. Several CSU graduate students used this CHANCES data set for theses and papers. CSU maintains a complete copy of the data set, which continues to be requested several times each year.

NOAA lab at David Skaggs Research Center, Boulder, Colo.

Environmental Applications Research in Boulder

Over the years, CIRA scientists have been collaborating on projects involving climate applications with researchers at the NOAA laboratories in Boulder. A few examples are presented below.

1) Collaborations on the development of computer software for the parallelization of atmospheric and oceanic weather and climate models through enhancements of the Weather Research and Forecast (WRF) model, the Scalable Modeling System (SMS) and the Regional Ocean Modeling System (ROMS) have been on-going for several years. The feasibility of combining geographically distributed computing resources into a single virtual resource was explored by creating and demonstrating a WRF/ROMS coupled model running simultaneously at the Forecast Systems Laboratory (FSL) in Boulder, Colorado and the Pacific Marine Environmental Laboratory (PMEL) in Seattle, Washington. During FY 2003-05, a prototype NOAA computational grid was developed. It includes processors located at FSL, PMEL, and the Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey. Additionally, a rudimentary grid-scheduler has been developed, which allows users to submit jobs from nodes anywhere on the grid. The jobs are able to execute on any of the grid computer clusters. Needed data can be staged to and/or from the remote clusters. A NOAA certification authority has been developed that provides a secure means for users to access the grid with a single sign-on. The coupling of the WRF and ROMS models across the NSF-sponsored TeraGrid was attempted.

2) The feasibility of forecasting runoff using a non-hydrostatic multi-scale regional climate model down to scales

Flashback: The 7-Meter Antenna

When we looked into ingesting global satellite imagery, we were informed that the DoD was retransmitting Meteosat satellite imagery over a dedicated satellite communications network called DOMSAT. In order to receive the data, we had to install an antenna, which was quite expensive. Because the Meteosat (and AVHRR) data were the only pieces that we were missing for the generation of a merged, global, satellite product, we looked into the acquisition of a used antenna that was sufficiently large to allow us to downlink DOMSAT data at our geographic location. After doing some research on "link calculations" (used to determine the size of antenna and sensitivity of the electronics), we were able to locate an antenna that was available at no cost, if we paid to have it dismantled and shipped. After a working lunch at "El Burrito" (a landmark restaurant), Neil Allen and I convinced Tom to let us spend the money it would take to haul the antenna out to Fort Collins.

The rest of the story: It turned out that the "free" antenna was located on the top of a seven-story building in Marina del Rey, California. In order to disassemble the antenna, we had to hire "Ernie's Transport" - an Alabama company that specialized in moving antennas, and would provide us with a helicopter to lift the antenna off the roof, to where it could be disassembled and then transported in one of Ernie's trucks to Fort Collins. This seemed like a reasonable way to go, so we signed on and convinced Mike Hiatt, a young engineer, that he needed to learn how to use a mini-excavator to clear a space for the pad, bury about 100' of cable, and oversee the pouring of a concrete pad to set the antenna on. Oh, there were a few little glitches, such as the fact that the antenna was one block from a hospital and the only time it could be moved was between noon and one o'clock in the afternoon, when patients weren't napping. And then there was the extra $1,200 charge for the LAPD to cordon off a two-block area around the building so that no one died from a falling antenna, should it break loose. The helicopter did its job, the antenna was taken apart and placed in the truck, and it arrived at CIRA close to the scheduled time. Ernie's crew unloaded it and handed us a bill for their services which had now ended, because neither the driver nor the helper had any idea about how to reassemble the antenna or to hook up the electronic components. After about a day of looking over the pieces, Mike Hiatt, Duane Whitcomb and Dale Reinke began putting the pieces of the antenna together, brought in a CSU crane to hoist it into place, and after about two or three days of hooking up and "tuning" the RF equipment had enough signal to begin downloading images.

One last anecdote: The antenna was pretty worn from the salty air along the California coast, so Mike decided to get a spray gun and add a layer of white paint. About halfway through, a gust of wind carried the overspray between the Atmospheric Science building and Annex A into the parking lot, leaving a uniform layer of white specks on several cars – including Dr. Randall's new BLACK car. The excitement of receiving the new data was tempered a bit for a few days...

– Don Reinke

that resolve individual valleys and massifs was examined. A set of three five-year experiments using a high-resolution coupled atmosphere-land surface modeling system to simulate runoff in a hydrologic model was conducted.

3) Regional climate simulations were performed for June 2004 with the WRF model to study the effects of soil moisture on precipitation and to compare results obtained with different convective parameterizations and with explicitly resolved convection. Convection was parameterized in simulations on a 20-km resolution grid, and cloud-resolving simulations were performed on a 1.7-km resolution grid. A preliminary comparison of modeled precipitation with a .25 degree resolution CPC analysis was presented. A more comprehensive comparison with stage 4 data was planned.

4) Participation in the Global Air-ocean IN-situ System (GAINS) support continued during FY 2002-04, including several demonstration test flights. GAINS is a long-duration stratospheric platform, instrumented for environmental sensing through a combination of dropsondes, XBTs, and chemistry, particulate, in-situ, and remote sensors. Initially designed as a 120-ft. diameter superpressure balloon carrying a payload of 780 pounds for year-long flights up to 75,000 ft., funding support has gradually shifted towards an Unmanned Aerial Vehicles (UAV) platform

The 7-meter antenna.

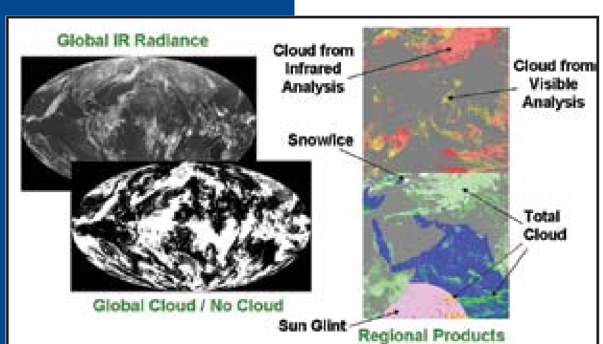
to support NOAA's adaptive and long-duration observing and monitoring goals for the next century.

Satellite Cloud Climatologies

The first cloud composites were done in the early days of meteorological satellites by superimposing satellite images on the same piece of photographic paper. CIRA brought the technique into the digital age. In the early 1980s, Marge Klitch, Frank Kelly, and John Weaver, under the guidance of Tom Vonder Haar, digitized hard copy photographs and then produced a digital composite image. These composites allowed them to study mesoscale cloud systems and medium-scale topographic effects from a new perspective.

Duane Whitcomb, Ken Eis and Michael Hiatt putting in the antenna base for the GOES data collection.

By 1985, digital GOES images collected at the Colorado State University Earthstation enabled this group to create composite images entirely in the digital domain. They developed algorithms using these new technique that produced cloud composites covering Colorado and surrounding states. These composites revealed a close coupling between terrain and cloud formation, and interesting details in the diurnal convection cycle. They continued to refine the compositing techniques and applied the results to long-term forecasting. During the late 1980s, Harold Gibson and Tom Vonder Haar used the same technique to reveal intricate patterns of cloud development near the U.S. southeastern coasts.



Satellite cloud percent composite for 1-4 hours preceding a high wind event within the Cheyenne County warning area.

During the 1990s, the algorithms and techniques developed at CIRA were used at STC-METSAT for various studies and products, including CHANCES, which combines high resolution data from a variety of geostationary and polar-orbiting satellites to produce a global cloud database. This three-year database was later used at CIRA to study cloud patterns over other regions of the world, such as the Middle East.

GOES cloud composites continue to be used at CIRA. Bernie Connell, in conjunction with Ken Gould at the National Weather Service office in Tallahassee, took the process a step further by dividing the data into regimes according to wind speed and direction. Since 1995, they have used these composites to study the development of the summer sea breeze and its effect on convection development. These products are currently used at the Tallahassee office in their thunderstorm predictions. Bernie Connell has also used cloud composites over Central America for fire detection and to study dry/rainy seasonal changes.

Since 1987, Cindy Combs has taken the idea of wind regime cloud composites and applied it to all the weather stations in the U.S. Additional studies have concentrated on convective development in Wakefield, Virginia during different wind conditions, cloud patterns upstream from Cheyenne, Wyoming as an aid in predicting high wind events, and winds and pressure gradients as predictors for the extent and timing of marine stratus over the San Francisco and Monterey area.

CHAPTER 3: *Applications of Satellite Observations*

Satellite observations, their subsequent analysis and the production of operational applications represent one of CIRA's strengths. Generally, CIRA activities in this broad area encompass several other main theme areas.

1. Earth station and infrastructure activities have provided data and hardware for the manipulation of the satellite data streams. Additionally, computer technologies have allowed the manipulation of data, its storage, analysis, navigation and calibration.
2. Data distribution includes the parsing of data files to meet scientist needs, as well as methods of getting data from CIRA's satellite mass storage to scientist workstations. More recently, distribution also includes the parsing and sectorizing of ancillary data sets, including other satellite data, to allow researchers to use all highly correlated, yet independent data to address scientific problems.
3. Assimilation and modeling of satellite data is a major method for exploiting and understanding the processes contained in the data and helping produce the applications required by NOAA and the DoD.
4. Application development also requires CIRA scientists to understand end-user data and production systems so the applications can be readily hosted on their operational or prototype systems.

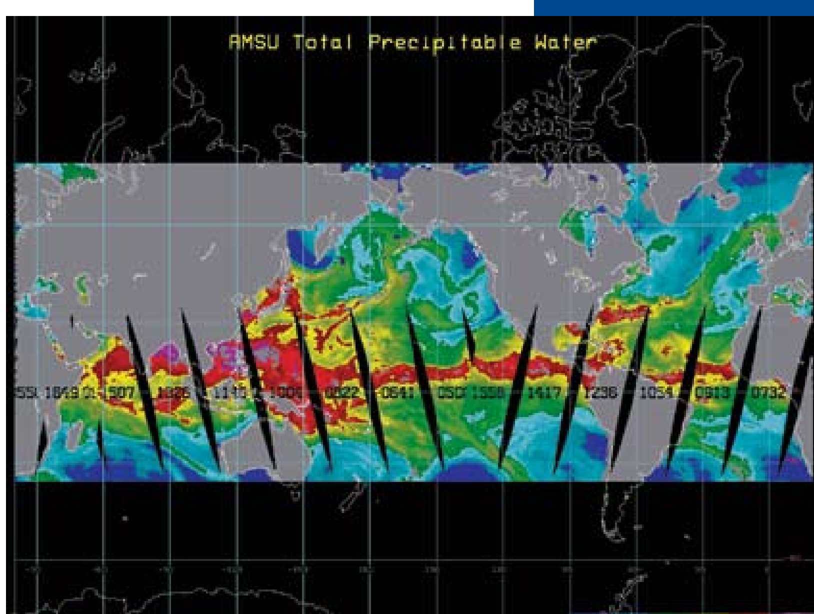
The following paragraphs illustrate aspects of these activities.

LEOs and GEOs

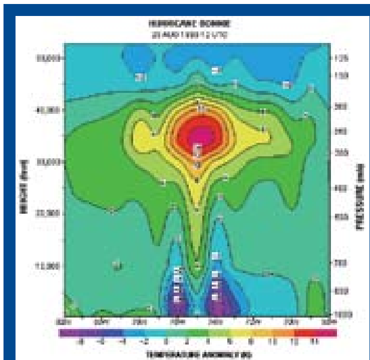
The first weather satellites were, of necessity, low earth orbiters (LEOs). Very soon, however, geostationary satellites (GEOs) became preferred for weather analysis and forecasting because they view the area of interest frequently, not just one or two times per day. Low earth orbiters became platforms for making atmospheric soundings with which to initialize numerical weather prediction models and for observing the high latitudes. Recently, however, the value of LEO data has been rediscovered, and CIRA has been a leader in this process.

LEO satellites have advantages over GEOs. First, being roughly 50 times nearer to earth, they offer higher spatial resolution. Second, they carry many more instruments and observe at many more wavelengths than GEOs. Third, they can carry instruments that are difficult, if not impossible, to place on GEOs; examples include microwave-sensing

CIRA's satellite activities moved from periodic, to campaign, to full collection as computer technology permitted.



Precipitable water from the NOAA 15 AMSU on 23 July 1999. Note that the time that the satellite crossed the equator is printed on the image to help the forecaster.



Temperature anomalies retrieved inside Hurricane Bonnie.

CIRA developed the AMSU data flow that helped permit NESDIS to fully exploit this data stream.

instruments and active sensors, such as radars and lidars, and scatterometers.

Using the AMSU (Advanced Microwave Sounding Unit) for Estimating Tropical Cyclone Intensity and Wind Structure

CIRA's AMSU project was one of the first to show the utility of LEO data for weather analysis and forecasting. The project began with the May 1998 launch of the NOAA 15 satellite, which carried three instruments collectively known as the Advanced Microwave Sounding Unit. Products derived from these instruments include rain rate, total precipitable water, cloud liquid water, snow cover, sea ice fraction, 1000-500mb thickness, and brightness temperature at three frequencies. These quantities were mapped to standard Mercator and polar stereographic map projections and written in McIDAS format for easy viewing at the CIRA lab as well as at the NESDIS/OSDPD/Satellite Services Division.

One important application of AMSU data is the analysis of tropical cyclones (i.e., tropical depressions, tropical storms, hurricanes). The "warm core" of a tropical cyclone was first observed and studied by Dr. Stanley Q. Kidder during his dissertation research. The AMSU instruments, which pass over the tropics several times each day, can "see" below the cloud-top layer and provide information about the vertical structure of these weather formations. Being able to make temperature soundings and observe rain bands beneath the central dense overcast of these systems is quite useful to the forecaster

CIRA has developed a dataset of over 2600 cases, using data from 1999-2004, where the AMSU has passed over a tropical cyclone. Several parameters can be derived from the AMSU data to give information about tropical cyclone pressures, winds, temperatures, moisture, and so forth. These parameters were statistically related to the actual reported tropical-cyclone intensities (in terms of maximum sustained winds and minimum pressures) to develop a model that provides an intensity estimate for all future passes of the AMSU over a tropical cyclone. Using a subset of the 2600 cases for which there was an air reconnaissance flight within 12 hours prior, similar models were developed to estimate the radii of 34-, 50-, and 64-kt winds in the northeast, southeast, southwest, and northwest quadrants of a tropical cyclone. These intensity and wind structure estimation models now are being run operationally for use by the National Hurricane Center.

Another tropical application of LEO data involves forecasting the amount of rain that might fall as a tropical cyclone makes landfall. The Tropical Rainfall Potential (TRaP) was invented by NESDIS personnel for this purpose using SSM/I

FLASHBACK: CIRA newsletter, Volume 9: Fall, 1994

CIRA's AMSU Project

The NOAA 15 weather satellite was successfully launched May 13, 1998 into a near polar orbit, carrying the first Advanced Microwave Sounding Unit (AMSU) sensors. The AMSU has 20 channels and is the first microwave instrument in space to combine geophysical channels (such as on the DMSP SSM/I instrument) with temperature sounding channels (such as on the NOAA MSU instrument) and moisture sounding channels (such as on the DMSP SSM/T2 instrument). Further, the AMSU offers higher resolution than most previous microwave instruments. Since microwaves penetrate clouds, the AMSU is nearly an all-weather meteorological instrument.

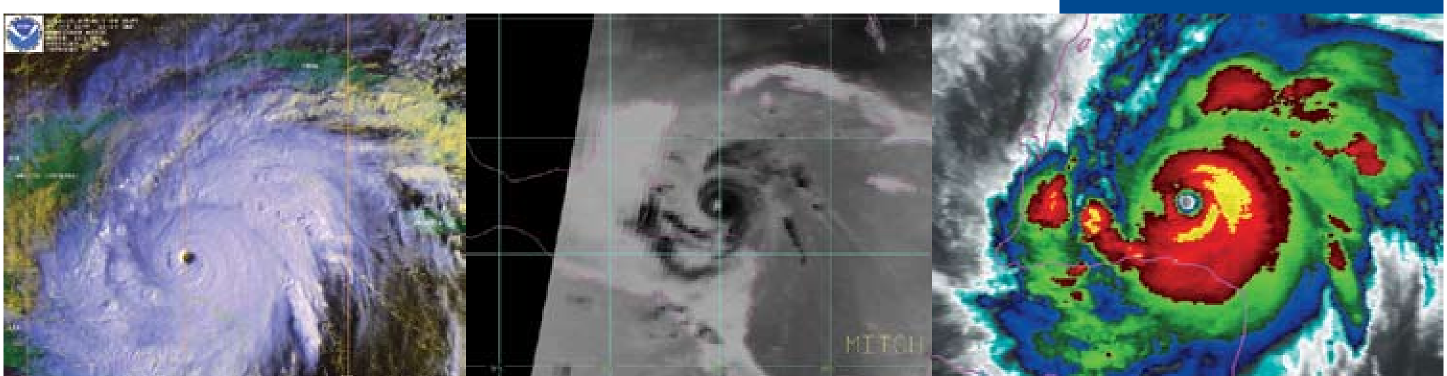
– Stanley Q. Kidder

data from the DMSP satellites. With AMSU data, the technique was refined to produce a graphical product which is very useful for issuing advisories and warnings. The TRaP technique simply moves the AMSU or SSM/I rainfall rate with the center of the storm to produce a map of the 24-hour rainfall amount.

In contrast to visible or infrared radiation, microwaves penetrate clouds. It is possible, therefore, to retrieve the column-integrated water content of the atmosphere (over the ocean) even below clouds, which is something infrared sounders cannot do. In addition, there are several LEOs carrying microwave instruments, especially the NOAA satellites and the DMSP satellites. CIRA developed a way to blend the data from six satellites into a unified precipitable water product which is completely updated every 6 hours, rather than the 12 hours achieved by a single satellite. The figure on the following page shows an example of this blended product, which is useful in the forecasting of heavy rain, tropical easterly waves, and tropical cyclones.

So, LEOs can do several things that GEOs cannot do. But can they ever provide the temporal resolution necessary for weather analysis and forecasting? Yes, by employing constellations of satellites, rather than a few satellites. NOAA 15 was launched into a 7:30 am-7:30 pm orbit. NOAA 16 was launched into a perpendicular orbit with an ascending node at 1:30 pm and a descending node at 1:30 am. NOAA 17 was launched into an orbit half way between NOAA 15 and NOAA 16 with a descending node at 10:30 am and an ascending node at 10:30 pm. If NOAA 18 had been launched into a 4:30 am/pm orbit, we would have achieved nearly complete global coverage of the earth each 3 hours. (There are gaps in the microwave coverage between successive orbits.) And if a future constellation of seven sunsynchronous satellites were launched into equally spaced orbits, we could have global coverage each 101 minutes. We look forward to the day when forecasters will have access to data from constellations of low earth orbiting satellites to complement and extend the data from geostationary satellites.

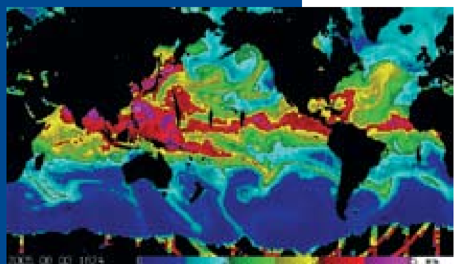
CIRA developed the first blended microwave products that used both AMSU and SSM/I data.



Hurricane Mitch: (left) AVHRR composite image; (middle) AMSU 89 GHz image showing rain bands (black) under central dense overcast; (right) GOES infrared image. [After Kidder et al. (2000)]

RAMSDIS, a Success in Technology Transition

The RAMSDIS (RAMM Advanced Meteorological Satellite Demonstration and Interpretation System) project was initiated in 1994. At that time, the project goal was to disseminate real-time, high quality, digital GOES (Geostationary Operational Environmental Satellite) data to select National Weather Service Forecast Offices (NWSFOs) via a powerful, low-cost, PC-based workstation for use in advanced satellite data display and analysis. The project, part of the



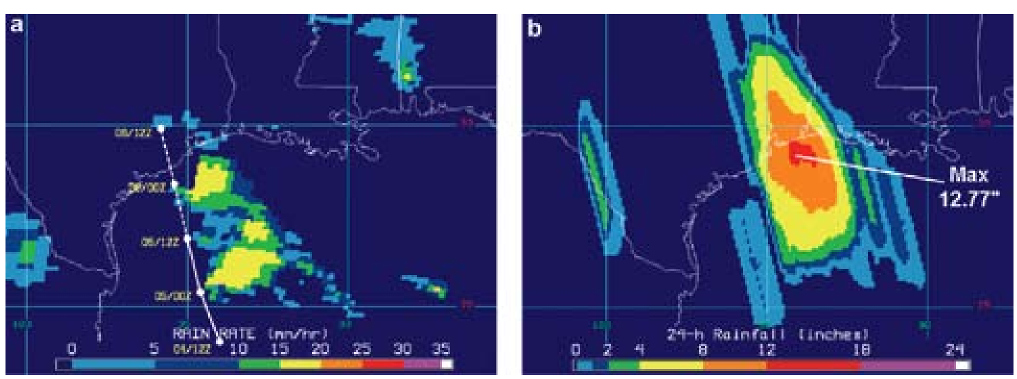
Blended total precipitable water (TPW) produced from the AMSU instruments on three NOAA satellites and the SSM/I instruments on three DMSP satellites. Note the typhoon near Taiwan and the tropical easterly wave in the eastern Atlantic.

GOES-I/M quality assurance plan, was designed to provide forecaster familiarization with the next generation GOES data sets, in preparation for NOAA's Advanced Weather Interactive Processing System (AWIPS) deployment; determine future forecaster training requirements to ensure full utilization of the advanced GOES data sets; and provide a platform for forecaster evaluation of GOES "Day-1" products and GOES "Day-2" product determination before the GOES data became operationally available via NOAAPORT.

RAMSDIS units were distributed and utilized by over half (about 70) of the NWSFOs from 1995-1999. The units provided forecasters with high quality, digital satellite image loops from all five of the channels of the GOES imager, covering state, regional, and continental scales. Also included were the reflectivity product and the fog product, which combine 10.7 µm and 3.9 µm data into imagery which is useful in the detection of supercooled clouds, nighttime stratus and fog, and fires. The RAMSDIS units also ingested surface and radiosonde reports, which allowed the forecasters to plot and contour surface and upper-air data onto the satellite images. These units were well received, as no other access to such high quality satellite imagery existed. As a testament to the success of the RAMSDIS project in the National Weather Service, many offices were reluctant to give up their systems when they received, as part of the NWS modernization program, their new AWIPS units, which included satellite imagery display capabilities.

With full deployment of NOAAPORT and AWIPS in 1999, the low cost RAMSDIS workstations were transitioned to international programs such as the Brazil Fires Project, the Hurricane Mitch Relief Effort, the WMO Regional Meteorological Training Centers program, to various NOAA Labs, NWSFOs and universities for joint research projects, and to field programs including FASTEX (Fronts and Atlantic Storm Track Experiment) and PACJET (Pacific Landfalling Jets Experiment).

During 1999-2001, the U.S. Agency for International Development provided funding through the NOAA/NESDIS/CIRA RAMM team to improve forecasting capabilities in Central America. Part of the CIRA/NOAA reconstruction efforts included the installation of a ground receive station and server at the National Meteorological Service in Costa Rica to serve real-time satellite data to the other Central American countries. Each of the Central American countries (Costa Rica, Panama, Nicaragua, Honduras, El Salvador, Guatemala, and Belize) received two RAMSDIS to ingest and display satellite imagery. The countries



Tropical Storm Allison: (a) rain rate and storm track; (b) forecast of 24-hour rainfall. The maximum observed rainfall was 12 inches. [After Kidder et al. (2005).]

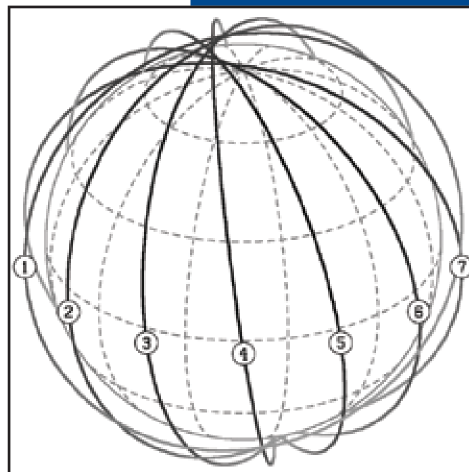
also received on-site training of the systems as well as 2 week-long training sessions in Costa Rica on how to better utilize satellite imagery in everyday forecasting tasks.

In 1998, RAMSDIS Online (ROL) was created to provide another alternative for displaying RAMSDIS products. The use of the web allows for a much larger audience to view the satellite products ingested and generated by RAMSDIS. Special ROL sections were added over the years showing coverage of fires, hurricanes/tropical storms, experimental products, and case study data sets of interesting weather events.

Research Collaboration with Boulder Scientists

Several research efforts in collaboration with NESDIS' National Geophysical Data Center occurred over the past few years that involved DMSP imagery, GIS, and other specialized remote sensing data manipulation and mapping techniques. These efforts included: 1) a project to demonstrate that coral reef bleaching can be detected with IKONOS satellite imagery using radiometric normalization of image pairs utilizing change detection techniques; 2) compilation of data for comparison of the capabilities of different instruments (DMSP, MODIS, VIRS) for fire detection; and 3) data processing and analysis to estimate the amount of impervious surface area within the conterminous United States, using DMSP satellite data, U.S. Census Bureau TIGER roads data, high resolution aerial photography, and Landsat TM classification data from USGS EROS Data Center. This project is part of NASA's Land Use Land Cover program, and the product is used as input to models for carbon cycling.

Quality assessment of the Cloud Top Height product (CTOP) created by the FAA AWRP Oceanic Weather Product Development Team was conducted by the Real-Time Verification team at FSL. The assessment provided an intercomparison-based analysis of CTOP with an operational cloud top height product. This analysis marked the first use of remote sensing data for verification of aviation weather products in the context of the AWTT process. Based strongly on the results of the CIRA analysis, the FAA technical reviewers decided to make the CTOP product available to operational organizations on an experimental basis.



A constellation of sunsynchronous satellites designed to observe the entire earth each 101 minutes. At the time pictured, all of the satellites would be traveling northward. One half orbit (50.5 min.) later the satellites would all be on the opposite side of the earth traveling south.

CloudSat Research

CloudSat development started in 1998 with CIRA named NASA mission's Data Processing Center (DPC). This satellite is expected to be launched in 2006. CloudSat is a multi-satellite, multi-sensor experiment designed to measure those properties of clouds that are critical for understanding their effects on both weather and climate. These cloud properties are not obtainable from current satellite measurement systems. The mission's primary science goal is to furnish data needed to evaluate and improve the way clouds are parameterized in global models, thereby contributing to better predictions of clouds and thus to the poorly understood cloud-climate feedback problem.

The key observations are the vertical profiles of cloud liquid water and ice water contents and related cloud physical and radiative properties. The spacecraft payload consists of a millimeter-wave radar. CloudSat will fly in tight formation with the CALIPSO

FLASHBACK: CIRA newsletter, Volume 13: Spring, 2000

CloudSat: A New View of Clouds From Space

The CloudSat satellite has two instruments: the Cloud Profiling Radar (CPR) and the Profiling Oxygen A-Band Spectrometer and Visible Imager (PABSI). With a planned signal-to- noise of 100:1, the PABSI spectrometer will be able to determine the optical depth and altitude of thin clouds and aerosols, but will also be sensitive to small changes in the optical depth of very deep clouds – a capability not presently possible with current systems. The PABSI imager will allow researchers to identify mesoscale weather systems corresponding to the cloud and aerosol profiles. Both the imager and spectrometer measure reflected sunlight and thus can only operate during daylight.

CloudSat will fly in tight formation with the PICALIPSO satellite; these two satellites will follow behind the EOS-PM satellite in a somewhat looser formation. CloudSat will be controlled such that both sets of sensors view the same ground track most of the time, with a delay of approximately 60 seconds between lidar and radar measurements. EOS-PM will carry a variety of complementary instruments, including CERES, AIRS, AMSR, and MODIS.

CloudSat represents a collaboration among a number of partners. Colorado State University is providing mission leadership through Dr. Stephens. The Jet Propulsion Laboratory will be responsible for mission operations and payload development. Ball Aerospace in Boulder is providing the spacecraft bus and will be responsible for spacecraft integration. The U.S. Air Force Space Test Program will provide ground operations and data communications. The Canadian Space Agency is contributing components to the CPR, and substantial validation support is being provided by the Dept. of Energy's Atmospheric Radiation Measurement (ARM) program, as well as by research agencies in Germany and Japan. CIRA will play a major role in the CloudSat project, providing data processing and data archiving for all CloudSat data. CIRA will also collect and archive supportive data such as geostationary satellite imagery and upper air and surface observations.

– Richard Austin

CloudSat is the first satellite project where the mission requires input from two different sensors on two different satellites (the CPR on CloudSat and the LIDAR on CALIPSO).

satellite (formerly known as PICASSO-CENA/ESSP3) carrying a backscattering lidar, and these two satellites will follow behind the Aqua satellite in a somewhat looser formation. The combination of data from the CloudSat radar with coincident measurements from CALIPSO and Aqua provides a rich source of information that can be used to assess the role of clouds in both weather and climate.

From CIRA's perspective this satellite is unique in two ways. First, it is the first time CIRA has acted on NASA's behalf as a primary mission node. CIRA's mission responsibility is to develop the DPC systems and operate the DPC during the mission, producing and distributing standard products to the CloudSat science team as well as the entire science community. Due to several launch delays, CIRA with the assistance of its contractor, Science and Technology Corporation, has been able to create software with several unique attributes.

1. The production software has been packaged in a stand-alone version that is provided to all the science development teams responsible for creating the product algorithms. These system packages are then used by the scientists as a development environment to write their code. This frees scientists from worry about the dreaded input and output interfaces. Typically, when scientists write an algorithm that uses satellite data, they write 90% of their code to ingest, navigate, and calibrate the data. Only after this work is completed do they write their "science code." This science code is then "ported" to a production system and recoded into more efficient operational code. Unfortunately this porting is quite expensive and usually introduces errors

and misunderstanding because it represents a "cultural interface" between the scientist and computer programmer worlds. CIRA's packaged environment eliminates the porting problems and the need for scientists to develop their own ingest/navigation/calibration code.

2. These development packages are also linked into a distributed configuration control system. Since the CloudSat products "cascade" into each other where each successive product is dependent upon the previous product's output, code development requires that changes in code that affect a product be known to developers of the subsequent product. CIRA's configuration management system automatically notifies all the players at different universities or government laboratories when critical changes occur.
3. The DPC software has been written in such a generic way that it can easily be configured to support a different satellite in the future.

The second unique aspect of this mission is that some of the standard products created will require input from more than one satellite. Currently, both CloudSat radar and CALIPSO lidar data are required. Since these two satellites are traveling in the same orbit as several other weather satellites and are separated by only a few seconds from each

CIRA's innovative processing software is also being incorporated into NASA Langley's DAAC for A-Train processing.

FLASHBACK: CIRA newsletter, Volume 17: Spring, 2002

CIRA Participation in the Joint Center for Satellite Data Assimilation

It is expected that in the next 10 years there will be a five orders of magnitude increase in the number of available satellite measurements. The complexity of data assimilation makes the optimal use of satellite measurements even more difficult and time consuming. It will be an enormous challenge to process these measurements and obtain their full benefit in operational weather forecasts. Data assimilation will play a critical role in achieving this "end-to-end" goal.

Operational centers realize the need for implementing new research and development, but are faced with limited funds and facilities. Research institutions would like to benefit from operational experience by using a code tested in an operational environment. As a response to the ever-increasing number and complexity of satellite measurements, NOAA and NASA recently joined efforts to maximize the utilization of satellite data to improve weather forecasts. The idea of bridging the gap between research and operations, sometimes called "the valley of death," is not new, but remains extremely challenging. The need for community fast radiative transfer models, a common model and data assimilation infrastructure, and for education and training of satellite data assimilation experts, were recognized as obvious common interests.

In order to achieve this goal, a Joint Center for Satellite Data Assimilation (JCSDA) was founded to study impact groups, atmospheric soundings, upper air winds, precipitation and clouds, ozone and aerosols, ocean and sea ice, land products and data assimilation techniques. The JCSDA is expected to provide general benefits to the research and operational community, such as improved weather forecasts, extension of range of useful forecasts, greater return on investment by earlier and enhanced use of space assets, and improved planning of future satellite instruments. More specific benefits of JCSDA provided to the research community include timely access to global environmental data from satellites and other sources, data and information services, support of oceanic, land, and atmospheric research on the use of satellite data for monitoring environmental characteristics and their change, and a strong technology transfer program to ensure maximum utilization of satellite data.

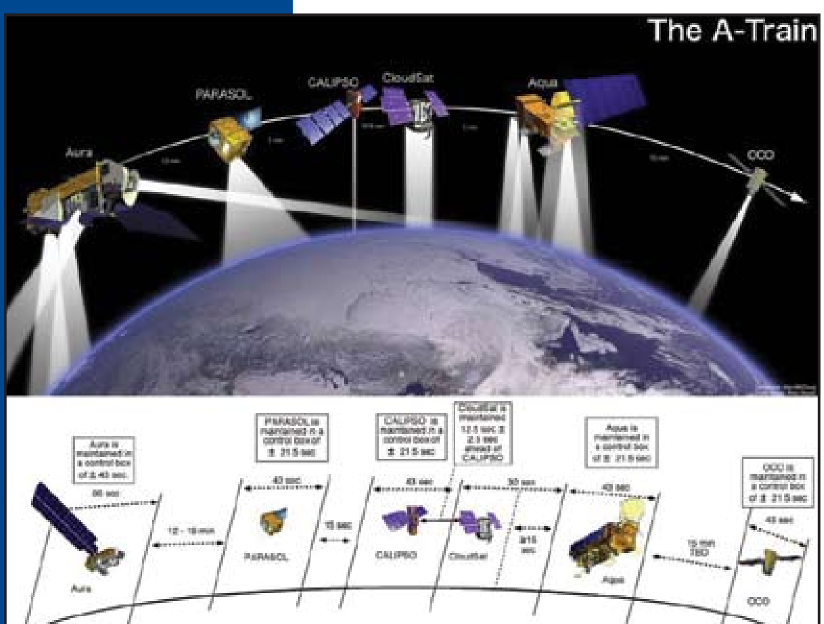
In addition to the JCSDA primary goals, there is also a component in satellite data assimilation development directed toward supporting the U.S. Weather Research Program, mainly to increase understanding and prediction of Hurricanes At Landfall (HAL), improve Quantitative Precipitation Forecasts (QPF), and extend accurate weather forecasts to day 7 and beyond. Recent data assimilation development at CIRA (RAMDAS), combined with already existing expertise in satellite measurements, forward models, and NWP modeling, has created a unique opportunity for CIRA's participation in JCSDA efforts.

– Milija Zupanski and Mark DeMaria

CIRA developed a correlated data extraction system that allowed CloudSat data to be delivered to scientists with all relevant data from other data sources already "clipped" to the region and time correlated to each CloudSat footprint.

other, the entire group of satellites has been dubbed the A-Train.

The DPC has been uniquely configured to provide highly correlated data from A-Train components. Scientists working with other satellite data must process data from various sources (satellites) close in space and time to the target satellite data set. This necessitates ordering large volumes of data, sorting out the specific points which correspond to the target data set, then discarding the bulk of the ordered data. The DPC system will build auxiliary data files from CALIPSO (and future satellites) which are correlated subsets of the non-CloudSat data. These auxiliary data sets will be provided to the science community, saving the shipping of large, mostly irrelevant data sets and the drudgery of pruning the data down to only what is needed.



The Future of Satellite Application Development

Future work in satellite-based applications will easily eclipse all that has been accomplished previously. In the 2005-2012 timeframe, over 100 environmental satellite sensors will be in orbit, including foreign and U.S. civilian/military sensors. Prototype applications for the two major operational systems, NPOESS and GOES-R, are currently being developed by CIRA scientists. GOES-R's HES hyperspectral sensor will provide totally new opportunities for scientific application development. These systems represent a challenge to all research institutions and national laboratories in terms of data flow (volume and updating pace), number of channels and spatial resolution, and most importantly the potential of recognition of captured new atmospheric phenomena.

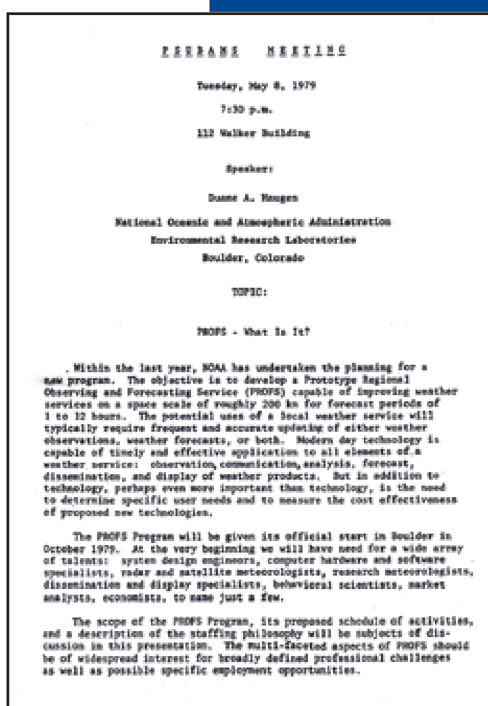
In addition to the new satellite sensors that will become available in the next decade, new methods of analysis of these data will add to the intellectual challenge. CIRA is just beginning to investigate multi-platform, multi-sensor methods for addressing atmospheric science problems using CloudSat and the A-Train as a means to build tools and gain skill in this never before attempted methodology. CIRA's research into various data assimilation methods is bringing the power of numerical modeling to the interpretation of these satellite data sets in all their combinations. Clearly, the next decade will offer new challenges to CIRA's scientific and technical staff, yet the potential for discovery is enormous and exciting.

CHAPTER 4: *Mesoscale Studies and Forecasting*

The establishment of CIRA in September 1980 formalized research collaborations between Colorado State University and the NOAA Environmental Research Laboratories (ERL) in Boulder. One of the major objectives of the embryonic partnership was support for the Prototype Regional Observing and Forecast Service (PROFS).

Officially launched in October 1979 and headquartered in Boulder, Colorado, PROFS was a NOAA effort with the objective to improve weather services and forecasting. Specific areas of investigation in support of PROFS included assistance with satellite data collection, integration of satellite data and products for the PROFS experimental data facility, the development of nowcast products, societal aspects of severe weather warnings, estimated uses and benefits derived from these products, and the training of PROFS personnel in the uses of satellite data and products. A memo issued in November 1981 by the PROFS-CSU steering committee outlined specific aspects of collaboration between the two groups, principally in the area of satellite data collection. A new system to receive and transmit satellite data from CSU to PROFS was installed while PROFS built its own direct readout ground station. CSU also played a vital support role in a series of real-time exercises conducted by PROFS to evaluate overall system capability and performance to deliver data and products to their workstations.

PROFS' first four-year phase was dedicated to building a "nowcasting" capability. The approach was to develop a system to acquire, process, and display the data necessary to study weather events in a real-time operational work environment. In addition to the satellite data collection efforts, PROFS explored real-time radar data acquisition, processing and display techniques, including applications to derive Constant Altitude Plan Position Indicator (CAPPI) images and echo tops maps from volumetric WSR-74C radar data. Algorithms that were later implemented in the NEXt generation RADar (NEXRAD) Doppler radar system were coded and evaluated prior to handoff to the bidding NEXRAD contractors. As described by Dan Birkenheuer, another CIRA scientist from its early days, "Our initial efforts were to derive an ingest system and my focus was initially on a "user level" storage format which we did devise using direct access FORTRAN for VAS data. Of course, things changed as time went on as we switched from "mode AA" to AAA and then to GVAR which really was out of my league. By then the PROFS data ingest side took over that task using other computer languages and strategies for data storage managed by other groups. Meanwhile, my efforts were more aimed at product evaluation and exploitation. In the late 1980s, John McGinley assimilated me into the LAPS development side of things focusing on satellite



[illegible] MEETING

Tuesday, May 8, 1979

7:30 p.m.

112 Walker Building

Speaker:

Duane A. Haugen

National Oceanic and Atmospheric Administration

Environmental Research Laboratories

Boulder, Colorado

TOPIC:

PROFS - What Is It?

Within the last year, NOAA has undertaken the planning for a new program. The objective is to develop a Prototype Regional Observing and Forecasting Service (PROFS) capable of improving weather services on a space scale of roughly 200 km for forecast periods of 1 to 12 hours. The potential uses of a local weather service will typically require frequent and accurate updating of either weather observations, weather forecasts, or both. Modern day technology is capable of timely and effective application to all elements of a weather service: observation, communication, analysis, forecast, dissemination, and display of weather products. But in addition to technology, perhaps even more important than technology, is the need to determine specific user needs and to measure the cost effectiveness of proposed new technologies.

The PROFS Program will be given its official start in Boulder in October 1979. At the very beginning we will have need for a wide array of talents: system design engineers, computer hardware and software specialists, radar and satellite meteorologists, research meteorologists, dissemination and display specialists, behavioral scientists, market analysts, economists, to name just a few.

The scope of the PROFS Program, its proposed schedule of activities, and a description of the staffing philosophy will be subjects of discussion in this presentation. The multi-faceted aspects of PROFS should be of widespread interest for broadly defined professional challenges as well as possible specific employment opportunities.

Flier announcing PROFS initiative, May 1979.

FLASHBACK: Robert Lipschutz was among the first CIRA employees to be collocated with the PROFS effort in Boulder. As he recalls:

"My office mate, Herb Winston, and I were the first CIRA Research Associates working in Boulder for the NOAA Environmental Research Laboratories (ERL). PROFS, which had just been formed a year or so before, was actively recruiting numerous meteorologists, programmers, and systems analysts to build the mesoscale data acquisition and display system that ultimately led to the Advanced Weather Interactive Processing System (AWIPS) which is now installed at every National Weather Service Forecast Office.

"The nascent arrangement between NOAA and the CIRA Joint Institute was a natural mechanism to bring Herb and me on board. In those days, the hiring process was considerably less bureaucratic. I was hired over the phone, after talking to Duane Haugen, a Branch Chief at PROFS, who had contacted my thesis advisor Dr. Hans Panofsky at Penn State. I remember, too, that Duane had come to Penn State in 1979 to give a talk on PROFS to generate interest and excitement about the program."

and moisture assimilation in local scale analysis and model initialization where I have remained since."

Another key technology for mesoscale nowcasting explored by PROFS was the real-time surface Mesonet, which comprised a 22-station network in northeastern Colorado.

CIRA support for the network included an interactive time series plotting capability and a thorough data quality assessment effort.

An initial evaluation of this capability occurred during the summer of 1982 with the first real-time forecast exercise meant to evaluate the PROFS real-time operational workstation as an aid to improving the timeliness and accuracy of short-term forecasts. Results suggested that improved forecasting performance was possible with the advent of advanced technology and training of forecasters in preparing short-term forecasts. After concentrating its first 4 years on several convective season real-time forecast exercises, PROFS conducted its first cool-season forecasting experiment during the winter of 1984.

Looking ahead into its second 4-year phase, the January 1984 PROFS program review restated the Phase I goals, showed how they had been fulfilled, and defined the goals for Phase II. The review emphasized continued commitment to the improved forecast goal, wrapped around AWIPS-90, planned ingest of VAS data, and work on NEXRAD algorithms, software, and applications programs. Collaboration with the Profiler group at the ERL Wave Propagation Lab on a joint data retrieval project was also mentioned. In concert with these goals, PROFS underwent an organizational change with the formation of two new branches in fiscal year 1985. A portion of the Science Branch of the Exploratory Development Group was detached to form the separate Analysis and Prediction Branch, dedicated to the development of a Mesoscale Analysis and Prediction System (forerunner to the current Rapid Update Cycle model) and the support of the FAA's Central Weather Processor program. The new Experimental Forecast Systems Branch was formed to concentrate on the development of products and applications for the PROFS advanced forecasting workstation (forerunner of the WFO-Advanced and AWIPS project). During 1985, the efforts of all six branches of PROFS focused on a real-time summer forecasting exercise. An important occurrence during the exercise was the Cheyenne flood of August 1. Exercise forecasters were able to better predict the severity of the storm with the help of the PROFS workstation and advanced data sets.

Early leaders of PROFS, including Don Beran, Ron Alberty, and Sandy MacDonald have served as CIRA Fellows over the years. The CIRA pioneers in Boulder, as mentioned above, were Dan Birkenheuer, Bob Lipschutz, and Herb Winston. Dan left CIRA in 1999, but during his nearly 20-year tenure, he supported the early efforts to archive forecasts and verification data to assess forecaster performance. Statistics played a key role in determining the display products and temporal data resolution necessary to maximize the cost-to-benefit ratio of the PROFS prototype system. Dan also worked to incorporate VAS satellite data into the PROFS Operational Workstation. Bob Lipschutz (Aug. 1981) developed a variety of data handling systems including a Doppler radar capability to support NEXRAD algorithm testing which ultimately led to some of the techniques found in the current AWIPS system. Herb Winston was also involved in the development of radar algorithms and the data transfer and ingest of VAS data. In addition, Kevin Brundage (May 1982) spent time with the Workstation Team and finally settled into the MAPS group.

John Weaver and Ray Zehr, representing CIRA/NESDIS, participated in the very first PROFS '82 real-time exercise, joined by Ed Szoke from NCAR and others in later exercises. Glenda Wahl (June 1983), Ron Kahn (Aug. 1983), Mike Biere (Nov. 1983), Tracy Smith (Jan. 1984), Jim Ramer (Jan. 1984), Joanne Edwards (Mar. 1984), Renate Brummer (1983/85 as PhD student; 1986), Greg Pratt (1985), MarySue Schultz (1985), Steve Albers (1986), Pete Stamus (1986), and Tom Kent (1987) were other "contract" personnel who matured with PROFS and eventually joined CIRA over the years.

Visiting one of the sites in the network pre-boom times in Colorado was a real eye-opener according to Birkenheuer:

I had the opportunity to "go along for the ride" to install the Briggsdale Mesonet station. The site was out in the Pawnee National Grasslands, about 30 miles east of Fort Collins. On the way, we saw numerous pronghorn, and I remember being struck by the vastness and beauty of the High Plains. It was a long day of heavy labor getting the tower hoisted and guyed, and the Stephenson screen assembled and instrumented. I also recall the wind blowing incessantly, and being very relieved to finally head home to Boulder.

– D. Birkenheuer

FLASHBACK: CIRA newsletter, Volume 16: Fall, 2001

Hurricane Research at CIRA

In August of this year, NOAA's Hurricane Research Division warned residents of the U.S. Atlantic and Gulf coasts to be aware of an escalation in tropical storm activity. This increase is due in large part to a multi-decadal cycle of climate change, with active Atlantic hurricane seasons expected to be prevalent for several more years. CIRA/RAMM research scientists are pursuing a variety of applied research topics and product development goals aimed at improving tropical cyclone forecasts. As the number of dangerous cyclones and hurricanes increases every year, this kind of information is invaluable to weather forecasters and disaster management officials alike. The emphasis of CIRA/RAMM team research currently underway is on optimizing the information content of satellite sensors and images. For example, recent advances in satellite microwave sounders have been used to produce independent measurements of hurricane pressure and wind fields. CIRA/RAMM project is archiving infrared images over all tropical cyclones through their entire life cycle in a common format. The 4 km resolution images at 30-minute time intervals capture important track and intensity changes.

The increase in Atlantic hurricane activity in recent years is confirmed by the numbers. During the six-year period, 1989-1994, there were only seven intense Atlantic hurricanes compared with the 23 that occurred in the period 1995-2000. Clearly, the type of data collected and the tools being developed by CIRA/RAMM researchers is both critical to the coastal residents of the U.S. and to the nation at large. As CNN recently reported, an insurance industry study found that damage from a hurricane could cause $20 to $50 billion in damage to a major coastal city. And if one was to make landfall in a heavily populated area, thousands of people could die. The life-saving potential of the work being done by the CIRA/RAMM team is clear.

– Ray Zehr

FLASHBACK: CIRA newsletter, Volume 12: Fall, 1999

Daily Hurricane Briefings at CIRA

At four o'clock each afternoon, an enthusiastic group of scientists gather around computer workstations in the CIRA computer lab to be briefed with up-to-the-minute information on the tracks, intensities, and forecasts of hurricanes and tropical storms. The main attraction is the opportunity to view high-quality animated satellite images along with observations and computer model analyses. An informal lively discussion often interrupts or follows the briefing. Participants represent a diverse group with a wide variety of interests, including CSU Atmospheric Science faculty, research associates, and graduate students.

The daily briefings take place from mid-July to mid-October, and a volunteer is assigned to lead the discussions each week. This provides an excellent opportunity for graduate students to refine their presentation and analysis skills. The discussions often expand to include specific problem areas in forecasting, remote sensing, media issues, and disaster preparedness.

The hurricane briefings began in 1995 as a result of CIRA's enhanced access to automated real-time satellite display capabilities through association with the NESDIS (National Environmental Satellite Data and Information Service) RAMM (Regional and Mesoscale Meteorology) Team. Ray Zehr (RAMM) and Kevin Schrab (former CIRA Research Associate) developed the first version of what became known as "Tropical RAMSDIS" (RAMM Advanced Meteorological Satellite Demonstration and Interpretation System).

RAMSDIS workstations were developed for use at NWS Forecast Offices, and each system was tailored for a specific geographical region. Tropical RAMSDIS, on the other hand, employs the same hardware and software design but is designed for global coverage of the tropics with geostationary satellite images. The high resolution satellite ingest is moved to follow individual hurricanes, typhoons and tropical storms through their entire lifetime. Access to five geostationary satellites provides excellent coverage of all tropical weather systems around the world.

It may seem a bit odd that there is so much interest in hurricanes at a high plains location such as Fort Collins, far removed from the hurricane threat. However, CIRA and Colorado State University have a long tradition of involvement in hurricane and tropical meteorology research. The late Dr. Herbert Riehl, founder of the Atmospheric Science Department, published his textbook Tropical Meteorology in 1954. CSU Atmospheric Science Professors Gray, Schubert, Montgomery, Johnson, and Pielke, among others, have investigated tropical meteorology research topics.

– Ray Zehr

Meanwhile, back in Fort Collins...

In 1980, Colorado State University and NESDIS (NESS at that time) entered into a joint development effort for the use of meteorological satellite data for research and environmental applications. With the PROFS (Prototype Regional Observing and Forecast System) activity in its early stages at the Environmental Research Laboratory in Boulder, it was recognized within NESDIS that a satellite focus in regional and mesoscale meteorology was needed in the Front Range area. In addition, there was a recognized need within NOAA to increase that component of research activities carried out jointly with academic institutions, thereby strengthening and broadening that interface. To help address those needs, NESDIS established the Regional and Mesoscale Meteorology (RAMM) Branch at CSU in the fall of 1980.

The RAMM Branch began with five NESDIS employees moving from Washington, D.C. to Fort Collins, Colorado: Dr. James Purdom as Branch Director, Robert Green, Roger Phillips, John Weaver, and Dr. Ray Zehr. When Dr. Purdom accepted the position as director of the NESIDS Office of Research and Applications in Washington, D.C., Dr. Mark DeMaria took the position as RAMM leader in 1998. Of the original team members, Robert Green accepted another position in the late 1980s and Roger Phillips has retired. The Branch has taken on three new NESDIS employees over the years, so the federal contingent is now six.

RAMM personnel continue to work closely with numerous CIRA research associates assigned to its projects, with an effective team of about 12 full-time research and support staff. They also help guide Department of Atmospheric Science graduate students working on their M.S. and Ph.D. programs.

Areas of meteorological investigation have expanded in scope since the Branch's early days. From its inception, the RAMM Branch has actively engaged in research at CIRA focused on utilizing satellite data in conjunction with other state-of-the-art data sets to better understand the development and evolution of convection and severe weather. A number of important findings have resulted from that research. Initial investigations focused on understanding and nowcasting convection and severe weather. The Branch's research focus has since broadened to include tropical storms and mesoscale modeling of the atmosphere. Results from these new areas of investigation have proven fruitful.

In the early days of meteorological satellites, the first cloud composites were created by superimposing satellite images on the same piece of photographic paper. CIRA brought the technique into the digital age. In the early 1980s, Marge Klitch, Frank Kelly, and John Weaver under the guidance of Tom Vonder Haar digitized hard copy photographs and then produced a digital composite image. These composites allowed them to study mesoscale cloud systems and medium-scale topographic effects from a new perspective.

By 1985, digital GOES images collected at the Colorado State University Earthstation enabled this group to create composite images entirely in the digital domain. They developed algorithms using these new techniques that produced cloud composites covering Colorado and surrounding states. These composites revealed a close coupling between terrain and cloud formation, as well as interesting details in the

GOES satellite.

FLASHBACK: CIRA newsletter, Volume 15: Spring, 2001

Improving Short-range Forecasts of Clouds and Precipitation in LAPS

One of the greatest deficiencies of numerical weather prediction models is their lack of skill in predicting clouds and precipitation in the early portions (0-6 hours) of their forecast period. The Local Analysis and Prediction Branch within the Forecast Research Division of NOAA's Forecast Systems Laboratory is attempting to address this issue for local scale modeling using a new version of their Local Analysis and Prediction System (LAPS) to directly initialize the cloud and precipitation fields of a local forecast model.

Although LAPS was developed over a decade ago, it has undergone nearly continuous improvement during that period. It has a wide variety of private and government users around the world and has demonstrated a robust capacity to combine nearly all available sources of meteorological information into a single, coherent three-dimensional view of the atmosphere for real-time "nowcasting" and short-range prediction. Throughout its history, the LAPS analyses have been coupled with a variety of mesoscale forecast models, including RAMS, MM5, Eta, and ARPS. Its capacity to ingest a multitude of data types, combined with its portability and computational efficiency, has made it ideal for such applications.

– Brent L. Shaw and Steven C. Albers

FLASHBACK: CIRA newsletter, Volume 18: Fall, 2002

CIRA Participation in IHOP

The International H2O Project (IHOP) was an extensive field project in the Southern Plains of the United States between 13 May and 25 June of 2002. The main focus of IHOP was to improve the characterization of the four-dimensional distribution of water vapor and its application to improving the understanding and prediction of convection. The four main components of the program were: quantitative precipitation forecast (QPF), convective initiation (CI), atmospheric boundary layer processes, and instrumentation. Scientists from around the world participated in this program, bringing an assortment of instrumentation designed to remotely measure the distribution of water vapor in the atmosphere. The hope of all involved was that someday some of these instruments, both ground-based and satellite-borne, might be able to provide much-improved measurements of moisture in the troposphere, and ultimately lead to better forecasts.

CIRA scientists at the NOAA Forecast Systems Laboratory in Boulder were involved in a number of aspects of IHOP, including design and participation in some of the experiments. They had a significant role in the planning and implementation of forecasting and nowcasting support for the field program, which included the opportunity to run and evaluate several high-resolution numerical models.

With an impressive array of instrumentation, both ground-based [including fixed remote sensors as well as an armada of mobile instrument-equipped vehicles from the National Severe Storms Laboratory (NSSL)], and a variety of airborne sensors and satellite measurements, IHOP provided an opportunity to test the impact of all this special data on short-range forecasts from high-resolution numerical models. A number of groups planned to participate with special runs of their models, with varying horizontal grid resolutions. Model runs during the IHOP field phase only included some of the special project data, and provided a baseline for later sensitivity studies.

– Ed Szoke

CHANCES was the first global hourly 5 km resolution nephanalysis ever created. It was also the first nephanalysis based solely on satellite data.

diurnal convection cycle. They continued to refine the compositing techniques and applied the results to long-term forecasting. During the late eighties, Harold Gibson and Tom Vonder Haar used the same technique to reveal intricate patterns of cloud development near the U.S. southeastern coasts.

During the nineties, the algorithms and techniques developed at CIRA were used at STC-METSAT for various studies and products, including CHANCES (the Climatological and Historical Analysis of Clouds for Environmental Simulations). CHANCES combines high resolution data from a variety of geostationary and polar-orbiting satellites to produce a global cloud database. This three-year database was later used at CIRA to study cloud patterns over other regions of the world, such as the Middle East.

GOES cloud composites continue to be used at CIRA. Bernie Connell, in conjunction with Ken Gould at the National Weather Service office in Tallahassee, took the process a step further by dividing the data into regimes according to wind speed and direction. Since 1995, they have used these composites to study the development of the summer sea breeze and its effect on convection development. These products are currently used at the Tallahassee office in their thunderstorm predictions. Bernie Connell has also used cloud composites over Central America to study dry/rainy seasonal changes and for fire detection.

Since 1987, Cindy Combs has taken the idea of wind regime cloud composites and applied it to all the U.S. weather stations in the U.S. Additional studies have concentrated on Wakefield, VA, to study convective development during different wind conditions; cloud patterns upstream from Cheyenne, Wyoming to aid in prediction high wind events; and using winds and pressure gradients as predictors for the extent and timing of marine stratus over the San Francisco/Monterey area.

The research success of the RAMM Branch in conjunction with CIRA has resulted in augmentations to the CSU satellite data handling system, as well as additions to the image display systems within the CIRA facility. Funding from NOAA has allowed the RAMM Branch to innovate in the development of satellite products and services from Geostationary Operational Environmental Satellites (GOES) data. With the launch of GOES-8 in 1994, a major focus of the RAMM Branch has been on the development and improvement of applications of satellite data to many aspects of weather analysis and forecasting.

CIRA has been heavily involved in the collection of the first images from each of the last several GOES. Ground station personnel are responsible for collecting and archiving the data stream from both the GOES Imager and Sounder. The imagery are then displayed and checked for quality control using various algorithms to assess the noise and the line-to-line striping in the imagery, as well as numerous quantitative analyses that can be performed on the data. Additional testing centers around very-rapid time-interval imagery and its uses. Feedback from these tests is provided to the NOAA Satellite Operations Control Center (SOCC) and well as to calibration experts at NOAA. A NOAA Technical Report is then produced containing results, not only from CIRA's tests, but from other NESDIS determinations of Imager and Sounder data quality. These checkouts will continue to be performed as each new GOES is launched, including the imminent launch of GOES-N.

With major changes in GOES instrumentation, there is also the need to develop image products that reflect improvements in spatial, temporal, spectral, and radiometric performance. A number of CIRA scientists are involved in such product improvement and development. CIRA is noted for some of its GOES Imager products, such as the combined fog/reflectivity product, visible and shortwave albedo products, skin temperature product. These efforts continue to be performed as the data evolve and improve with each succeeding GOES satellite.

CIRA's RAMM Branch team, Fall 2005: Deb Molenar, Ray Zehr, Mark DeMaria, Don Hillger, and John Weaver.

The future of GOES is advanced through the development of new/experimental products that would be useful in operations. These experimental products can lead to recommendations for the evolution and future of the GOES system. RAMM personnel are heavily involved in the efforts to develop a new set of geostationary operational satellites that will commence in 2012, called the GOES-R series. GOES-R Risk Reduction efforts involve simulation of future satellite data by utilizing current experimental satellite data. The GOES-R series will incorporate hyper-spectral instrumentation, unlike the multi-spectral capabilities of the current GOES series. This GOES-R series will carry new imaging and sounding instruments whose performances will exceed that of their counterparts aboard the current GOES fleet. Higher spatial and temporal resolution, a greater number of frequency bands, and a less restrictive scanning

CIRA provided NESDIS the first GOES-8 and 9 images after launch for NOAA PR.

CIRA is developing GOES-R simulations that will allow meteorologists to understand the characteristics of the data before it is launched. These simulations will also assist NOAA in determining sensor performance trade-offs that will balance cost vs. meteorological impacts.

schedule will allow meteorologists in both the research and operational communities to better understand and predict the weather. Although the launch is many years away, work related to maximizing the benefits of the GOES-R imager has already begun. In particular, synthetic images designed to simulate what GOES-R images will actually look like have been generated using a cloud-resolving model and a radiative transfer model. By generating synthetic images, research and development of products which combine data from the different frequency bands available on the new satellite can begin before it is launched, extending the operational lifetime of the spacecraft.

Another major effort at the RAMM Branch has been the development of the RAMM Advanced Meteorological Satellite Demonstration and Interpretation System (RAMSDIS) in the 1990s. RAMSDIS was developed to fill a gap between advancing digital satellite technology and the lack of capable display systems to make the data available to operational forecasters. While RAMSDIS was developed to provide a low-cost method for getting real-time digital satellite data into National Weather Service (NWS) offices, RAMSDIS OnLine (ROL) was constructed in 1998 with the idea of putting RAMSDIS and some of its capabilities on the World Wide Web. ROL allows for a much larger audience to view

FLASHBACK: CIRA newsletter, Volume 18: Fall, 2002

RUC-2 Implementation

A joint effort between CIRA staff and our federal partners at the Forecast Systems Lab in Boulder has resulted in an update of the RUC system. The Rapid Update Cycle (RUC) is a system that provides high frequency, hourly analyses of data sources over the 48 states, as well as short-range numerical forecasts. The RUC is in operational use at NOAA's National Centers for Environmental Prediction (NCEP) in Camp Springs, Maryland.

NCEP's mission is to provide weather forecasts, warnings and guidance to the public, and as such the RUC is a useful tool in this assignment. The RUC is one of a kind in its ability to produce updated, national scale numerical analyses and forecasts more frequently than once every six hours. The system was developed in answer to the needs of the aviation community and others for high-frequency, mesoscale analyses and short-range forecasts covering the contiguous United States.

The new RUC-2 is a 20-km (as opposed to 40-km), 50-level version of the RUC. The four key aspects of the new version include: finer (20-kilometer) horizontal resolution (requiring about eight times the computations of the 40-kilometer version for the forecast model), an improved version of the RUC forecast model, assimilation of GOES based cloud- top pressure to improve the initial RUC cloud fields for each forecast, and use of a three-dimensional variational analysis, replacing the current optimal interpolation analysis. Also, the existing soil model was enhanced to include a 2-layer snow model and high-resolution land-use/soil type and topography data.

CIRA passes on its congratulations to the CIRA researchers who contributed to the update: RUC development group – Kevin Brundage, Tracy Lorraine Smith; Other Forecast Research Division collaborators – Ed Szoke, Adrian Marroquin; Information & Technology Services – Bob Lipschutz, Paul Hamer, Glen Pankow; Systems Development Division – Jim Ramer; Aviation Division – Dan Schaffer, Jacques Middlecoff.

GOES images and products. (See further discussion about RAMSDIS and RAMSDIS Online in Chapter 3.)

The RAMM Branch has always been involved in training meteorologists on the use of satellite data. To facilitate this training, the Branch has developed learning modules on the use of GOES imagery that are available on the Web. Also, a virtual laboratory accessible through the Internet allows researchers at other institutions to use digital satellite data collected at CIRA and collaborate with our researchers on particular weather events. The RAMM Branch is actively involved in training with routine participation in both national and international training programs including the NWS COMET Satellite Meteorology series. As an outgrowth of these activities, the VISIT program was developed as a means for regular training of NWS and other satellite data users.

In summary, the RAMM Branch has played a significant role in CIRA since its inception in 1980. The focus of the RAMM Branch is to develop new applications of meteorological satellite data to further the science of forecasting severe and/or convective weather events. Other areas of high priority research include: 1) The innovative use of computer technology in assimilating and utilizing satellite observations (i.e., radar, wind profiler, numerical model and other meteorological information) to more rapidly assess the state of the mesoscale environment; 2) Developing tropical cyclone forecasting techniques for determining formation, intensity, structure, and track; 3) Contributing to the evolution of satellite sensor technology; and 4) Providing training to NWS and other forecasters in the application of satellite data to all elements of weather analysis.

Joint Mesoscale Studies at the Boulder Federal Lab

Following on the heels of the PROFS support during the early years, CIRA scientists in Boulder have continued to collaborate closely with their colleagues in several NOAA research laboratories, principally the Forecast Systems Lab (FSL), the Environmental Technology Lab (ETL), and the NESDIS National Geophysical Data Center. Their research activities have touched every aspect of the CIRA (and NOAA) research themes and cross-cutting areas. A few of the more notable examples are highlighted below.

- Collaborations with the FSL Director's Office on advanced forecast modeling produced several innovative findings; for example, the Bounded Derivative theory can be used to initialize balanced flows for the mid-latitude mesoscale case and for all equatorial cases. Dr. Browning received the 1998 ERL Outstanding Scientific Paper Award for his 1997 work on the role of gravity waves in mesoscale motions.
- Several new research collaborations on mesoscale studies were initiated at the start of the 21st century. One involved the development of a new convective ensemble-based parameterization for the Rapid Update Cycle (RUC). Another effort involved the analysis of bore dynamics during the IHOP 2002 field experiment. A third effort involved the development of a time-lagged ensemble forecast system based on various RUC forecasts initialized at different times. Another effort was begun to develop a wavelet-based diagnostic tools to better detect gravity waves and clear air turbulence.
- GPS tomography technique was tested using actual GPS data and the resulting water vapor analysis was

CIRA developed RAMDIS, the first NWS-deployed satellite analysis system that allowed easy transfer of new analysis scenes from a university to operational forecasters.

Implementation of RUC-2 at NCEP greatly improved the use of satellite data in the initialization of NOAA's numerical modeling.

compared with satellite water vapor imagery and sounding data obtained during IHOP with good results.

- First year of proof-of-concept testing of local data assimilation and NWP within a NWS Forecast Office produced favorable results. Satellite, radar, and other local data were used for real-time initialization of the WRF model on a Linux cluster.
- In perhaps the first quasi-operational implementation of the new WRF model and the first NWS-sanctioned local modeling effort, CIRA researchers participated in the Coastal Storms Initiative to perform a proof-of-concept for local data assimilation and NWP within a NWS Forecast Office (Jacksonville). With the first use of satellite and radar data for real-time WRF initialization, early results were promising.
- Collaborations with the Boulder WFO on evaluations of an experimental infrasound system developed by ETL began in 2004. Cases of tornado events were examined to determine the potential value of the new system to provide enhancement to radar in the detection of tornadoes.
- A specially configured mesoscale ensemble forecast system comprised of MM5 and WRF model runs was developed to support the Road Weather Maintenance Decision Support System (MDSS) for the FHA during FY03-04. LAPS analysis was used to initialize both WRF and MM5 to produce 48 runs per day out to 15 hours during the entire 2003/2004 winter. These forecast grids serve as input to provide forecast winter road conditions and recommended treatment options for road maintenance personnel.
- Support of the U.S. Fire Consortia for Advanced Modeling of Meteorology and Smoke continued during 2004 with enhanced fire weather products including a "Critical Fire Weather Index." Plots of surface latent heat flux forecasts and solar radiation observations were created to help diagnose and improve surface relative humidity forecasts.
- SCAN (System for Convection Analysis and Nowcasting) developed by the NWS/MDL was ported into Taiwan Central Weather Bureau's AWIPS-like weather forecasting workstation during FY03-04 to better integrate weather surveillance radar data for short-term severe weather analyses and forecasts. Follow-on effort to integrate MDL's Flash Flood Monitoring Program into AWIPS for hydrologic forecast and emergency management support was initiated in support of collaborative research with both Taiwan and South Korea.
- The results of the collaborative work with Canada's RPN and UCLA to ascertain the appropriate large-scale forcing that should be included in the hyperbolic system was incorporated into the Canadian operational global assimilation system and model in 2003. The reduction in the error relative to in-situ surface pressure and upper air data over North America were provided on the Canadian website: http://www.msc-smc.ec.gc.ca/cmc/index_e.html.
- During 1997-98, an improved version of the RUC Version 2 was implemented at NCEP. This higher resolution (40km) RUC-2 system incorporated a suite of microphysics parameterizations based on MM5, a state-of-the-art soil/vegetation model, and utilized a variety of new data sources such as satellite-derived precipitable water. The FSL RUC team responsible for develop-

FLASHBACK: CIRA newsletter, Volume 20: Fall, 2003

Data Assimilation: Why and How?

Measurements of atmospheric conditions are performed regularly around the globe several times a day via networks of ground-based weather stations, aircraft, and remote sensing platforms. The total number of weather data from all the networks is large. For example, the National Center for Environmental Prediction (NCEP) collects about 10^6 observation data points every three hours. This number of observations is not, however, sufficient to characterize the entire atmospheric state, since this represents an observation for every 197 square miles.

The atmospheric state is very complex, as it is a collection of air, water vapor, and a variety of particles characterized with continuous fields of energy and mass in motion. Temperature, pressure, and concentration of water vapor and particles including other phases of water in the atmosphere vary in space on scales as small as a millimeter. This suggests that a full description of the atmospheric condition at any time would require as many pieces of information as there are millimeter unit volumes in the atmosphere. In addition, to know how this very large state changes with time it would have to be recorded very frequently, for example every few seconds or minutes. Thus, the total number of pieces of weather information for the complete description of the atmospheric state is apparently orders of magnitude larger than the number of available weather measurements.

Is the information of atmospheric state on millimeter spatial scales and second time scales necessary for good weather analysis and prediction? The answer to this question depends on what we hope to achieve. Weather phenomena are characterized with a spectrum of spatial scales from millimeters to the entire globe. Each of these scales has specific requirements for a sufficient number of measurements to fully describe it. For example, synoptic-scale weather phenomena such as cyclones and anticyclones and the associated continental scale fronts could be well represented with measurements having horizontal spatial resolution of about 100 km. Also, the synoptic-scale measurements should include vertical scales of about 100 m in the lower troposphere to 1000 m in the higher troposphere. This together requires a volume of about 10^7 measurements assuming they are readily available with approximately even distribution in space, and that all physical quantities needed to describe the atmospheric state on synoptic scales are measured at the same time. This estimated number is compatible with the current number of weather measurements but these are not evenly distributed in space, nor are all quantities measured at the same time. Many are measured directly. In fact more than 99% of the weather measurements today are provided by satellite remote sensing, which implies that they do not represent direct measurements of the atmospheric state such as temperature, pressure, and humidity.

This implies that some procedure must be applied to the measurements to map them into a regular distribution in space, referenced at the same point in time from which the weather prediction is then produced for the given range of scales. This procedure is known as the weather data analysis. When the weather data analysis is constrained by known governing equations similar to a numerical weather prediction models, it is called data assimilation. Thus, data assimilation assumes the utilization of a physically-based model of the atmosphere in producing weather analysis.

CIRA investigations of data assimilation methods specifically include high resolution weather models and a variety of satellite and other measurements about the meso and synoptic scale weather processes. Current data assimilation projects include:

- 4D variational (4DVAR) data assimilation methodology with CSU Regional Atmospheric Modeling System (RAMS)
- Assimilation of cloudy radiances using visible and infrared satellite measurements
- Radiative transfer modeling for all weather radiance data assimilation
- Microwave land surface modeling for soil moisture data assimilation
- Ensemble data assimilation methodology
- Assimilation of precipitation measurements
- Estimation of model errors in data assimilation

– Tomislava Vukicevic

FLASHBACK: CIRA newsletter, Volume 11: Spring, 1999

Precipitation Research

Flooding is one of the most deadly weather related hazards, accounting for roughly 100 deaths per year in the United States. In an attempt to reduce the number of flood related fatalities, the National Weather Service has named quantitative precipitation forecasting (QPF) and estimation as top priorities. In response to this priority, CIRA is investigating new approaches to precipitation diagnosis. It may seem that determining rainfall would be a simple matter of measuring the depth of water that accumulated in a rain gauge, but rain gauges are plagued with problems. Even if the gauges themselves were consistently accurate, the poor spatial density of gauge sites allows storms to pass between gauges, resulting in little if any sampling of the precipitation region.

Radar, too, has its problems. Radar estimates can have errors on the order of 200% and greater, and radar coverage of the continental U.S. is incomplete. Satellite measurements are not perfect either, introducing viewing angle problems and being limited to observing only storm tops. Although any one method of estimating precipitation is faulty, the combined information gained from these tools may provide an accurate diagnosis of rainfall. CIRA is currently researching methods of combining satellite imagery, radar, station observations, and soundings to improve current QPF algorithms.

In addition to the observations, CIRA is implementing the Regional Atmospheric Modeling System (RAMS), developed at Colorado State University. A recent project studies factors affecting the efficiency with which a storm converts water vapor entering the cloud base to liquid precipitation reaching the ground. Another project involves the inclusion of satellite-observed clouds in RAMS. We are currently working with the precipitation group at NOAA/NESDIS to aid them in the refinement of their precipitation diagnosis algorithm that uses primarily geostationary satellite observations.

– Eric R. Hilgendorf

NOAA/FSL AWIPS team, circa 1999-2000.

ment and implementation of RUC-2 was awarded the OAR 1998 Bronze Medal Award.

- In April of 2002, a 20km, 50-level version of the RUC was integrated into operation at NCEP. This new RUC version (RUC-20) incorporated a variety of new data sources, including GPS cloud-top pressure, precipitable water, boundary-layer profilers and RASS. The physics package used in the forecast engine was also significantly enhanced to improve convective parameterization and cloud microphysics. The existing soil model was enhanced to include a 2-layer snow model and high-resolution land-use/soil type and topography data.
- In May 2003, the CIRA RUC team participated in replacing the analysis scheme used in the operational 20km RUC (OI) at NCEP with a 3D variational method. Use of the 3DVAR package allowed more efficient integration of additional observation data.
- A new version of the operational RUC was implemented at NCEP on 28 June 2005, with increased horizontal resolution, down to 13km, several new data sources, and improved surface, precipitation and cloud forecasts. The RUC was also used extensively for data impact studies, most recently evaluating wind profilers, lidar and ACARS moisture observations.

Joint Typhoon Warning Center

More recent mesoscale research has been undertaken by Dr. John Knaff in the area of typhoon warning and prediction. In his words, "One of the most rewarding projects that I have been involved in at CIRA relates to the operational transition of techniques to aid tropical cyclone (TC) intensity forecasting at the Department of Defense Joint Typhoon Warning Center. Two separate projects were funded by the Office of Naval Research, the first to develop intensity guidance for the western North Pacific in 2001 and the second to create similar models for use in the North Indian Ocean and the Southern Hemisphere in 2004. The projects were similar as they both involved the development of purely statistical models based on climatology and persistence used for verification, and statistical models that made use of global model forecast fields, commonly referred to as statistical-dynamical models. The models based on climatology and persistence were named the 5-day Statistical Typhoon Intensity Forecast or ST5D. The statistical-dynamical models were called the Statistical Typhoon Intensity Prediction Scheme or STIPS and there was also a version of the model that accounted for landfalling effects, referred to as decay-STIPS."

"In 2001, ST5D was installed and in 2002 STIPS was installed into JTWC operations. Both models made nearly immediate impacts as they were providing significantly improved intensity forecast guidance, especially for forecasts beyond 36 hours. Since that time, the western North Pacific version of STIPS has been updated and improved. Currently, decay-STIPS and STIPS are the only skillful (i.e., better than ST5D – climatology and persistence) available at JTWC. As a result of these models, 5-year running means of intensity errors are trending downward. In late 2004, the Southern Hemisphere versions of STIPS and ST5D have just begun to be evaluated. Based on a sample of 11 storms, STIPS and Decay STIPS are the only intensity forecast schemes that have provided skillful intensity forecasts during this time. At the time of writing this summary, plans are underway to incorporate additional information about the ocean's heat content to the STIPS models. This information will likely result in additional improvements in the ability to predict tropical cyclone intensity change in the western North Pacific, North Indian Ocean and Southern Hemisphere."

Joint Hurricane Testbed Activities

The NESDIS RAMM Branch Director, Dr. Mark DeMaria, cites the success of operational hurricane intensity forecasts as another highlight of CIRA history. He writes, "One of my most interesting projects at RAMMB was the improvement of operational hurricane intensity forecasts through better utilization of satellite observations. This was a joint effort with John Knaff and Ray Zehr and was partially supported by the NOAA Joint Hurricane Testbed."

"It is more difficult to forecast hurricane intensity changes than hurricane tracks. Over the last few years, the most accurate intensity forecast model used by the National Hurricane Center (NHC) is based on fairly simple statistical relationships. This statistical model was significantly improved by the incorporation of input from geostationary and polar orbiting satellites. A limitation of NHC's statistical intensity model was that it did not include information about the thunderstorms near the storm center, or the sub-surface ocean structure. Geostationary satellite imagery provided a measure of the thunderstorm activity,

CIRA's STIPS model installed at JTWC in 2002 showed immediate improvements in typhoon intensity forecasts beyond 36 hours. In 20 years intensity forecasts for hurricanes have improved about 1% per year. CIRA's SHIPS model, when implemented at NHC in 2004 showed 10% improvements in the Eastern Pacific and 4% in the Atlantic.

FLASHBACK: CIRA newsletter, Volume 23: Spring, 2005

CIRA Contributions to the Joint Hurricane Testbed

Transitioning new forecasting techniques and algorithms from research to operations has been termed "Crossing the Valley of Death;" unless concerted efforts are made to ensure that new developments are tested and implemented, they can languish and never be fully realized. To facilitate this transfer for tropical cyclone applications, NOAA established the Joint Hurricane Testbed (JHT) in 2001. In this program, funding is provided on a two-year cycle for promising research applications that are ready to be tested in an operational environment at the National Hurricane Center (NHC) in Miami. At the end of the evaluation period, a decision is made by NHC whether or not to make the application operational, depending on the performance and upkeep requirements. CIRA has participated in the JHT over the past several years, and two new products were declared operational after the testing period. Two additional products currently are in the evaluation phase, with real-time testing to occur during the 2005 tropical season.

The first cycle of JHT projects occurred in 2002-2003. CIRA received funding to test a new method for estimating tropical cyclone intensity and structure from the Advanced Microwave Sounding Unit (AMSU) and a new version of the Statistical Hurricane Intensity Prediction Scheme (SHIPS) that utilizes satellite information. The AMSU instrument has the advantage over infrared satellite measurements in that it can penetrate below the tops of clouds and provide information about the vertical structure of a tropical cyclone. Hurricane intensity forecasts have considerably less skill than track forecasts. To improve the ability to forecast intensity changes, a new, experimental version of NHC's operational Statistical Hurricane Intensity Prediction Scheme (SHIPS) was developed using new predictors from satellite data, including inner core convective structure parameters determined from GOES infrared data and the ocean heat content (OHC) estimated from satellite altimetry data.

New tropical cyclone algorithms are being developed and tested as part of ongoing JHT projects at CIRA. The ability to further improve the SHIPS model through the incorporation of aircraft observations and horizontal structure information from GOES satellites is being investigated. Although the aircraft reconnaissance data are available only in a limited part of the Atlantic basin, they usually are collected for the storms that have the greatest potential to affect the U.S. To utilize these data in a fully automated mode required for real-time operations, a detailed quality control and objective analysis system has been developed.

Although the ability to forecast tropical cyclone tracks and intensity is improving, there will always be forecast errors. To help quantify the uncertainty, a probability model is also being developed as part of the JHT. A Monte Carlo method is being applied, which accounts for uncertainties in the track, intensity, and wind-structure forecasts from NHC. In this method, the performance of the NHC forecasts from the past several years is used to generate the appropriate probability distributions.

– Mark DeMaria, John Knaff, Julie Demuth, Raymond Zehr, and Jack Dostalek

and satellite altimetry data were used to estimate the total amount of heat stored in the ocean (which fuels hurricanes). The new model with this satellite input was implemented at NHC, parallel runs were performed in 2002 and 2003, and the new model was made operational for the very busy 2004 hurricane season. The operational SHIPS intensity forecasts were improved by about 10% in the eastern Pacific and 4% in the Atlantic due to the satellite input. Over the past 20 years, the operational intensity forecasts have improved by less than 1% per year, so this work represents a four year advance in the Atlantic and a 10 year advance in the eastern Pacific."

Data Assimilation Work

Data Assimilation studies represent a growing field of mesoscale research at CIRA. These studies began at CIRA in the mid-1980s with collaborations among Drs. Thomas Vonder Haar, William Cotton, Roger Pielke and several postdoctoral scientists. The research was supported by the DoD Center for Geosciences. Dr. Tomislava Vukicevic was recruited by CIRA in 1998 with the goal to help develop a research program on enhancing the ability to dynamically incorporate satellite remote sensing observations into modeling of the atmospheric system to accurately analyze and predict weather on variety of spatial and temporal scales. Dr. Vukicevic's personal ambition was met with even larger enthusiasm by the diverse CIRA research community to undertake the strenuous task of integrating complex models of atmospheric physics and associated observations, together with mathematical algorithms for so-called optimal estimation of controls in the dynamical systems. The researchers agreed that accurate assessment of the states and also changes in the atmospheric system are achievable by the skilled integration of the best information from the worlds of modeling and observations, which are today mostly provided by high quality satellite remote sensing measurements.

Close collaboration was easily established between the experts on satellite remote sensing, data assimilation, mesoscale numerical weather prediction and computer programming with strong support from CIRA's Center for Geosciences/ Atmospheric Research program,

FLASHBACK: CIRA newsletter, Volume 16: Fall, 2001

Two of a Different Kind: Merging Models and Satellites for Better Weather Predictions

Since the launch of the first weather satellite, scientists have tried to use the information beamed back to earth in improving their weather forecasts. Despite significant technological advances, only a fraction of the data currently transmitted by weather satellites is actually used in forecast models. Many obstacles have impeded their inclusion, but CIRA scientists have developed solutions to bring together weather forecast models and satellite observations. With funding provided by the Department of Defense through CG/AR (the Center for Geosciences/Atmospheric Research), the science team has been working for nearly three years on the project. Team leader Dr. Tomislava Vukicevic manages the effort with her team including Drs. Duska Zupanski and Milija Zupanski, both formerly of the National Centers for Environmental Prediction (NCEP), and Dr. Tom Greenwald.

The project involves the use of CSU's Regional Atmospheric and Modeling System (RAMS) as the core forecast model and has focused on utilizing data from the Geostationary Operational Environmental Satellite (GOES) instruments under all weather conditions. Known as the Regional Atmospheric Modeling and Data Assimilation System or RAMDAS for short, this advanced system will be the first of its kind in the world. Slated for completion this fall, RAMDAS is a 4DVAR, or four-dimensional, variational system that integrates satellite observations with forecast models. The advantage of 4DVAR lies in its ability to provide the element of time along with the three spatial dimensions for a more natural, or physically consistent way of bringing observations into the model. The downside of 4DVAR is that it is very computationally intensive and requires the use of a collection of computers. A special cluster of PCs has been designated at CIRA for this purpose.

Several other forecast and research centers around the world have also been using the 4DVAR approach. RAMDAS is unique in that it uses some of the most sophisticated models available to explicitly predict clouds. This will not only improve forecasts of clouds but has other benefits as well, such as potentially improving rain forecasts. RAMDAS will incorporate satellite observations not only in clear regions, which is done routinely by other forecast centers, but also in cloudy regions. In addition, the satellite observations will be used in RAMDAS as they are; they will not undergo pre-processing to transform the data into variables that the forecast model predicts. Pre-processing oftentimes produces biases, which can degrade forecast performance.

RAMDAS will remain a research tool for at least several years before this type of system is used in an operational setting. In the meantime the research team expects to learn much about the impact of satellite observations on forecasts. These insights can be passed on in the development of future 4DVAR and satellite observational systems. The team's desire is not only to provide new, sophisticated tools for doing research, but also to become directly involved in educating graduate students in this emerging science. They expect to work closely with their colleagues at the Department of Atmospheric Science at CSU.

– Tom Greenwald and Mary McInnis

sponsored by the U.S. Department of Defense through the Army Research Lab. Additional support was also obtained from a variety of programs funded by other federal agencies, including NSF, NOAA and NASA. The successful collaboration and excellent support from the administration resulted not only in a good number of scientific publications, but also in a numerical modeling system that continues to be used for further advanced research, including PhD student dissertations. An additional result of this fruitful collaboration is an established research environment which invites addressing challenging research problems. Solving these problems requires a global vision of the atmospheric system, not just geographically but perhaps more importantly in multi disciplinary approach.

Among the various projects in this area were:

Four-dimensional variational data assimilation (supported by CG/AR):

This project, conducted from 2001-2003, was a collaborative effort between Drs. Milija Zupanski, Dusanka Zupanski, and Tomi Vukicevic. It adopted the variational algorithm and ideas developed for day-to-day operational use and applied them to challenging problems with clouds and microphysics. This project was aimed at using satellite measurements in an effort to provide better weather forecasts for clouds and related processes. Initial results, describing the methodology and impact, show that indeed it is possible to apply the variational methodology to assimilate cloud related variables and fields.

Ensemble assimilation/prediction (supported by NSF, CG/AR, NOAA/THORPEX, NOAA/NESDIS):

This project, started in 2003, is a team effort by Dusanka Zupanski, Steven Fletcher, and many other collaborators at Colorado State University, Florida State University, Portland State University, and federal agencies. The developed ensemble methodology, named the maximum likelihood ensemble filter, is a probabilistic method for estimating the likelihood of weather events at all scales, from city streets to continents. Instead of trying to think of the weather as an exact set of values for temperatures, winds, pressures, etc., this methodology views the weather events as events with certain likelihood (probability) of happening. The method is tied to the theory of chaos, as it attempts to find a small space (attractor) where the really important weather is occurring. Preliminary results suggest that this is indeed possible, and future research will address the question of how long one can trust the weather forecasts, referred to as the predictability of weather, before it becomes chaotic and unreliable. In addition, an important aspect of this research is addressing ways to treat non-Gaussian errors, as most of the real-life problems are behaving in nonlinear and complex manner which follows non-Gaussian error statistics.

Ensemble forecasting is being used operationally today, which uses a set of suboptimal initial perturbations that do not take into account the true uncertainty of the current atmosphere. The explicit knowledge of this uncertainty is achieved by combining the uncertainties in model and in observations, through ensemble data assimilation. These two components, the ensemble forecasting and ensemble data assimilation, are being incorporated into CIRA's EnKF system.

Model error estimation (supported by NSF-Carbon Science, DoD-CG/AR, NASA/ Carbon Science, NASA/TRMM, NOAA/ GOES-R):

This research project started in 2001. Methodology to estimate and correct errors in forecast models is continuously being developed and improved. This methodology is similar to standard data assimilation methods, but it uses (assimilates) observations to estimate and correct errors in forecast models. The model error estimation method was examined in application to the RAMS atmospheric model using a variational data assimilation approach, in collaboration with Milija Zupanski and Tomi Vukicevic, during the period 2001-2003. Since 2003, the model error estimation method is being further refined and examined in various applications of ensemble-based data assimilation. In collaboration with Milija Zupanski, Mark DeMaria, Louie Grasso, Arthur Hou from NASA, Chris Kummerow and Scott Denning from the CSU/Atmospheric Science Department, this research is currently being applied to various atmospheric and carbon transport models under TRMM Program, GOES-R Risk Reduction Program, and North American Carbon Program.

Information theory and ensemble data assimilation (supported by NASA/TRMM, NOAA/GOES-R):

This is a new research project, started in 2004. The goal of this research is to develop practical methods to calculate how much information, which is above the noise level, can be obtained from various atmospheric observations. A general framework linking information theory and ensemble data assimilation has been proposed and is currently being examined in various applications. An important application of this framework lies in estimating value added of satellite observations for the current and future satellite missions. This research is being performed in collaboration with Milija Zupanski, Mark DeMaria, and Arthur Hou from NASA under TRMM Program and GOES-R Risk Reduction Program.

CIRA's data assimilation work was the first to incorporate satellite data into numerical models-in the presence of clouds. All other work assimilated satellite data only in cloud-cleared regions.

Chapter 5: *CIRA/National Park Service Air Quality Research*

CIRA manages the IMPROVE network – the longest standing haze observation in the United States.

Since the early 1980s CIRA has supported a visibility research program funded by the National Park Service and directed by Dr. William Malm. Through the years, this group has conducted research which has helped in formulating and implementing the Clean Air Act mandate to protect the air quality and visual resources of national parks and wilderness areas, so-called Class 1 areas. In April 1999 the Environmental Protection Agency (EPA) promulgated regional haze regulations (RHR). These regulations require that states (and Indian tribes) develop plans (subject to 10-year review and revision) which will show reasonable progress toward returning "natural" visibility conditions to these pristine areas over the next 60 years.

NPS/CIRA researchers have been instrumental in advancing the science and developing the methodologies enabling these regulations. Past accomplishments include developing the appropriate metrics to use for characterizing visibility, determining the most appropriate instruments to measure visibility for this application and designing and implementing the national monitoring network for visibility, the Interagency Monitoring of PROtected Visual Environments (IMPROVE) network. In addition to research on the IMPROVE network, the group conducts special studies, generally associated with specific national parks, that aid in understanding relative contributions of pollution sources to visibility. Recently the group has simulated regional air quality using models of the distribution and chemical transformation of pollutant gases and particles. These models, driven by other models of the regional meteorology, require a very complex inventory of pollutant emissions from all of the sources of pollution in the region.

Currently, the NPS/CIRA group has been developing expertise in designing and implementing web based data analysis and technical support systems. For example, the group has designed and implemented the Visibility Information Exchange Web System (VIEWS); the official IMPROVE website and a new air toxics data archive. The NPS group is among the nation's leaders in air pollution research, especially for aerosols and their effects on visibility and other air quality related values. Current research in model evaluation and validation is setting the standard for air quality applications internationally. The web systems implemented by the group are receiving increasing attention and becoming a standard for providing technical air quality information.

In the following we will provide an overview of visibility and air quality, discuss recent activities with the IMPROVE monitoring network, with special studies aimed at characterizing (measuring and simulating) regional haze in a specific locations and describe recent work the NPS/CIRA group has undertaken in developing and presenting web based data archives and analysis systems. We conclude with a brief description of some anticipated future research for the NPS/CIRA group.

What Air Quality Problems Do We Address?

Since the mid 1970s people have been increasingly concerned that the quality of air in parts of the United States that should be clean, especially national parks and other types of wild or wilderness lands, is not as clean as it should be. This concern was formalized into law when Congress passed the 1977 amendments to the Clean Air Act. The Act had long recognized the need for citizens to be protected from unhealthy levels of air pollution and established a legal framework for states to regulate this air pollution. However, the 1977 amendments further established the principle that air quality in areas of the U.S. where it had not yet deteriorated to unhealthy status also should be protected. Specifically it established a permit program requiring extensive analysis and the use of "best available control technologies" before new pollution sources could be located in such areas.

Further, partly in response to testimony from western landscape photographer Ansel Adams, Congress set a goal of remedying any existing visibility impairment in the cleanest areas, those areas the Act designated as Class 1 areas. Class 1 areas consist of federally-managed national parks and wilderness above certain size classifications. Specifically, 156 areas have been designated, mostly in the western U.S., where visibility values should be protected.

Since visibility protection was established in 1977, the National Park Service has led the effort to translate this general goal into practical terms and specific actions to control both existing and newly proposed pollution sources. The NPS/CIRA research team was established when National Park Service scientist Bill Malm moved to CIRA in 1980, shortly after CIRA was formed. He created a NPS/CIRA team which has been instrumental ever since in accomplishing this national goal of visibility protection.

Through the years a number of unique and evolving technologies and research efforts have been undertaken by the group. Initially, work focused on identifying and classifying types of visibility degradation. This led to distinguishing "plume blight" from "regional haze." Plume blight, as the

FLASHBACK: CIRA newsletter, Volume 15: Spring, 2001

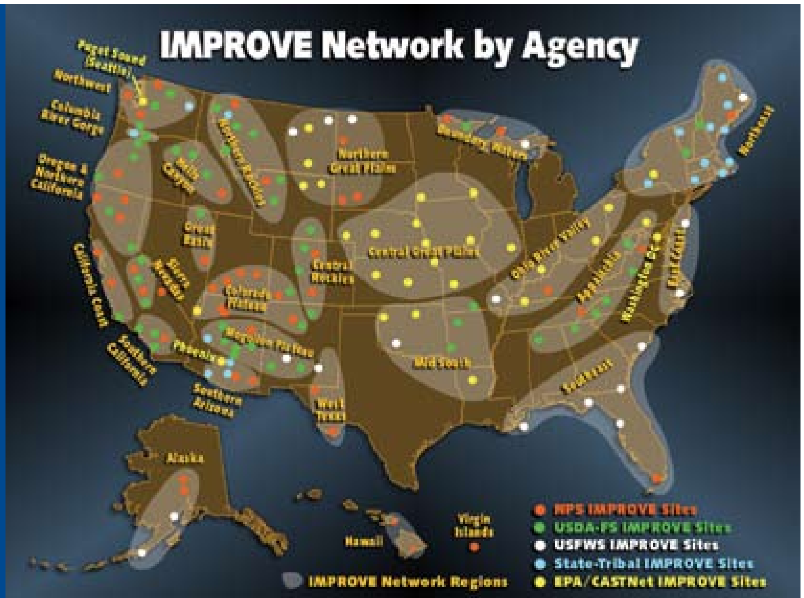
IMPROVE and WRAP Launch New Websites

In the 1990 Clean Air Act, a Grand Canyon Visibility Transport Commission (GCVTC) was established to identify causes and develop strategies to improve visibility degradation in the Grand Canyon and nearby Class I areas. In 1997 the western states, tribal governments and federal agencies formed the Western Regional Air Partnership (WRAP) to implement recommendations from the GCVTC and deal with other regional air quality issues. In 1999, the EPA issued regional haze regulations that require states and tribes to develop and implement strategies to improve visibility in Class I areas, based on IMPROVE program data.

These recent developments imply a need for new approaches for disseminating IMPROVE information. First, the regional haze rule has expanded the focus of IMPROVE from its original purpose as a scientific database to that of assuming added regulatory responsibilities. To support regional haze rules, the IMPROVE monitoring network needs to have openly documented QA/QC procedures and results, and the data needs to be as widely and easily available as possible. In addition, states and tribes new to the issue of regional haze need background information about visibility science, history and regulations. Secondly, WRAP has determined there is a need for air quality and related information to be made readily available to all of their partners through a web-based, interactive database.

To support these needs, two new websites are under development by CIRA staff. The IMPROVE website is focused on delivering IMPROVE data and general information about visibility science and regulations. The WRAP website, being developed for WRAP's Ambient Monitoring and Reporting Forum, is focused on providing visibility, air quality and meteorological data to WRAP partners in an online database. The IMPROVE data are central to both websites. Therefore, the co-development of the websites is mutually beneficial with WRAP benefiting from the database development for the delivery of the IMPROVE data, and the IMPROVE website benefiting from the integrated WRAP database and data visualization tools to be developed.

– Bret Schichtel and Doug Fox



name implies, can be associated with a specific source or sources. Early work by the group included extensive field measurement campaigns designed to quantify the causes of plume blight and to support efforts to retrofit control technologies for the worst offenders. Much of this research focused on the visually stunning resources of the southwestern U.S. More recently, the NPS/CIRA team has addressed its work to regional haze. This research has included developing a metric for meaningfully defining levels of impaired visibility, designing and implementing a national scale monitoring program (IMPROVE) to characterize its spatial patterns and how they change over time. With the promulgation of the regional haze regulations in 1999, this research monitoring network took on formal legal/regulatory significance, vastly expanded and has become a focal point for identifying the baseline and trends for future visibility impairment.

A constant concern of the group has been the development of measurement technologies to aid in the quantification of visibility impairment. These technologies have taken two fundamentally different paths. One track has involved optical measurements of different aspects of visibility, and the other focused on collecting air samples and quantifying chemical constituents of the aerosols present. Early research on optical measurements was quickly transitioned to a Fort Collins engineering company, Air Resource Specialists (ARS), Inc., whose employees have continued to collaborate closely with the NPS/CIRA group. The second track led to the establishment of the IMPROVE monitoring network. This network now determines the formal measure of visibility and represents the basis of the regional haze regulations.

IMPROVE Monitoring Network

IMPROVE and related monitoring currently consists of a network of 177 sites where aerosol data are collected regularly. The network has expanded to this number from its original 70 sites when the regional haze regulations were enacted. Of these sites, 110 are specifically designated IMPROVE sites located to represent Class 1 areas. The other 67 aerosol samplers sites are located by state, tribal and local air quality agencies to collect additional data. The general goal of the IMPROVE network is to measure and carefully quantify the ambient aerosol content in the air. To this end the IMPROVE sampler collects a volume of ambient air for 24 hours each third day. This air sampler is designed to collect all the particulate material in the air that is smaller than 2.5 micrometers in diameter (so-called PM2.5) on filters, which are then analyzed to identify the amount and chemical makeup of all these aerosols.

To relate these chemical measurements to visibility, the IMPROVE equation has been developed. This equation relates the measured concentration of various chemical aerosol constituents to the extinction coefficient, a measure of how far light travels in the atmosphere. To provide a continuous check on how well the IMPROVE equation works, there are 15 transmissometers (an

FLASHBACK: CIRA newsletter, Volume 16: Fall, 2001

Regional Haze

Recently, visibility protection has gained importance through promulgation of regional haze regulations. Because regional haze results from many different emissions transported over long distances, EPA and the air agencies have decided to conduct haze technical support regionally, and have formed five Regional Planning Organizations (RPO) to carry it out.

The results of IMPROVE visibility and aerosol monitoring have clearly established that all Class I areas in the United States experience impaired visibility due to regional haze. IMPROVE measurements have become the official tool for determining the status of visibility and tracking progress toward improving it. Mixed, well-aged aerosols from a wide variety of sources cause regional haze. Primary causes of haze include scattering by ammoniated sulfate, ammonium nitrate, organic carbon, soil and coarse mass, and adsorption by elemental carbon or soot. The sulfates and nitrates are hygroscopic, i.e. they attract so much water that a relative humidity factor needs to be considered. Regional haze is sufficiently well-characterized by this set of six visibility components that the EPA has based their new regulatory program on it.

CIRA scientists are working with the EPA to ensure that the IMPROVE data are sufficiently quality-assured to be used for this important regulation. They are helping EPA develop the appropriate calculation procedures and are assisting in evaluating and documenting them. Over the past year, the CIRA air group has conducted training sessions for three of the Regional Planning Organizations and developed training material to support the regulations.

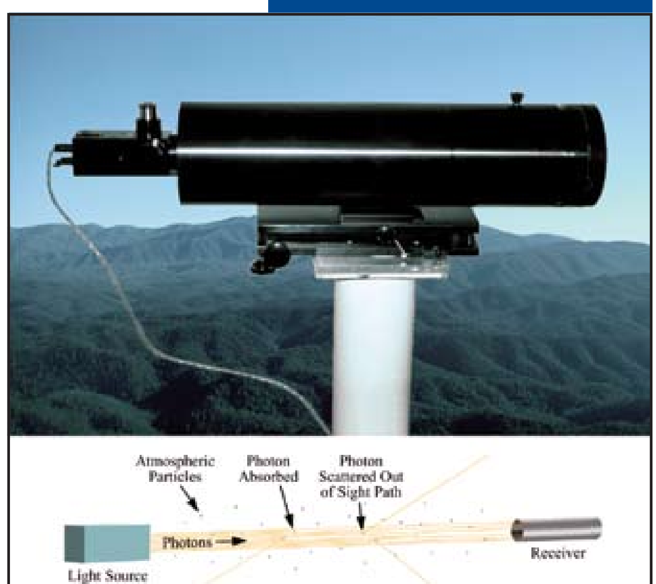
– Doug Fox

instrument that provides a direct measure of the extinction), 44 nephelometers (an instrument that provides a direct measure of the scattering a major component of extinction), 11 film or digital camera systems and 51 Web camera systems to supplement the aerosol data collection.

The aerosol particles less than 2.5 micrometer in diameter are collected on Teflon, nylon and quartz filter substrates so that they can be subjected to a variety of chemical analyses. These analyses yield data allowing an approximation of the chemical nature of the particles to be determined. This chemical speciation has been essential in establishing the relationship between pollution sources and their final impact on visibility even after hundreds to thousands of kilometers of transport and both photochemical and aqueous phase transformations.

The logistics of the IMPROVE network are complex. The aerosol samplers are constructed, deployed, operated and quality assured by a team of scientists from the University of California in Davis. Filters are analyzed at three different laboratories; one at UC Davis, one at the University of Nevada's Desert Research Institute and one at the Research Triangle Institute. Optical instrumentation is deployed, operated, quality assured and analyzed by Air Resources Specialists, Inc. NPS/CIRA staff are responsible for quality assurance of the combined data set, including calculation of reconstructed extinction, various comparisons within the analyzed data (e.g., reconstructing the total mass measured from among the constituent elements) and comparisons with the optical measurements.

In addition to their role in quality assurance, NPS/CIRA staff archive



Transmissometer

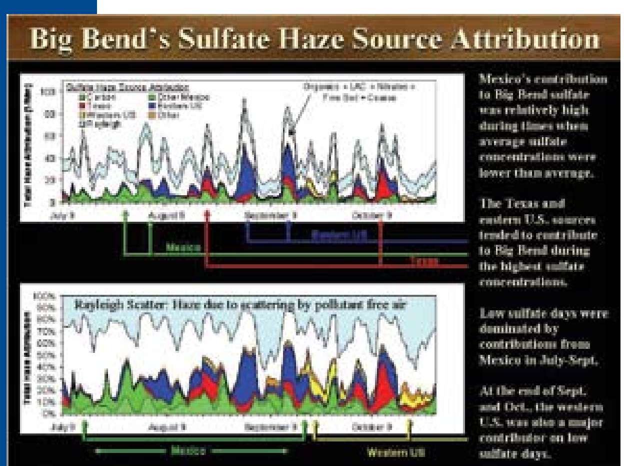
The extinction coefficient is a measure of how many photons are scattered or absorbed by a concentration of particles, and is expressed as a number proportional to the amount of photons scattered or absorbed per distance. The sum of scattering and absorption, referred to as extinction or attenuation, is measured by the transmissometer. An incandescent lamp is usually used as a light source, and the receiver is a telescope fitted with an appropriate detector. The light source and detector can be placed 1-10 kilometers apart, and the measurement is usually referred to as long-path measurement.

the IMPROVE data and make it available to its user community through the IMPROVE web site. The IMPROVE database enables verification of the most recent cuts in emissions as well as continued progress toward the national visibility goal.

The list of NPS/CIRA staff members involved in this activity includes NPS scientists Bill Malm, Kristi Gebhart and Bret Schichtel and CIRA researchers Jenny Hand, Linsey DeBell, Scott Copeland, Rodger Ames and Shawn McClure. Close collaboration has also involved CSU faculty in the departments of Atmospheric Sciences (Jeff Collett and Sonia Kreidenweis) and Statistics (Hari Iyer) and employees of ARS, Inc.

Special Studies

Through its 25-year history, the NPS/CIRA group has participated in a number of special studies. Under the original visibility regulation (promulgated by the EPA in 1980) source attribution analyses were required for



Class I areas where it was believed that one or more sources substantially contribute to visibility impairment. When routine monitoring data are insufficient for the attribution analysis, the NPS/CIRA group conducted special studies. These studies were designed to obtain the necessary air quality, meteorological, and emission data to identify the sources contributing to visibility impairment as well as their frequency, duration, and contribution to impairment. In addition to this formal source attribution, special studies have been performed to enhance the science of visibility monitoring and learn about aerosol physio-chemical-optical properties. Some of the NPA/CIRA studies are listed below.

The Winter Haze Intensive Tracer Experiment (WHITEX) – This project was established to study the visibility impacts of emissions from the Navajo Generating Station. The database contains data from 13 locations which sampled from January 1 to February 18, 1987. Samples were collected every 6, 12, and 24 hours depending on the site and sampler. The particulate samples were analyzed for PM2.5 mass and its elemental constituents, organics, ions, and light absorption.

The Navajo Generating Station Visibility Study (NGS) – The NGS Visibility Study was conducted by the Salt River Project, the operators of NGS, from January 10 through March 31, 1990. Its purpose was to address visibility impairment in Grand Canyon National Park during the winter months and the levels of improvement that might be achieved if SO2 emissions from NGS were reduced. The study was performed to provide input to the rulemaking process of the EPA regarding NGS SO2 controls. Perfluorocarbon tracers (PFT) were released from the three stacks of NGS. Surface and upper air meteorology, particle and gaseous components, and tracers were measured at many sites. The study concluded that the NGS plume was not present at Hopi Point for most of the days. The tracer data quality from this experiment was insufficient for quantitative source apportionment and the results emphasized the need for better tracer measurements in future studies.

FLASHBACK: CIRA newsletter, Volume 12: Fall, 1999

BRAVO: Big Bend Regional Aerosol and Visibility Observational Study

Since the mid 1980s the NPS has been concerned about air pollution from sources located in Mexico that may impact visibility in parks of the southwestern United States. CIRA has joined with the NPS, the CSU Atmospheric Science Department and the Environmental Protection Agency to conduct the Big Bend Regional Aerosol and Visibility Observational Study (BRAVO) in order to understand the causes of visibility impairment in the park, identify the sources responsible, and provide a scientific basis for informed bi-national policy decisions regarding trans-boundary air pollution between the U.S. and Mexico. Study objectives are to:

- Quantify the impacts of major sources (or source regions) in both the U.S. and Mexico on Big Bend haze including: carbon I/II power plants in Mexico; industrial source areas on the Texas gulf coast and in Monterrey and Tula, Mexico; coal-fired power plants and refineries in Texas; and large sulfur dioxide source regions in the southeastern and midwestern U.S.
- Determine the chemical constituents of Big Bend haze
- Determine the role of meteorology on Big Bend haze
- Identify the most likely pollutant transport corridors associated with Big Bend haze
- Assess the changes to Big Bend haze levels that would result from emission controls.

The BRAVO study is expected to cost about $7 million. The monitoring program ran from July to October 1999, and preliminary data analysis should be completed within a year.

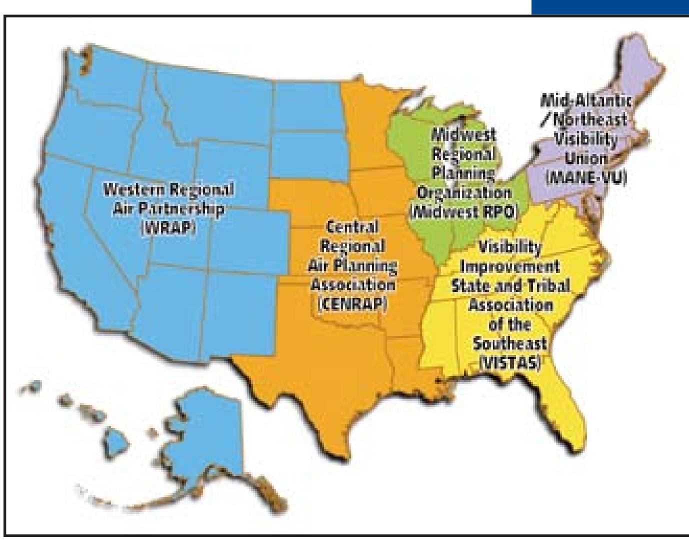
– Julie Winchester

The Pacific Northwest Regional Visibility Experiment Using Natural Tracers (PREVENT) – This project was established to study visibility causes and effects in Washington state, west of the Cascades. The network consisted of 34 monitors located in Washington and Oregon. Daily particulate samples were collected from June to September, 1990, and analyzed for PM2.5 mass and its elemental constituents and light absorption.

Measurement of Haze and Visual Effects (MOHAVE) – This study was established to help determine the contributions of the Mohave power generating station (located in southern Nevada) and other sources to haze in Class I areas of the Southwestern U.S. The MOHAVE network employed 43 IMPROVE type samplers in the Southwest, collecting daily particulate samples over a 24 hour period. The network collected data over a winter and summer period from January 10 to February 15, 1992 and July 11 to September 2, 1992. The particulate samples were analyzed for PM2.5 and its elemental constituents, organics, ions, light absorption and PM10.

The Mount Zirkel Visibility Study (MZVS) – This visibility study was designed to determine the extent of visibility impairment at the Mt. Zirkel Wilderness Area in northwestern Colorado and contribution of the major sources responsible for any visibility impairment. Measurements to address these objectives were made during a one-year period, starting in December 1994.

South East Aerosol and Visibility Study (SEAVS) – This study measured aerosols under humid Southeastern U.S. conditions to determine the contribution



Regional Planning Organizations.

Joshua Tree National Park (JOTR) camera monitoring.

of major aerosol constituents, including water, to the total particle mass and light extinction. Field measurements included particle size, water and optics, aerosol composition, meteorology and human perception of scenes at the Great Smoky Mountains National Park over a 6-week period during the summer of 1995.

Big Bend Regional Aerosol and Visibility Observational Study (BRAVO) – This international study with Mexico, mandated by the NAPAP treaty, was designed to investigate the causes of haze at the Big Bend National Park located on the border between Texas and Mexico. A measurement network was operated from July to October, 1999, measuring fine aerosol mass and its constituents, atmospheric optical properties, gaseous air pollutants and meteorology at Big Bend. Subsequent to the field program a major data analysis and regional air quality modeling effort was undertaken by the NPS/CIRA group and other collaborators.

One result from the study is illustrated below. This figure characterizes the contribution to visibility impairment from sources of sulfate pollution (primarily emitted from power plants and other large industrial sources) at Big Bend National Park resulting from different geographic regions: larger scale boundary conditions (generally outside North America), the western U.S., the eastern U.S., Mexico and Texas. This analysis involved the application of regional air quality simulation modeling in turn consisting of: a mesoscale meteorological simulation model (the community version of the Penn State-NCAR MM5); a regional atmospheric chemistry model (the REMSAD model); and a variety of apportionment modeling techniques to quantified the source-receptor relationships.

NPS/CIRA staff involved in the BRAVO study included NPS scientists Bill Malm, Kristi Gebhart, Mike Barna and Bret Schichtel and CIRA researchers Derek Day, Jenny Hand, and Marco Rodriguez. Close collaboration also involved CSU faculty in the departments of Atmospheric Sciences (Jeff Collett and Sonia Kreidenweis) and in Statistics (Hari Iyer), employees of ARS, Inc., Marc Pitchford from NOAA/EPA and a wide range of other groups.

Web-Based Data Archives and Analysis Systems

The regional haze regulations have spawned requirements for region wide analysis of air pollution sources and their impact on Class I area visibility. In a sense, the type of work done by the BRAVO study for Big Bend National Park in Texas is now being done for each of the 156 Class I areas through the U.S. This effort is being organized and managed by five Regional Planning Organizations (RPO) which have been established for this purpose. The map below shows the geographical location of each RPO.

Originally under funding from the Western Regional Air Partnership (WRAP) and eventually for all of the RPOs, the NPS/CIRA group is continuing to develop and support the Visibility Information Exchange Web System (VIEWS), a linked database and web site. VIEWS supports the regional haze regulations by providing a comprehensive database of ambient aerosols and air quality data from over 20 different networks covering the United States.

VIEWS provides a comprehensive on-line delivery of the data and on-the-fly comparisons and calculations of composition, trends, and back trajectories, as well as a host of other tools to aid the air quality monitoring component of the analyses conducted by the RPOs. For example, a screen shot of VIEWS illustrates a contour map of the monitoring network along with the composition of one of the sites, which is easily generated on the fly by the VIEWS web system, shown below.

The VIEWS approach to data base archival and analysis has recently been adapted by the NPS/CIRA team to other web sites. For example, much of the functionality contained in the IMPROVE web site is based on the VIEWS architecture and recently the group has developed a similar web data system for the Air Toxics program of the U.S. EPA.

NPS/CIRA staff members involved in the development of web data archival and analysis systems include NPS scientist Bret Schichtel and CIRA researchers Doug Fox, Rodger Ames and Shawn McClure.

Future Research

Among the high priority challenges facing the visibility research community are sorting the impacts of nitrate and of carbonaceous aerosols on visibility as well as identifying options and opportunities for reducing their emissions.

Under the leadership of NPS scientist Mike Barna, the NPS/CIRA group is continuing to develop regional

FLASHBACK: CIRA newsletter, Volume 23: Spring, 2005

The Visibility Information Exchange Web System (VIEWS)

The Visibility Information Exchange Web System (VIEWS) is an online system designed to acquire, manage, and provide access to data and metadata related to visibility and air quality, specifically to support the efforts of five Regional Planning Organizations (RPOs) in meeting the requirements of the Environmental Protection Agency's Regional Haze Rule. The Rule requires states and tribes to develop and implement plans to reduce the pollution that causes visibility impairment in 156 national parks and wilderness areas designated by the Clean Air Act as Class I areas, to achieve natural visibility conditions (no manmade visibility impairment) by 2064.

The primary purpose of VIEWS is to aid RPOs in the analysis and interpretation of air quality data so they in turn can provide technical support to the states and tribes. The IMPROVE dataset has regulatory significance under the Regional Haze Rule, and VIEWS provides access to custom IMPROVE data products. VIEWS makes these and a variety of supporting datasets available via a web-based interface that includes ad hoc query and custom display tools. The fully developed database behind VIEWS is customized to provide web access to air quality data and facilitate the import and quality control of new datasets.

VIEWS is designed and funded to support all of the regional planning organizations but it had its start as an activity of the Western Regional Air Partnership (WRAP). Since more than 75 percent of the pristine national parks and wilderness areas are located in the West, WRAP has the biggest job of all the RPOs. WRAP is made up of 14 western states, numerous tribes, and federal agencies. The WRAP region includes the states of Alaska, Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, North Dakota, Oregon, South Dakota, Utah, Washington, and Wyoming. Over 400 federally-recognized tribes and Alaska native villages within the WRAP region are equal partners in the regional haze planning process. Federal participants are the Department of the Interior (National Park Service and Fish & Wildlife Service), the Department of Agriculture (Forest Service), and the Environmental Protection Agency.

One measure of a successful website is the amount of visitor traffic it receives. To date, the VIEWS website is averaging about 500 unique visitors per month from more than 90 different countries. In addition, over 50 other websites have links directing their visitors to the VIEWS website. VIEWS web-based tools and database capabilities continue to evolve in response to feedback from VIEWS users and stakeholders.

– Rodger Ames, Doug Fox, Shawn McClure, Tom Moore, Bret Schichtel air quality modeling experience and expertise. Researchers are conducting regional modeling for anticipated new air pollution sources to better assess their potential to impact Class 1 areas.

Determining to what extent wildfire impacts visibility and sorting out just how much of it is “natural” represents is difficult task. This question is being addressed using a number of the tools developed by the NPS/CIRA research group. Recently, under the leadership of NPS scientist Bret Schichtel CIRA has been funded by the Joint Fire Sciences Program (JFSP) of the Departments of Agriculture and Interior to develop improved source apportionment tools for application to wildfire impacts. Similarly, the JFSP has accepted a comprehensive proposal directed by NPS scientist Bill Malm in collaboration with Atmospheric Sciences Professors Collett and Kreidenweis to conduct a series of experiments, both in the field and in special laboratory conditions, to further characterize emissions of aerosols and volatile organic compounds which have the capacity to generate added aerosols in the atmosphere, and to study their physical, chemical and optical properties.

Recently, the WRAP has involved the NPS/CIRA group in developing a more comprehensive web based data archive and analysis system. This site will essentially be a technical support system delivering the data and analyses needed by WRAP supporting states and tribes in implementing the regional haze regulations. This involves a significant conceptual expansion of the VIEWS database design to incorporate emissions data and modeling results in such a way that analysts can construct comprehensive comparisons and deliver them in publication ready formats. This work is led at CIRA by Shawn McClure and Rodger Ames.

In an attempt to assess the complex roles that nitrogen-based atmospheric compounds play in impacting visibility and other air quality related values at Rocky Mountain National Park, NPS scientist Bill Malm is organizing a comprehensive field study including monitoring and modeling efforts scheduled to take place over the next three years in the front range of Colorado.

FLASHBACK: CIRA newsletter, Volume 18: Fall, 2002

Images of Smoke and Fires from MODIS and GOES

Data from both the MODerate-resolution Imaging Spectroradiometer (MODIS) and the Geostationary Operational Environmental Satellite (GOES) were used to view the forest and range fires in the western U.S. during the summer of 2002. The diversity of bands on MODIS and GOES allows many types of atmospheric and surface features to be seen. Often these features are detected more readily by differencing the spectral band images to reveal the details of interest.

MODIS data are available from NASA’s Earth Observation Satellite (EOS) AM-1 Terra (launched in 1999) and EOS PM-1 Aqua (launched in 2002), both in low-earth polar orbit. Imagery is available at 1 km (infrared) ground resolution but 12 hour temporal resolution from each satellite. The MODIS instrument contains 36 spectral bands. Half of the bands are in the visible and near infrared portion of the spectrum, and the other half are in the shortwave and longwave infrared. GOES Imager data are available from GOES-8 (east) and GOES-10 (west) in much higher geostationary orbit. Imagery is available in 5 spectral bands (much broader than MODIS bands) at 4 km (infrared) ground spatial resolution every 15 minutes from each satellite.

While GOES data are available with high time frequency for viewing fires and smoke, MODIS data offers an increased number of spectral bands to help reveal details and variations in the smoke plumes and their associated fires. These multi-spectral data are continuing to be explored for smoke and fires and other atmospheric and surface features that are not as easily detected with fewer spectral bands.

– Don Hillger

CHAPTER 6: *CIRA Science Support Activities*

Science support at CIRA was formally recognized by NOAA during CIRA's 2003 Five-Year Review as a meritorious effort worthy of special note. These activities can generally be divided into three areas:

1. Satellite earth station and data ingest
2. Low cost methods of data archival and manipulation including serving data to the scientific staff.
3. Innovative approaches to combining satellite data from different satellite platforms with conventional weather observations and modeled data.

CIRA science support activities have provided several significant achievements, which have been recognized at the national level.

1. With a small development budget and only two engineers, CIRA produced the first after-launch GOES-GVAR imagery for GOES-8 and 9. CIRA provided these images to NESDIS for release though their public relations department to the national press.
2. Using an innovative approach for PC exploitation, personal computers were netted together. CIRA developed an ingest and analysis system for NESDIS for the new AMSU A/B data stream soon after this instrument was launched.
3. CIRA has developed the CloudSat Data Processing Center (DPC) system to support this important NASA satellite mission. Recognized by NASA as highly innovative and creative, the DPC system provides unprecedented flexibility in configuring for new data products, input data streams, and even new satellite data opportunities.

CIRA's Science Support of ISCCP since 1983:

The idea for the International Satellite Cloud Climatology Project (ISCCP) was initiated by Vonder Haar and Paltridge in 1979. CIRA began collecting GOES 6 data for ISCCP in July 1983. During the 1980s, ISCCP represented quite an ambitious computer project, involving the processing of more than 1 gigabyte of data per day. We employed students, programmers and researchers in the day-to-day task of mounting data tapes and quality controlling the data.

It was often necessary to reposition the receiving antenna to track the satellite. We even put together a backup antenna by mounting a surplus radar dish on a dump truck. It was then possible to reorient the antenna by driving the truck or tilting the bed. Although this worked, luckily the 15-meter dish was very reliable and the backup was not often required.

As ISCCP continued, the U.S. received a variety of geosynchronous satellite views of western North America. Thanks to the efforts of Don Reinke, the 10-meter C band antenna was installed and used to collect Meteosat 3 data for ISCCP. Data has been collected for ISCCP from GOES 7, 8, 9, 10 and 12. CIRA scientists also worked with the National Center for Atmospheric Research (NCAR) to prepare some INSAT data for ISCCP.

With advances in computer technology and stability of the satellites ISCCP data is now processed with relative ease. The project has progressed to enable the study of many cloud processes and allows a search for systematic changes in the cloud cover over time. Those primarily responsible for ISCCP over the years were G. Garrett Campbell, Bill Davis, Kelly Dean, Tom Vonder Haar and Dave Watson. The engineers maintaining the ground station included Mike Hiatt, Karll Renken, Mark Witcomb and Duane Whitcomb. Thanks are due to NOAA for funding CIRA as part of this international effort.

– G. Garrett Campbell

Computer equipment at CIRA in the 1980s.

One of CIRA's primary research goals, to use multi-platform, multi-sensor approaches to solve atmospheric science questions, is highly dependent on a robust, low-cost computer infrastructure.

The DPC has been designed to provide easy inclusion of scientist-produced algorithms directly into the operational system while maintaining proper configuration control and system reliability. Several future NASA missions are contemplating using CIRA's approach for their ground support systems. The Langley DAAC is incorporating several DPC features into their A-Train data system.

Specific examples of the work in this dynamic area follow.

Earth Station and Satellite Ingest

Prior to the creation of CIRA and continuing today, there has been a race between satellite data sensor volume and ground-based data processing technology. In the 1980s, the new GOES satellite sensors were sending more data than early 1980 technology could process. CIRA installed major infrastructure components, such as a 10-meter antenna, in order to capture the data. It was not until the late 1980s that CIRA possessed sufficient computer resources to do more than produce images on a COMTAL imaging system.

In the late 1980s, CIRA spent a major percentage of its total budget on computer leases, maintenance contracts, and custom hardware required to convert the satellite data stream into digital information recognizable by computers. It cost several million dollars for CIRA to process and store images at approximately 20 GB a day on Exabyte tapes. The figure at left illustrates the computer equipment used to perform these modest functions. As an interesting side note, all of the equipment pictured can easily be replaced by a single low-cost PC today.

Currently, CIRA spends less than four percent of its budget on infrastructure, which includes the collection, analysis, storage, and distribution to scientists of data from six satellites and over 200 desktop computers. This is all done with a staff that has decreased from eight to two. With this small staff, CIRA:

1. Provides higher reliability (collecting over 99% of the available satellite data, with the one percent loss mostly due to extended power outages)
2. Provides tailored products and sectors to researchers
3. Stores all data in a reliable, validated, low cost DVD-based system
4. Provides a computational resource with over 2000 times more capability than in 1980 (Moore's law would predict a 170-fold increase in capacity for the 20-year period.)
5. Provides system monitoring 24 hours per day through automated monitoring and notification systems.

This increase in productivity in the infrastructure support is only partially explained by the increase in computer capability and lowered costs during the last 20 years. Some of the innovative processes used by CIRA to achieve these levels of support include:

1. Inexpensive, self-maintainable PC computers were used to replace highly expensive name-brand workstations, both in the earthstation and on the desktops.
2. CIRA standardized all computers to use a single operating system so that

An Evolution in Technology at CIRA

Two of my long-term major projects at CIRA were the introduction and integration of the personal computer and the development of key earthstation technologies. In the 1980s, CIRA used mainframe computers. These expensive computers required special environment rooms and maintenance contracts to keep them operating. Additionally, only the scientific staff used these computers. The administration personnel used other computers for word processing. This made it very inefficient to get science documents converted to the administrative computers for publication. When the personal computer was introduced, I saw an opportunity to change this topology. These personal computers were inexpensive, relatively powerful, self maintainable, and in most cases had improved software applications. These computers quickly spread to each employee's desk, and soon all personnel used the same software platform. Today, this topology is widely used in large peer-to-peer networks and considered common. However, CIRA was early to demonstrate that the PC put CIRA ahead of the cost/performance ratio, pushing CIRA science to new levels with smaller technology budgets. These PCs have not only dominated the desktops; today they are being used in large clusters to perform mainframe-type computations.

CIRA also was a pioneer in earthstation technology. In the late 1980s and early 1990s, CIRA was one of the few organizations able to collect, process, and display large amounts of meteorological satellite data. In particular, I developed the first single-chip hardware processing board, which greatly simplified the earthstation design process. In later years, besides many optimizations, I developed the first automatic robotic DVD archive system for automatically archiving this satellite data. Today, CIRA collects and archives data from several satellite sources with a very minimal staff. Recently, NASA selected CIRA as a key data processing center, due in part to these innovations.

– Michael Hiatt

data exchange, support, and maintenance were significantly reduced.

3. A CIRA-developed NETMON program was deployed to monitor every computer, server, and ingest system in CIRA, and to notify staff of high priority outages via e-mail.
4. A "build-your-own" philosophy emerged. CIRA determined that the cost of creating generic computer systems with standard parts and subsystems was less than buying the ready-made systems currently available. Although initial costs might be higher due to CIRA's choice to use better quality parts, the ability to upgrade and reconfigure systems over time (rather than discarding entire obsolete systems in a year or two) leads to lower total costs. The use of generic parts means that repair time is measured in hours, rather than days.
5. Custom systems such as RAID towers are employed only where highly reliable data and systems are needed.
6. Data sharing and support to scientific customers is much improved since all PCs are configured to build their own custom data sets, read stored data on standard DVD platters, and use standardized tools to navigate, calibrate, and manipulate data.

Infrastructure Activities in Boulder

CIRA's Data Systems Group at the Forecast Systems Laboratory (FSL) in Boulder designed and developed new software to streamline the acquisition and processing of data. This new software was created using object-oriented

Another Witness to Change Over the Years:

I have seen the transition of the CIRA Earthstation from a cluster of DEC workstations to the current Windows PC network.

As a student hourly in early 1988, I was involved in helping Nan McClurg with the daily operations of archiving satellite data on our VAX/VMS systems. I would read and write data to 9-track tapes while I did my homework in the Atmospheric Science computer lab.

In 1998 as a full-time software engineer, I had the opportunity to assist Duane Whitcomb in the development of the first true real-time GOES data collection system. The software to simultaneously process, write, and transfer data was developed on our Windows PC network.

One of the more innovative and useful products that I developed with Michael Hiatt at CIRA is called LANreporter. This software was designed to monitor computers and directories in our Windows network and notify the appropriate users via e-mail and webpages when problems occur. LANreporter has enabled us to effectively manage our growing PC network.

Last year I was the lead programmer supporting Michael Hiatt in the development of the Meteosat Second-Generation (MSG) data collection system. The improved Meteosat images from this system have allowed meteorologists to provide more accurate medium and short-term weather forecasts.

Currently I am working with Phil Partain to develop software for the CloudSat Data Processing Center. I have designed and implemented the Ingest System that will transfer and process raw CloudSat data, Stored State of Health (SSOH) data, Definitive Ephemeris tables, and other data sources to create the initial 1A-CPR and 1A-AUX products to be used in creating all of the subsequent Level 2 products. I also have worked with Phil to create the CloudSat Data Ordering System webpages for distributing data to the science team and the general user community.

– Dale Reinke

methods to reduce maintenance and to allow for the generic handling of data types, thereby shortening the development time for decoders and translators by an order of magnitude. Multiple computers operate in a distributed, event-driven environment known as the Object Data System (ODS) to acquire, process, store, and distribute conventional and advanced meteorological data. These data services are provided to scientists and software developers who use them in various modeling, application, and meteorological analysis/forecast workstation research and development activities. An example of the enhancement is the implementation of new ODS-based methods for transferring real-time datasets to the Mass Store System (MSS). This new system tars and compresses multiple data files before they are moved to the MSS, thus greatly reducing the number of individual files transferred.

CIRA scientists with the Advanced Computing group at FSL also collaborated on the design and development of a prototype WRF Portal – a Java-based GUI front end for running WRF. The design incorporates a mySQL database, Java application, and communication protocols between the client side application, WRF Portal, and server side workflow manager/job scheduler. The grid portal is expected to simplify the development, test, and verification of the WRF model. The portal will allow users to submit jobs from nodes anywhere on the grid. The jobs are able to execute on any of the grid compute clusters. Needed data can be staged to and/or from the remote clusters. Development of the portal is being explored as a way to simplify testing, share research results, and apportion compute and data resources with collaborating agencies.

CLEX Activities

Adam Kankiewicz

The most memorable CIRA-related work I have been involved in has been the Cloud Layer Experiments (CLEX) that the Center for Geosciences/Atmospheric Research (CG/AR) has run over the past few years. The overall goal of CLEX is to learn more about the lifecycle and characteristics of mid-level, mixed-phase clouds.

I was a forecaster and data manager for CLEX-5 (Nov.-Dec. 1999) in which we had the UND Citation flying over Oklahoma and Montana. Maj. Rob Fleishauer was working on his Ph.D in Atmospheric Science with Tom Vonder Haar as his advisor, and was lead flight scientist for most of the missions. Vince Larson (currently a professor at UW-Milwaukee) was a CIRA post doc who helped out with several science areas of CLEX-5.

CLEX-8 was a smaller effort run during May-June 2001, centered over the Nebraska and South Dakota regions. This effort had Larry Carey (currently at TAMU) and me flying on board the SPEC Lear Jet out of the JeffCo airport. We had two successful missions.

CLEX-9 was our most successful CLEX field campaign to date. This was a major effort run during Oct.-Nov. 2001, centered over North Platte, Nebraska. Dr. John Davis ran the ground instru-

Fall 2001, CLEX Project, refueling in North Platte, Nebraska.

FLASHBACK: CIRA newsletter, Volume 20: Fall, 2003

Technology at CIRA

Progress in the atmospheric sciences is dependent upon a synergy of science and technology. Our understanding of the atmosphere includes theoretical physics and chemistry, but is practically limited by the quality of our observations and our ability to model and predict. Those limitations are more than likely due to technology: sensors too expensive to deploy in numbers, sensors with long-term drift and calibration problems, computers too small to model the physics and chemistry we already understand, and communications links too narrow to accommodate the flow of the data we can produce. Technology also hampers the understanding and distribution of weather information in the operational community. This article will highlight two forms of technology currently under development within CIRA.

Enabling Technologies: These are core technologies that improve either the infrastructure of the science support systems in CIRA, or provide a means to improve the dissemination, computation, or storing of information. Enabling technologies do not focus on what is being disseminated, computed, or stored, but rather generic technologies that can potentially affect many applications or functions. In some instances the technologies do not represent innovation in terms of function, but they are unique in that they represent improved efficiency or cost-saving ideas. Examples of these technologies are:

Grid Computing – This technology uses existing computer resources (desktop administrative machines and scientific workstations not used at night) to perform large computational jobs. The only limitation is that the job needs to be partitionable. This technology offers a low-cost alternative to high-performance computing.

DVD-Archive Systems – This technology is now offering a low cost method of storing the massive data sets produced by satellites. A year ago these systems cost tens of thousands of dollars and were only provided by turnkey "solutions" companies. Today they are made with commodity parts and can be built for less then $5,000.

Wavelet Compression Techniques – This technology has developed a new compression algorithm that allows both imagery and gridded data to be compressed for transmission. This is a unique application and unlike JPEG and JPEG 2000 (also Wavelet based) it allows the user to explicitly select the accuracy of the data.

Project Technologies

These are technologies that have been developed for specific scientific, educational, or operational purposes. Here the focus is on the end product or application and represents a specific use of technology.

Examples include:

Volcanic Ash Coordination Tool Project – This system allows inter-agency coordination during the forecast process associated with volcanic events in the Alaska region.

Observation of Coral Bleaching Using IKONOS Satellite Data – This technology is exploring the use of very high resolution (better then 5-meter resolution) satellite data to determine the thermal heating stress on coral reef structures.

– Ken Eis

CLEX project, picture taken from the air during a flight in Fall 2001.

The CLEX experiment series have probed mid-level clouds which have received less scientific attention than cirrus, stratus, or convective clouds historically.

ment site (at North Platte, NE), while Larry Carey and I led the forecasting teams and flew on board the Wyoming King Air research aircraft. The most memorable (or forgettable might be a better way to think of it) part of this experiment was the 3:00 AM go/no go decision that had to be made on possible flight days. Larry and I would call each other around 2:00 AM and incoherently discuss the pros and cons of flying on that particular day. If a go decision was reached, then one of us would drive (often avoiding cows standing in the middle of highway 287) to Laramie, Wyo., to hop on board the research aircraft for flights that day. Flying in the co-pilot seat on board the King Air helped alleviate the air sickness we both had experienced while flying on previous research aircraft.

John Forsythe

A memorable CIRA experience was my participation in all of the Cloud Layer Experiments (CLEX). The DoD needed research on forecasting and understanding mid-level, mixed phase clouds since they were poorly forecast during the Gulf War. During the major CLEX campaigns (1996, 1999, 2001), we gradually learned that the earlier in the morning we had the aircraft on station in the mid-level clouds, the better our chances of success. Unfortunately, for the operations support and forecasting team, that meant we had to be at work earlier and earlier to make a go/nogo decision. So we would typically arrive at the CIGS room, outfitted as the Ops center, at 2 - 3 AM for weeks at a time. Walt Peterson and I manned the ops center on CLEX-1, and Don Reinke was the leader. We would also have midday forecast meetings to plan operations. It was very exciting to try to forecast these overlooked mid-level clouds. We recruited some excellent forecast assistance from the ranks of the atmos students, like Tim Hall, Matt Parker, Jason Nachamkin, and Jason Knievel, as well as Tom's students in the field like Stefan Tulich and Rob Fleishauer. We had excellent CIRA scientists involved like John Davis, Adam Kankiewicz, Vince Larson, and Larry Carey. Tim Hall went on in the USAF to be the lead forecaster for Air Force One. We were teaching ourselves how to forecast these clouds, how to best plan this type of experiment etc as we went along, since it hadn't been done before. Our work paid off as the experiments have been increasingly successful and have led to many publications and greater understanding for our DoD sponsors.

FLASHBACK: CIRA newsletter, Volume 22: Fall, 2004

The Increasing Role of Satellite Data in the GLOBE Program

The GLOBE Program is an international science education program designed to increase scientific understanding of the Earth as a system, support improved student achievement in science and mathematics, and enhance environmental awareness through inquiry-based learning activities. Under the guidance of their teachers, students worldwide collect environmental data around their schools and post these findings on the Internet. GLOBE scientists design protocols for measurements that can be accomplished by K-12 students, and are also useful in scientific research. As scientists respond to the major environmental issues of today, laboratory and classroom collaboration help unravel how complex, interconnected processes affect the global environment. GLOBE's unique global database holds more than 11 million student measurements and associated metadata records that offer atmospheric, soil, land cover, hydrological, and phenological information accessible universally on the Web for research and visualization.

Since October 2003, GLOBE has been managed by the University Corporation for Atmospheric Research (UCAR) in partnership with Colorado State University (CSU) under a NASA Cooperative Agreement. Along with the new GLOBE management structure, the responsibilities for the CIRA GLOBE team have also changed significantly. The Team has now assumed responsibility for the entire systems infrastructure previously handled by four different groups (CSU/CIRA, NASA Goddard Space Flight Center, NASA Ames Research Center, and the National Geophysical Data Center). The list of systems tasks now performed by the CIRA team includes the administration of the main GLOBE Webserver, development of data acquisition tools, maintenance of the central GLOBE database, coordination and collaboration involving the mirrored GLOBE Web and database systems, and design, development and enhancement of all data access and visualization functions.

Since the early years of GLOBE, participating schools have worked closely with satellite data. The GLOBE land cover and biometry protocols were introduced to the Program in 1996. As part of the data analysis, students are encouraged to use LandSat imagery to compare their data collection results with the high-resolution satellite image. The data collected by GLOBE students on the ground for the land cover study site helps land cover scientists create and properly label land cover maps produced from satellite images and aerial photography. Another group of satellites continues to play an important role in GLOBE. Since 1997, infrared imagery from the geostationary satellites GOES (East and West), Meteosat, and GMS are accessed several times a day and are imported into the GLOBE reference database.

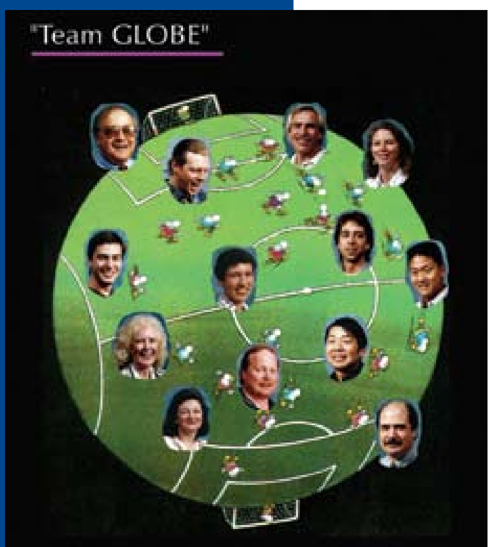
As its name implies, CloudSat will collect data on clouds with an instrument known as a Cloud Profiling Radar. Clouds are one of the least understood elements of climate and the hydrological cycle. Yet, without an understanding of clouds, weather forecasting and climate modeling become extremely difficult. The CloudSat Education Network is working closely with the GLOBE Program and provides the opportunity for schools to partner with the CloudSat Science and Education teams. The base level of participation in the CloudSat Education Network is the reporting of cloud cover, cloud type, temperature and precipitation data every 16 days, coinciding with the satellite overpass.

With the recent launch of Aqua and Aura, and additional new satellite missions like CloudSat, CALIPSO, PARASOL, and OCO over the next few years, GLOBE students around the world will have more opportunities to participate in these missions and assist scientists in their research on the Earth's atmosphere. Mission scientists will be comparing GLOBE data on clouds, aerosols, ozone, precipitation, water vapor, UV, and CO2 to images and measurements collected by these orbiting satellite sensors. The GLOBE Program is also expected to expand over the next few years to incorporate networks involving citizen groups, Scouts, and other informal "after school" organizations.

– Renate Brummer, Cliff Matsumoto, and Debra Krumm

CHAPTER 7: *Education, Training, and Outreach Activities*

CIRA's education and outreach activities, conducted at many levels, include primary (K-12) summer program support, tours, summer internships for high school and undergraduate students, and more formal programs such as GLOBE. Some of the formal training programs (i.e., VISIT) and hardware systems (RAMSDIS) also represent significant activities focused on training professional meteorologists. In the case of VISIT, CIRA has developed a national-level telecommunications training program for National Weather Service (NWS) and other professional meteorologists. RAMSDIS was developed to provide NWS forecasters a satellite display system and, more significantly, a means to transfer research results from Colorado State University and CIRA to operational users in the NWS. To this day, RAMSDIS represents one of the best examples of technology transition of science to operations in the U.S.



CIRA's GLOBE Team, circa 1995

Outreach activities have proven to be even more diverse. The Flash Flood Laboratory provided information and organizational systems theory to the flash flood warning process in local communities and supported a NATO workshop. CoCoRaHS, a Colorado Climate program to train volunteer weather observers with display software to take local precipitation measurements, has received increasing support for several years. The RMTC program trains Latin American national-level atmospheric researchers and meteorologists and provides a means for experienced Caribbean regional forecasters to use advanced technology. This program also offers the U.S. new insights into tropical forecasting problems. FX-NET workstation development, another educational outreach program, has allowed the power of the NWS AWIPS system

FLASHBACK: CIRA newsletter, Volume 23: Spring, 2005

NOAA Science on a Sphere (SOS)

As we all were taught in grade school, a globe is the only accurate way to present a map of the entire earth. Global datasets cannot be accurately represented on a flat surface. Science On a Sphere™ (SOS) updates the trusty globe, bringing it into the age of computers and global remote sensing datasets. Much as a planetarium realistically portrays the wonders of the night skies, SOS vividly and accurately portrays the wonders of our Earth, other planets and moons, even the sun.

Invented by Dr. Alexander MacDonald, head of NOAA's Forecast Systems Laboratory (FSL), SOS is essentially a six-foot spherical movie screen with a set of computer-driven projectors shining on it. Custom software provides the magic of the theater, coordinating the projected data into a seamless animated globe. The authors are CIRA researchers among those at FSL working to further enhance and perfect the SOS software and displayed datasets

NOAA global remote-sensing and modeling activities provide an abundant source of data for display on the sphere, only a small part of which have been incorporated into SOS at this time. Global infrared satellite imagery, sea surface temperatures, climate models, X-ray sun imagery, earth bathymetry, and surface elevation data are among the NOAA datasets we commonly display on the sphere. NASA datasets also provide a look at other planets and moons of our solar system.

– Michael Biere and Steve Albers

to be made available to low bandwidth users in the educational and commercial sectors.

The following sections will describe some of these activities in more detail.

GLOBE

The GLOBE Program was created in the early 1990s. It originated as an idea of former Vice President Al Gore, whose book, *Earth in the Balance*, envisioned students all over the world collecting environmental data to help monitor the health of our planet Earth. During the summer of 1993, Dr. Sandy MacDonald (Director of the NOAA Forecast Systems Laboratory) was asked by Gore to write a strategic plan for the implementation of such a program. The program was named the Global Learning and Observations to Benefit the Environment (GLOBE) Program, and it was officially announced on Earth Day in 1994. The GLOBE headquarters was located in Washington D.C. and managed by staff from NOAA, NASA, EPA, and the Department of Education, in close collaboration with NSF and the Department of State.

Within twelve months, the K-12 program began its operational phase. Each participating GLOBE school sent at least one teacher to a special GLOBE teacher training workshop to ensure that the teachers understood the program milestones, the scientific background and the measurement protocols developed by GLOBE scientists. At the program's inception, 450 U.S. teachers received GLOBE training, and their students were soon using the World Wide Web to send GLOBE measurements to a central database. The initial GLOBE measurements were in the area of atmosphere and climate, hydrology and water chemistry, and biology.

A CIRA team of nine computer scientists, meteorologists, and teachers assumed responsibility for designing and developing a GLOBE Web server with numerous pages describing the program and its scientific protocols. Data entry pages were designed to allow schools to send their data either by using GLOBE Web pages or simply by e-mail. A data acquisition system capable of ingesting and archiving GLOBE student data from all over the world was created. According to GLOBE's initial and long-term Director Tom Pyke, the 1994/95 version of the GLOBE data entry pages was among the first existing Web-based transactional pages.

By late spring of 1995, GLOBE became truly international. Seven European countries participated in the first international GLOBE workshop in Prague, Czech Republic, and GLOBE schools representing these countries began sending data shortly thereafter. This was the beginning of a time of rapid growth for GLOBE. By the fall of 1996, more than 3000 GLOBE schools from 39 countries were participating in the program. In May 1998, participation had increased to 9000 GLOBE schools representing 87 countries. By the end of 2002, the GLOBE world map depicted 100 participating countries with more than 12,000 GLOBE schools. By the summer of 2005, GLOBE milestones had changed again-now including 108 countries, more than 16,000 schools and a GLOBE database that held more than 13 million GLOBE data records.

The GLOBE program has evolved and matured tremendously during the

GLOBE participants taking atmospheric and phenology measurements around the world.

GLOBE's 108 countries as of August 2005 are shaded in green.

decade of its existence. Continuously and on a yearly basis, GLOBE scientists have improved and refined existing protocols and added new measurement protocols. The spectrum of GLOBE measurements has widened considerably, the Web site increased to more than 1000 dynamic pages, the Web pages design was refined to incorporate the latest technologies, a complete mirror server was installed in Germany, an additional server was created to separately support GLOBE training, a GLOBE Help Desk was introduced, and hundreds of GLOBE partner organizations volunteered to conduct the GLOBE training for interested teachers world wide. The CIRA GLOBE systems team received the 2004 CIRA Research Initiative Award for their outstanding contribution to the program's success.

Fire weather forecaster using FX-Net at the Lakewood, Colorado GACC Office.

Later in the same year, the GLOBE program was awarded the Goldman Sachs Foundation Prize for Excellence in International Education in the Media and Technology category.

During its successful ten-year existence, GLOBE also experienced several major management changes. After roughly 6 years of NOAA-NASA-NSF interagency management, the program became a NASA outreach and education program, with NSF continuing to support the science side of GLOBE. Since October 2003, GLOBE has been managed by the University Corporation for Atmospheric Research (UCAR) in partnership with Colorado State University (CSU) under a NASA Cooperative Agreement.

Simultaneously, the CSU Atmospheric Science Department (ATS) assumed a predominant role within the GLOBE science team. During the past two years, ATS has been directly responsible for developing and supporting all GLOBE science measurement protocols, including detailed description of protocols and instrument specifications, in collaboration with NSF-funded science principal investigators. ATS also ensured the scientific validity of GLOBE data and played the role of liaison to the science community. ATS members continue to provide support for the GLOBE Help Desk.

The CIRA GLOBE systems team inherited the overall responsibility for the development and maintenance of the entire GLOBE Web site, database, and real-time data acquisition system, including visualization of all student data and the acquisition and display of reference data – tasks formerly conducted by staff within NASA and NGDC. With the program entering its second decade, the new GLOBE management is revising some of the program's mission goals and milestones to help ensure renewed school/student participation worldwide and to better posture the program for self-sustainment.

The FX-Net Workstation

In 1997, Dr. Sandy MacDonald, the Director of the NOAA Forecast Systems Laboratory (FSL), envisioned developing a network-based meteorological workstation that could provide access to the basic display capability of an AWIPS workstation via the Internet. AWIPS, the Advanced Weather Interactive Processing System, was the FSL-built meteorological workstation system used at National Weather Service Weather Forecast Offices (WFO). Throughout the 1980s, all FSL-built forecaster workstations, including the pre-AWIPS systems, used VAX/VMS computers and Ramtek display hardware. Acknowledging the advent of the open-systems computing philosophy, FSL initiated a new workstation development known as FX (for FSL X-window-based forecaster work-station) in 1992. Based on this new technology, the "FX-Net" project was born five years later.

The FX-Net design goal was to offer an inexpensive PC workstation system for use in a variety of forecast, training, education, and research applications not requiring the full capabilities of a WFO-type AWIPS system. Most of the research and development for FX-Net was conducted by CIRA researchers. Initially, they focused on the delivery method for large file sizes to be transmitted over relatively low bandwidth. Although designed primarily for Internet use, FX-Net also accommodated local network, dial-up, and dedicated line use. The system consisted of an AWIPS data server, an FX-Net server, and a PC client. The FX-Net server was a modified AWIPS workstation. It was locally mounted next to the AWIPS data server via a high-speed link.

The FX-Net client sent requests for small-sized products via the Internet to the FX-Net server, which responded by sending the products to the client. The user interface of the FX-Net client closely resembled the AWIPS workstation user interface, except for reduced resolution and complexity to allow for rapid Internet response. Some of the FX-Net client functionality features included load, animation, overlay, toggle, zoom, and swap. The client Java application ran on a number of standard PC platforms, such as Windows NT, Windows 2000, and Windows XP. Internet bandwidth down to 56 kbps was considered sufficient to transmit FX-Net products.

The available FX-Net products could be categorized into four groups: satellite data, model graphics and observations, radar imagery, and model imagery. Wavelet transform was used to compress model and satellite imagery. The application of this compression technique was critical to the success of delivering very large-size imagery via the Internet in a reasonable amount of time. The small loss of fidelity in the imagery was acceptable in exchange for very high compression ratios. Processing time was even further minimized by pre-generating and compressing satellite data on the FX-Net server side. In contrast to the satellite imagery, the radar imagery was encoded in a standard lossless image compression format (GIF) and the small-sized model graphics were represented in a standard vector graphics format.

The first FX-Net users were universities and others facilities in the research environment. In 1998, the FX-Net team installed the PC client workstation software at Plymouth State College in New Hampshire in support of their meteorology classes and meteorological research. During the next three years, installations at the University of New Hampshire, the University of Northern Iowa, and Colorado State University followed. The FX-Net server for these clients was located in Boulder at FSL.

During the summer of 2001, the National Interagency Fire Center (NIFC) requested that FX-Net be modified to permit its use as the primary real-time meteorological workstation by fire weather forecasters at NIFC and at the Geographic Area Coordination Centers (GACC). The plan called for the FX-Net workstation to be used during the 2002 fire season on an experimental basis, with the FX-Net server located at FSL in Boulder. If the workstation was accepted by the fire weather forecast community at NIFC and GACC Offices, the agreement called for the introduction of an operational solution for the 2003

FX-Net PC clients supported forecast offices at each of five different Winter Olympics outdoor venues around Salt Lake City, Utah.

Everyone who owns a digital camera knows about data compression and its lossiness (degradation in image quality). CIRA's data compression method is the only one that allows the user to set the error to not exceed a value; this new method allows scientists to use high levels of data compression and not worry about loss of data integrity.

fire season. The FX-Net team added a variety of new functionalities to the FX-Net client with the goal of making additional products available to the fire weather community and adding new user-friendly tools to the client. One of the more outstanding new data sets was a complete text browser, which allowed for the display of a large number of National Weather Service forecast and discussion products. Several special display scales were also added to allow the viewing of high-resolution satellite imagery in areas with high potential for wild fires.

Over the past few years, a new version of the wavelet data compression was applied to the FX-Net system to more efficiently compress satellite and model grid images, and to reduce the file encoding and decoding time. This new version of FX-Net was fielded at the National Interagency Fire Center, at Western and Southern NWS Regional Headquarters offices, and for university clients and NOAA researchers.

The new Wavelet-based compression algorithm was ported to UNIX, Linux, and Win2000 operating systems. This system was targeted to uplink satellite data to NOAA's P-3 aircraft for hurricane surveillance and penetration. It was successfully deployed during the 2004 hurricane season.

During 2002, FX-Net successfully supported all weather forecasting functions at the Salt Lake City Winter Olympics. For this scenario, the FX-Net server was located at the NWS Western Region Headquarters in Salt Lake City. Forecasting offices at each of the five different Winter Olympics outdoor venues were equipped with FX-Net PC clients.

During the summer of 2002, FX-Net also supported the AIRMAP Program. This was a University of New Hampshire (UNH) based, NOAA-funded program, which focused on the long-term monitoring and forecasting of air quality parameters like nitrogen oxides, sulfur dioxide, carbon monoxide and low-level ozone. These pollutants can be hazardous to human health when present in the lower atmosphere. Many of these chemicals are the result of burning fossil fuels, and are responsible for New Hampshire's high levels of acid rain. The primary mission of AIRMAP was to develop a detailed understanding of climate variability and the source of persistent air pollutants in New England. The availability of a real-time display station such as FX-Net became very important to the program's success. The FX-Net team modified the existing real-time meteorological workstation by adding air quality-related data sets to the ingest and display system. A new FX-Net/AQ client was successfully released in July 2002, just in time to support the real-time forecasters who participated in a "High-Resolution Temperature and Air Quality" (TAQ) field experiment during the summer of 2002. AIRMAP was part of the TAQ field project.

During 2003, four complete FX-Net systems were installed at four NWS Regional Headquarters to support Incident Meteorologists (IMETs) in the field as well as to provide remote data collection offices with AWIPS-like products.

AWIPS – Cornerstone of NWS Modernization

CIRA research groups in the WFO-Advanced project at FSL played a vital role in the successful deployment of AWIPS at all NWS Weather Forecast Offices across the country during 1999. The core software of AWIPS, including the main data ingest and display systems, were developed as part of the WFO-Advanced project. The outstanding accomplishments of the AWIPS team were recognized with the Department of Commerce Gold Medal.

The Local Data Acquisition and Dissemination system (LDAD), a key component of AWIPS, was also implemented at NWS WFOs during 1999-2000. A test Web site was developed to evaluate the final major component of the dissemination strategy. Collaboration continued on the web dissemination component of LDAD known as the Internet-based Emergency Management Decision Support (EMDS) system during FY01/02. It is a web-based applet/application for use by a small number of state and local government users and/or a large number of public Internet users. The EMDS disseminates all types of weather data, including high-resolution weather analysis/forecast/model grids, radial radar grids, observations, quality control information and textual forecasts in a multi-modal GUI to a variety of users. It also allows the local and state government agencies to integrate weather information from the National Weather Service with their GIS data sets to create a personalized Decision Support System. The full deployment of EMDS at all WFOs was a major accomplishment for 2002.

With the conversion of AWIPS from an HPUX to a Linux operating system during FY04/05, new technologies for implementation on Linux platforms were explored to address the ever-increasing amount of data. An Advanced Linux Prototype System was

FLASHBACK: CIRA newsletter, Volume 19: Spring, 2003

911 Dispatch Cards for Natural Disasters Still Popular

Under the auspices of the VISIT program spearheaded by NOAA, a number of researchers at CIRA have been engaged in training efforts that transfer advances in research to the hands-on world of National Weather Service forecasters. John Weaver, a member of NOAA's RAMM Branch based at CIRA, has been involved with many such training efforts during his 23 years at the institute.

One such training effort came in the aftermath of the devastating flash flood that affected Fort Collins, Colorado the night of July 28, 1997. At the time of the event, Weaver was volunteering with the Fort Collins Office of Emergency Management (OEM). In the weeks and months that followed, Weaver worked with local responding agencies to explore and identify the "failure points" during that unprecedented event. Although the response on the part of emergency dispatchers was impressive that night, their lack of experience with natural disasters specifically left them ill-equipped to deal with the types of calls they received.

CIRA/RAMM researchers sought to investigate whether these deficiencies were peculiar to the Fort Collins OEM, or if this was common to emergency management offices throughout the country. A survey of dispatch centers and/or emergency managers in 20 states followed, and it was found that many were similarly unprepared for natural disasters. With the problem identified, a joint effort between the City of Fort Collins Office of Emergency Management, the National Weather Service, NOAA, FEMA and CIRA was launched.

The solution came in the form of a Powerpoint presentation, operating like a flow chart, which featured Natural Disaster Information Cards (NDIC). These dispatch cards were used in teletraining courses funded by VISIT for emergency offices around the country. Dispatchers could choose a type of natural disaster (blizzards, floods, lightning, hail, or tornadoes) then follow the sequence of cards/screens to learn how best to handle the call and what advice to dispense.

The system later evolved to a simplified HTML format. The most frequent usage for the cards is for in-house training, followed closely by a review for dispatchers on the morning of the day of an anticipated event. Events occur too quickly in real-time for the system to be useful without this prior review, though the advice is readily available if a call taker forgets specifics. Though the card system was completed in 1999, many refinements have been added in subsequent years. Interest in the program surged after the terrorist attacks of September 11, 2001, and much thought was given to expanding the cards for use in other types of emergencies.

– John Weaver and Mary McInnis-Efaw

FLASHBACK: CIRA newsletter, Volume 10: 1996

GOES Imagery Tutorials

One of the major endeavors of the NOAA Regional and Mesoscale Meteorology (RAMM) team at CIRA is the training of NWS forecasters in the use and utility of digital satellite imagery from the new GOES satellites. Computer-based learning modules that were designed to run on the RAMM Advanced Meteorological Satellite Demonstration and Interpretation System (RAMSDIS) workstations, available at many NWS forecast offices, were developed to provide such instruction on-site. These modules are also available for use by others via the World-Wide Web. The first module, "An Introduction to GOES-8," provided an overview of the capabilities of the first operational satellite from NOAA's new, three-axis stabilized geostationary satellite series.

Recently, a more focused module entitled "GOES'.3.9:m Channel Tutorial" was released for widespread dissemination on the Web. As its title implies, this training module concentrates on the unique benefits to be derived by using this previously unavailable spectral channel's imagery, both alone and in combination with selected other GOES channels.

– Roger Phillip

formulated, focusing on employment of new network and database technologies. Also, a specialized version of the Display-3D (D3D) interface for AWIPS was implemented for display of 3D lightning data at Cape Canaveral.

Prototyping and Aviation Collaboration Effort (PACE) Project

The PACE effort comprised of two separate investigative projects-TMU and FX-Connect-made significant progress during 2003-2005. The effort is driven by the need for innovative software tools and data products to minimize adverse weather disruptions in air traffic operations. For phase I of the TMU project, a prototype Tactical Convective Hazards Product was prototyped and enhanced. The FXC Volcanic Ash Coordination Tool (VACT) project is a response to the needs of collaborating agencies in generating consistent Volcanic Ash Advisories. The initial release of the FXC VACT systems, including the delivery and installation of both hardware and software, along with major enhancements, occurred during 2005. FSL's Aviation Systems Development and Deployment Branch, responsible for PACE, and the ADDS project described below were recognized with the National Weather Association's Aviation Meteorology Award in 2004.

SOS on location in a Broomfield, Colorado, classroom.

An Aviation Digital Data Service (ADDS) Web page was developed which contains static and user interactive displays geared toward aviation dispatchers and pilots. The page provides digital analyses, forecasts, and observations of aviation impact variables relevant to decision-making in gridded, graphical and text format. This Aviation Weather Research Program project was selected as a winner of the 2000 Government Technology Leadership Award.

Science on a Sphere™ (SOS) Project

The NOAA Science on a SphereTM (SOS) project displays and animates global datasets in a spatially accurate and visually compelling way on a 6-foot spherical screen. CIRA provides key technical support to the project, particularly research into effective user interfaces for the system and new visualizations. During the past two years, novel visualization of global weather phenomena and in-the-round visualization of other planets and moons in our solar system were developed for the SOS

FLASHBACK: CIRA newsletter, Volume 21: Spring, 2004

National and International Training Activities at CIRA

The Regional and Mesoscale Meteorology (RAMM) Team supports both national and international training activities at CIRA that are specifically directed towards increased use and understanding of satellite data. Nationally these include the Virtual Institute for Satellite Integration Training (VISIT) program and a newly emerging Satellite Hydrology and Meteorology (SHyMET) program. Internationally, they include interaction with the Regional Meteorological Training Centers (RMTCs) in Costa Rica and Barbados.

VISIT was created in 1998 with funding from the National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) and the National Weather Service (NWS). Distance learning became necessary as NWS training requirements outpaced the availability of travel funds for classroom training. A software package, VISITview, was developed at the Cooperative Institute for Meteorological Satellite Studies (CIMSS) to meet the specific distance learning requirements of VISIT. The VISITview software, along with a telephone conference call, allows for a synchronous teletraining session to take place so that training sessions may be administered to NWS offices. VISIT is composed of staff from CIMSS, the NWS training division, NESDIS, and CIRA.

The SHyMet Course is being designed to cover some of the basics of satellite instrumentation, orbits, calibration, navigation, and radiation theory while also including identification of atmospheric and surface phenomena, and the integration of meteorological analysis with satellite observations and products into the weather forecasting and warning process. This course will be taught through a combination of teletraining, CD-ROM, Web-based instruction, and on-site training. At the end of the distance training portion of the program, participants will attend a 3.5-day SHyMet Workshop offered at the COMET Classroom in Boulder, Colorado. Although distance training has significantly improved over the years, experience has shown that a dedicated in-class training effort is also highly beneficial. Upon successful completion of SHyMet, participants will be certified to use satellite data and products as part of the NWS weather forecasting and warning program. The target audience for the training includes the satellite focal point and Science and Operations Officer at each NWS operational office. The proposed first offering is in 2005.

The RMTC in Costa Rica is closely associated with the Universidad de Costa Rica, and the RMTC in Barbados is closely associated with the Caribbean Institute of Meteorology and Hydrology. Activities with the RMTCs have focused on building case studies of heavy rain events associated with hurricanes, tropical waves and the incursion of mid-latitude systems during northern hemisphere winter. Research has also focused on fire detection, volcanic ash detection, satellite rainfall estimation, and satellite cloud climatologies. Real-time use of satellite imagery is encouraged by making GOES-East satellite imagery available in java loops on the Web.

The underlying goals of the national and international training activities have been to increase awareness, understanding, and utilization of satellite imagery and image products within weather forecast offices. The imagery must be readily accessible and must provide additional information to be used. In the NWS forecast offices, the amount of all types of weather information available locally to the forecaster has significantly increased over the years. Our experience has shown that it is important to have directed training that shows where satellite imagery and products are located on the system as well as how to utilize it properly under various situations – under day-to-day operations as well as under severe-weather warning operations. Outside the U.S., the challenges have been to make digital imagery available locally and where this is not possible, provide Internet links where products can be viewed. The added training component has greatly increased the utilization of satellite imagery as well as communication among various countries involved.

– Bernadette Connell, Dan Bikos, Dan Lindsey, John Weaver, and Tony Mostek display platform. A full set of Jupiter's Galilean satellites is now available for display. Photo-mosaics of several Saturnian satellites were updated by reprojecting and overlaying recently taken Cassini flyby images. Maps of five Uranian satellites were added as well as one for Neptune. Some image processing was performed to add a high-resolution Voyager mosaic to a pre-existing map of Neptune's moon Triton. SOS was installed during 2005 in its first permanent science museum location at the Nauticus Museum in Norfolk, VA. SOS continues in use at the Science Fiction Museum in Seattle.

VISIT teletraining in session.

The VISIT Program

The Virtual Institute for Satellite Integration Training (VISIT) program began at CIRA in 1998. Its mission is to accelerate the transfer of research results based on atmospheric remote sensing data into National Weather Service operations. Dan Bikos has worked with the VISIT program since its inception, and has personally developed and instructed 9 teletraining courses to date. John Weaver (NOAA/NESDIS/RAMM) has also made significant contributions by assisting in the development and delivery of twelve sessions, and Daniel Lindsey joined the team in 2002 and instructed a number of sessions. Most recently, Jeff Braun joined the VISIT team in January of 2005, bringing with him more than five years of trench work in the National Weather Service (the VISIT program's target audience), and has begun to teach and help develop teletraining sessions. Overall, the VISIT program has developed 55 courses,

FLASHBACK: CIRA newsletter, Volume 11: Spring, 1999

RAMSDIS On-Line: A Web-based Tool for the Satellite Data User

RAMSDIS On-Line (ROL), a popular website offering animated real-time GOES data and developed in 1998 by the Regional and Mesoscale Meteorology (RAMM) Team at CIRA, has been accessed by an average of 400 users per day. RAMSDIS systems, developed by the RAMM Team to provide NWS forecasters with low-cost access to real-time digital satellite data, are in use in over 60 NWS forecast offices nationwide. ROL allows a much larger audience to view the GOES products ingested and generated by RAMSDIS.

ROL, constructed with the novice user in mind, offers several image sectors from two different satellites: western U.S. (currently GOES-10), or eastern U.S. (currently GOES-8). The user may select from the various satellite products, and options allow the user to view a loop or just the latest image. Images of certain sectors and resolutions are ingested on a RAMSDIS unit. Once ingested images are displayed with the proper graphics and color enhancements, GIF files of the display are created and transferred to a server to allow access from ROL.

Special ROL sections include coverage of fires, hurricanes/tropical storms, and past case studies of interesting weather events. ROL provides users with 4 GOES channels: visible, thermal infrared, water vapor, and shortwave infrared, each of varying resolutions and enhancements. ROL coverage of the wild fires affecting Florida, Mexico, and Brazil assisted incident meteorologists in the field in locating and combating these fires. For the hurricane season, several tropical image sectors show users the development and progression of the latest tropical storms. The "archives and case studies" page displays historical data including tornadoes, hail, and wind damage, and other interesting phenomena such as the 1998 total solar eclipse of the sun.

– Dave Watson and Don Hillger

FLASHBACK: CIRA newsletter, Volume 15: Spring, 2001

IMPROVE and WRAP Launch New Websites

In the 1990 Clean Air Act, a Grand Canyon Visibility Transport Commission (GCVTC) was established to identify causes and develop strategies to improve visibility degradation in the Grand Canyon and nearby Class I areas. In 1997 the western states, tribal governments and federal agencies formed the Western Regional Air Partnership (WRAP) to implement recommendations from the GCVTC and deal with other regional air quality issues. In 1999, the EPA issued regional haze regulations that require states and tribes to develop and implement strategies to improve visibility in Class I areas, based on IMPROVE program data.

These recent developments imply a need for new approaches for disseminating IMPROVE information. First, the regional haze rule has expanded the focus of IMPROVE from its original purpose as a scientific database to that of assuming added regulatory responsibilities. To support regional haze rules, the IMPROVE monitoring network needs to have openly documented QA/QC procedures and results, and the data needs to be as widely and easily available as possible. In addition, states and tribes new to the issue of regional haze need background information about visibility science, history and regulations. Secondly, WRAP has determined there is a need for air quality and related information to be made readily available to all of their partners through a web-based, interactive database.

To support these needs, two new websites are under development by CIRA staff. The IMPROVE website is focused on delivering IMPROVE data and general information about visibility science and regulations. The WRAP website, being developed for WRAP's Ambient Monitoring and Reporting Forum, provides visibility, air quality and meteorological data to WRAP partners in an online database. The IMPROVE data are central to both websites. Therefore, the co-development of the websites is mutually beneficial with WRAP benefiting from the database development for the delivery of the IMPROVE data, and the IMPROVE website benefiting from the integrated WRAP database and data visualization tools to be developed.

– Bret Schichtel and Doug Fox

delivered more than 900 teletraining sessions, and issued over 15,000 certificates of completion. The distance learning approach has saved considerable money (travel costs and time away from work) while maintaining quality training for National Weather Service forecasters.

RAMSDIS, a Success in Technology Transition

The RAMSDIS (RAMM Advanced Meteorological Satellite Demonstration and Interpretation System) project was initiated in 1994. At that time, the project goal was to disseminate real-time, high quality, digital GOES (Geostationary Operational Environmental Satellite) data to select National Weather Service Forecast Offices (NWSFOs) via a powerful, low-cost, PC-based workstation for use in advanced satellite data display and analysis. The project, part of the GOES-I/M quality assurance plan, was designed to provide forecaster familiarization with the next generation GOES data sets, in preparation for NOAA's Advanced Weather Interactive Processing System (AWIPS) deployment; determine future forecaster training requirements to ensure full utilization of the advanced GOES data sets; and provide a platform for forecaster evaluation of GOES "Day-1" products and GOES "Day-2" product determination before the GOES data became operationally available via NOAAPORT.

RAMSDIS units were distributed and utilized by over half (about 70) of the NWSFOs from 1995-1999. The units provided forecasters with high quality, digital satellite image loops from all five of the channels of the GOES imager, covering state, regional, and continental scales. Also included were the reflectivity product and the fog product, which combine 10.7 μm and 3.9 μm data into imagery which is useful in the detection of supercooled clouds, nighttime stratus and fog, and fires. The RAMSDIS units also ingested surface and radiosonde

A RAMSDIS workstation.

reports, which allowed the forecasters to plot and contour surface and upper-air data onto the satellite images. These units were well received, as no other access to such high quality satellite imagery existed. As a testament to the success of the RAMSDIS project in the National Weather Service, many offices were reluctant to give up their systems when they received, as part of the NWS modernization program, their new AWIPS units, which included satellite imagery display capabilities.

With full deployment of NOAA-PORT and AWIPS in 1999, the low cost RAMSDIS workstations were transitioned to international programs such as the Brazil Fires Project, the Hurricane Mitch Relief Effort, the WMO Regional Meteorological Training Centers program, to various NOAA Labs, NWS-FOs and universities for joint research projects, and to field programs including FASTEX (Fronts and Atlantic Storm Track Experiment) and PACJET (Pacific Landfalling Jets Experiment).

During 1999-2001, the U.S. Agency for International Development provided funding through the NOAA/NESDIS/CIRA RAMM team to improve forecasting capabilities in Central America. Part of the CIRA/NOAA reconstruction efforts included the installation of a ground receive station and server at the National Meteorological Service in Costa Rica to serve real-time satellite data to the other Central American countries. Each Central American country received two RAMSDIS to ingest and display satellite imagery. The countries also received on-site training of the systems as well as two week-long training sessions in Costa Rica on how to better utilize satellite imagery in everyday forecasting tasks.

In 1998, RAMSDIS Online (ROL) was created to provide another alternative for displaying RAMSDIS products. The use of the web allows for a much larger audience to view the satellite products ingested and generated by RAMSDIS. Special ROL sections were added over the years showing coverage of fires, hurricanes/tropical storms, experimental products, and case study data sets of interesting weather events.

CIRA/National Park Service (NPS) Air Quality Outreach

Soon after the institute was created, CIRA researchers began working with National Park Service employees to investigate air quality in the national parks and wilderness areas of the United States. The following newsletter

FLASHBACK: CIRA newsletter, Volume 22: Fall, 2004

Science Teacher Receives CIRA Grant

Joe Willey, a middle school teacher from the panhandle of Texas, recently spent two weeks in Colorado developing weather related educational resources for teachers. A grant from the Cooperative Institute for Research in the Atmosphere allowed Joe to team up with atmospheric scientists working with the Community Collaborative Rain and Hail Study (CoCoRaHS).

Joe worked with Nolan Doesken and other CoCoRaHS staff members to review and produce educational materials that can be easily included in teachers' weather-related curriculum. Joe's passion for the weather has caused him to challenge students and teachers alike: "Tell me a subject that doesn't somehow include or relate to the weather. When one teacher suggested choir, I replied, 'How about Singing in the Rain, Raindrops Keep Falling on My Head, or Stormy Weather?' In all my years teaching, no one yet has been able to come up with a subject that I can't find some way to include weather!"

– Margi Cech and Nolan Doesken

excerpt describes one of the outreach accomplishments of this CIRA partnership: the development of a website displaying data from the Interagency Monitoring of PROtected Visual Environments (IMPROVE) network. For a fuller description of CIRA's air quality efforts, please consult Chapter 5.

CoCoRaHS

The Community Collaborative Rain and Hail Study (CoCoRaHS) under the direction of Assistant State Climatologist and Department of Atmospheric Science employee, Nolan Doesken, recruits volunteers from the campus as well as the community at large to volunteer as weather observers. Colorado's variable storm precipitation patterns make for interesting observing. Many CIRA employees have played critical support roles in CoCoRaHS, and CIRA has supported summer teacher interns as a part of the program for several years.

Since CoCoRaHS began in 1998, the evidence of its success shows in the numbers. In 2001, the staff equipped and trained nearly 200 new weather observers with ages ranging from 8 to 80. In addition, training programs and

FLASHBACK: CIRA newsletter, Volume 24: Fall, 2005

Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS)

In 1998, a small group of weather volunteers in Northern Colorado under the direction of the Colorado Climate Center at Colorado State University began measuring rainfall and hail at their homes to help track local precipitation patterns from summer thunderstorms. Since that time, the project has grown into a multi-state network, called the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS), in which more than 2,000 citizens measure and report precipitation amounts year-round.

There are no electronic measurement devices in CoCoRaHS. Volunteers use clear plastic rain gauges to manually measure the quantity of precipitation. During winter, the depth of snow is measured using rulers and "snow boards." Snow boards are flat, white surfaces placed on the ground in representative locations to aid in measuring the accumulation of snow. Quantitative measurements of hail are taken using "hail pads," which are squares of Styrofoam wrapped with aluminum foil. The hail stones leave dents on the pads, making it easy to count and measure the number, size, hardness, and trajectory of hail stones hitting the surface. Together, this suite of measurements allows a very comprehensive assessment of the moisture falling from the sky.

A web site has been developed where volunteers enter their data each day. State, county, and city maps are automatically updated on a daily basis, and precipitation patterns for each day since the project began can be accessed and viewed. Summary reports can be quickly generated, showing the distribution of hail stone sizes and the number of days that have had hail each year. As of August 19, 2005, there had been 794 reports of hail in 2005. The largest stones measured had a diameter of three inches, but only 8 percent of all storm reports included stones of 1 inch diameter or greater.

Scientists are using CoCoRaHS data as ground truth in evaluating and calibrating radar and satellite data. Hydrologists are incorporating CoCoRaHS data in watershed modeling, streamflow prediction, and groundwater assessments. The National Weather Service utilizes CoCoRaHS data for forecast verification and as input for issuing local severe weather warnings. Many teachers are getting students involved in CoCoRaHS to learn how scientists collect and analyze scientific data. Most importantly, volunteers of all ages and backgrounds are learning about their local climate and the importance of precipitation in daily life.

The National Science Foundation's Informal Science Education program is the primary sponsor of CoCoRaHS, but many other federal, state, and local organizations contribute. CIRA sponsors a science teacher internship program in which teachers work directly with CoCoRaHS scientists to develop and test educational materials and lesson plans. Nearly 20 additional states have inquired about becoming involved in the project, and current plans are to add the states of Pennsylvania, Virginia, Maryland, and the District of Columbia in the near future.

– Nolan Doesken and Henry Reges

presentations were given to groups of teachers and several other organizations. Over 450 volunteers are participating in the project this summer, and close to 800 volunteers of all ages have now been trained. Hundreds more may join this year as the program is expanding into Denver, Boulder and the surrounding foothills.

Employment for 21 high school and college students has been funded through sponsor support since the program began. As the project grows, local leadership becomes increasingly important. In exchange for the data that volunteers so willingly collect and share, CoCoRaHS continues to offer educational opportunities to help volunteers learn more about weather, climate and water.

Clearly, the success of CoCoRaHS has resulted in exponential growth over the years. The involvement of CIRA personnel in the inception and continued growth of the study not only illustrates commitment to the outreach mission of the Institute, but also demonstrates sincere personal interest in weather observation and research.

APPENDIX: *CIRA's "Highlights of the Highlights"*

Prior to 1995, highlights were not compiled.

1995-1996

In 1994, the Department of Commerce awarded CIRA's Office of Research and Applications' RAMM Team with its Silver Medal Award for Meritorious Federal Service. This award recognized the Federal/University research team's work in the implementation of systems and science support to the GOES-NEXT Satellite Program.

Once again CIRA captured and made available to NESDIS the first day imagery from a new GOES satellite- this time GOES-9.

CIRA worked with CSU's Research Foundation (CSURF) and UNIDATA of UCAR and NSF to license CIRA's RAMSDIS system to UNIDATA for redistribution to its subscribers. The UNIDATA license will make the technology available to over 100 universities and other UNIDATA subscribers.

There are currently 70 RAMSDIS workstations deployed at field sites. Sixty (60) of these are in NWS Forecast Offices, indicating how NWS has embraced this CIRA-created satellite product display system. A special Letter of Commendation to the RAMSDIS Team was received from Dr. Joe Friday, Director of NWS.

Dr. Christopher R. Adams of CIRA has been selected as a recipient of the 1996 National Weather Service (NWS) Modernization Award. He is the first non-NWS employee selected for this award. In his selection, Dr. Elbert W. Friday, Jr., Director of the NWS, recognized Dr. Adams' work: "You are being recognized for exceptionally skilled and dedicated efforts in the National Weather Service modernization and associated restructuring. Your commitment to the modernization has not only demonstrated a vision for the future but has supported that vision with dedication and hard work in the finest tradition." Dr. Adams has been leading the NWS' modernization efforts to incorporate social science research on individual and community hazards warning response into NWS operations. Dr. Adams was a the NOAA Headquarters in Silver Spring, MD on October 30th to accept the award for his work as part of a team developing and conducting training for the new NWS warning coordination meteorologists.

COMET Support. CIRA's RAMM Team and members of CIRA's staff, including Dr. Stan Kidder and Matt Kelsch, have provided COMET with expert teachers. Case study satellite data sets, analysis, and processing support were also provided by the RAMM Team. Much of this support is reflected in the recently released COMET Satellite Meteorology and Remote Sensing Module. RAMM Team members worked closely with COMET staff to add RAMM advanced satellite data analysis techniques to COMET's GARP software which is used in the COMET classroom.

Many CIRA collaborators were involved in FSL's extensive Olympics support. The augmentation of the normal local Atlanta Forecast Office capabilities included: Installation of the Local Area Prediction System (LAPS) and the running of a 2-km grid scale RAMS forecast model. Firsts associated with this installation included the first 30-minute cycle operation frequency for LAPS and the first time LAPS has run at an 8-km grid scale. In addition, CIRA forecasters and programming staff provided extensive support to the Olympic and ParaOlympic games. Forecast staff held daily weather briefings over the Olympic sector and forwarded this information to the Olympic Forecast Office. A RAMSDIS workstation at the Olympic Forecast Office provided satellite data for the forecast efforts. CIRA programming and meteorological staff were on call 18 hours a day to provide support for this effort. In addition, information from the visible and infrared RAMSDIS satellite imagery was used in initialization of the LAPS model. CIRA and RAMM Team members received a commendation from Dr. Friday for these efforts.

CIRA Director Tom Vonder Haar and Senior Scientist Stan Kidder published *Satellite Meteorology – An Introduction,* Academic Press, 465 pp. The book is well-received as the first fundamental textbook in this emerging area of Atmospheric Science.

Under Center for Geosciences sponsored research, CIRA has developed a new method for retrieving cloud liquid water over land from space. This method is based on the polarization difference of the 85 GHz channels included on the Special Sensor Microwave/Imager (SSM/I) which flies onboard the DMSP series of satellites. The retrieval of cloud liquid water is critical for better estimates of aircraft icing, and for remote sensing through clouds.

1996-1997

CIRA researchers, on behalf of the Forecast Systems Laboratory, installed FSL's Local Analysis and Prediction System (LAPS) at the Air Force Global Weather Center (AFGWC - now the AF Weather Agency (AFWA)). This analysis package now interfaces with the MM5 mesocscale forecast model also installed by CIRA personnel at an earlier time. The new relocatable package represents a significant improvement in the Air Force's capability to support contingencies such as the SFOR operations in Bosnia.

The GLOBE program has expanded to more than 5,000 schools in 59 countries.

CIRA researchers have successfully coupled a microphysical parcel model with an aqueous-[haze chemistry model that simulates the oxidization of sulfur dioxide.

1997-1998

No highlights compiled.

1998-1999

A productivity tool was developed for the aviation forecasters at the FAA's Aviation Weather Center in Kansas City to automate the process of generating convective SIGMETs. The point-and-click tool will replace cumbersome, manual production of text flight advisories that are issued hourly.

A Real-Time Verification System has been implemented at the Aviation Weather Center to provide on-the-spot verification of various icing and turbulence algorithms. These intercomparisons permit independent evaluations of the strengths and weaknesses of each algorithm.

The GLOBE program initiated in 1995 has now expanded to over 7000 schools in 84 countries. GLOBE student measurements are conducted in the areas of Atmosphere, Hydrology, Soil, Land Cover and Biology investigations.

CIRA research groups in the WFO-Advanced project at FSL played a vital role in the successful on-schedule deployment of AWIPS at all 150 NWS Weather Forecast Offices across the country. The core software of AWIPS, including the main data ingest and display systems, was developed as part of the WFO-Advanced project. AWIPS was selected the winner of the 1999 Computerworld Smithsonian Award in the category of "Environment, Energy, and

Agriculture" for best and most innovative technology.

Dr. John Knaff and Dr. Ray Zehr have discovered a 6-hour oscillation of convection within the inner core region of hurricanes. This pulsation was noticed using 15-min. imagery.

Initiated the CloudSat program. CIRA will be the data processing center for CloudSat, a NASA-funded cloud radar satellite experiment that is expected to fly in March of 2003. This active cloud imaging radar data along with the Oxygen A-band and Lidar data from Picasso-CENA will provide significant new research opportunities. Another significant aspect of CloudSat is the experience we will get from an engineering and science perspective from flying in close formation with two other satellites, Picasso-CENA (15 second time coincidence) and EOS-PM (60 second time coincidence with Picasso). This makes one very capable virtual satellite collection platform.

In collaboration with the RAMM Team and Mitch Goldberg of NESDIS/ORA, set up a system to clip out the AMSU data around tropical cyclones, retrieve temperature soundings in and around the storm, and calculate the surface pressure and azimuthally averaged winds in the storm. These products are available in real-time on the RAMM Team website.

Development of a teletraining session on lightning climatology for the NWS as part of the VISIT project.

CSU-RAMS mesoscale model was used to demonstrate the sensitivity of dryline formation on soil moisture.

Contributed section on the societal impacts of temperature extremes in the United Nations' International Decade for Disaster Reduction's "Natural Disaster Management."

Preparations have been made for the deployment of field equipment and the North Dakota Citation aircraft for the CLEX-5 field experiment that will take place in the vicinity of the DOE/ARM CART site in the fall of 1999.

Distribution of NOAA 15 AMSU data and products to NWS users.

Project BRAVO – a trans-boundary special study conducted in conjunction with Mexico to study the sources and impacts of air pollution along the Rio Grand and its impact on the Class I visibility areas of Big Bend and Guadalupe Mountains National Parks.

IMPROVE – a continuing monitoring effort that maintains a database of aerosol and optical data measured at selected Class I visibility areas in the United States; the database is heavily utilized by various Federal/State agencies, industry and environmental groups.

Completed and occupied the CIRA Building addition. This extension provided about 50 percent more space to allow room for visiting scientists, collaborators and a new conference room for meetings and seminars.

1999-2000

Developed semi-operational scheme to forecast 24-hour rainfall from tropical cyclones using AMSU rain rate data and track forecasts.

Calculation of various cloud properties obtained from the ARM CART site in Barrow, Alaska, SHEBA, and a multi-radar IOP at the SGP CART sites and comparison with in-situ aircraft measurements occurred this past year. A cloud parameterization technique that depends only upon the large-scale relative humidity and cloud and ice water mixing ratios was compared with cloud fraction profiles determined from cloud radar measurements.

The GLOBE program initiated in 1995 has now expanded to over 9000 schools in 90+ partner countries. GLOBE student measurements are conducted in the areas of Atmosphere, Hydrology, Soil, Land Cover and Biology investigations.

The Flash Flood Laboratory organized and conducted the NATO Advanced Studies Institute, Coping with Flash Floods, November 8-17, 1999 in Ravello, Italy.

3DVAR technique for water vapor retrieval using GPS slant-path integrated water vapor was investigated. Microwave profiler data was introduced to help resolve the issue of multiplicity of solutions. A multi-grid technique was also implemented to speed up the numerical convergence of the solutions.

ETL's High Resolution Doppler Lidar (HRDL) was deployed to the CASES-99 field site near Wichita, Kansas in October 1999 to obtain data to help increase our understanding of the nighttime stable boundary layer (SBL). HRDL recorded approximately 200 hours of data during 15 days of operation, including 12 intensive operation periods (IOPs). This extensive dataset contains measurements of radial velocity and aerosol backscatter showing excellent examples of nocturnal, low-level-jet (LLJ) behavior, gravity waves, shear instabilities, density currents, drainage flows and turbulent eddy formation.

CIRA was just awarded a project under the sponsorship of the Western Governor's Association to develop an interactive online database and web browser for the Western Regional Air Partnership (WRAP). This site will incorporate the NPS/CIRA IMPROVE monitoring data collected at 120 sites throughout the U.S. to characterize visibility for national parks, wilderness and other specially protected air quality areas. This work supports the regional haze regulations established by the EPA last year.

A parameter for estimating the likelihood of tropical cyclone formation in the tropical Atlantic correctly predicted the very active 1999 Atlantic hurricane season, and is currently being used by the National Hurricane Center (NHC) in Miami to help prepare their tropical weather outlooks during the 2000 season. (www.cira.colostate.edu/ramm/gparm/genesis.asp)

The Colorado State University (CSU) Regional Atmospheric Modeling System (RAMS) is being used to identify processes that are important for the initiation of convection that leads to severe weather and the interaction of storms with their environments.

Members of the RAMM Team organized a two-week (December 16-17, 1999) satellite meteorology training course held at the Regional Meteorological Training Center in Costa Rica attended by about 35 participants from 16 countries in Central and South American and the Caribbean.

LDAD – a key component of AWIPS – was also implemented at NWS WFOs. A test website was developed to evaluate the final major component of the dissemination strategy. The Intranet/internet-based Emergency Management Decision Support (EMDS) system will serve as the core for the web dissemination component.

A directive-based model parallelization tool called the Parallel Pre-Processor (PPP) that was developed and released to the public domain last year was used to parallelize the RUC and ETA models. These models are now running on the new HPTi supercomputing platform at FSL.

2000-2001

Operational backup support for NCEP's RUC-2 model continued smoothly this past year. CIRA staff members on the RUC team are currently testing their new 20-km, 50-level version that is scheduled for operational implementation in January 2002. The new RUC version incorporates a variety of new data sources, including GPS cloud-top pressure, precipitable water, boundary layer profilers, and RASS. The OI analysis package will be replaced with a 3D variational analysis package to support the new observations.

CloudSat will fly in formation with Aqua with its nadir-pointing active 94GHz cloud profiling radar. Product generation will not only come from the active radar profiles but will merge MODIS and other sensor data from Aqua with CloudSat for improved cloud analysis.

Activities on developing a mesoscale observing network over the North American continent and adjacent ocean areas to support the next generation of numerical weather prediction models continued this past year. Increased coordination with the European community, Canada and regional U.S. carriers was pursued to expand the coverage of aircraft-provided weather data. As part of the NAOS program, experiments to test the value of targeted observations in the Pacific for improving downstream forecasts and in hurricanes to improve track and intensity forecasts were completed.

Working with the U.S. Environmental Protection Agency, the CIRA/NPS group has developed detailed analysis guidance to determine the relationships between IMPROVE measured aerosol constituents, i.e., sulfates, nitrates, carbon, soil, coarse mass and visibility. These analytical tools will be codified in the formal regulations for regional haze being published in 2001.

RAMM Team contributed to nine new Virtual Institute for Satellite Integration Training (VISIT) sessions and since 1999, has helped to remotely train more than 5000 participants via internet-based software.

A new project was initiated with the FAA for support of the Fort Worth Air Route Traffic Control Center (ARTCC). The FX Connect software developed at FSL will be a major component of a weather support system intended to facilitate collaboration and improve synergism between ARTCC air traffic weather forecasters and other operational weather forecasting facilities. Another major component of this system will be the newly developed FX-Linux AWIPS data ingest system.

The project of using DMSP nighttime imagery for monitoring the activity of the southern California squid fishery was completed and delivered in a GIS-tool format. The task of mapping coral reefs surrounding the Virgin Islands and Puerto Rico, using stereo pairs of aerial photographs to create orthophoto mosaics was also completed. Integration of lights imagery, high-resolution aerial photography, land cover data, and transportation networks was performed for a project aimed at estimating the amounts of urban sprawl and its accompanying effect on the terrestrial carbon dynamics of the U.S.

2001-2002

Development of an operational ensemble forecast system, including several diverse regional forecast models such as NCEP's Eta and RSM, FSL's RUC and NSSL's MM5 began this past year. The resulting ensemble forecast products are expected to improve the overall model prediction.

The CIRA infrastructure grew by 15 percent overall. Many systems were upgraded to Pentium 4 technology with additional memory and hard drive space. An additional local area network subnet was added to accommodate the growth. A new 1TB mass storage was brought online for general research. The modeling cluster was expanded to 24 Pentium-4 nodes. CIRA's local network was upgraded as necessary and a firewall was added for additional security. CIRA's storage archive continues to be a reliable source now using both DLT tapes and DVD disks.

A well-posed, open boundary multiscale ocean model is being developed for the Office of Naval Research. A simple and computationally efficient model has been developed to demonstrate the accuracy and stability of the open boundary treatment. Preliminary results from this model have shown the feasibility of this approach. Theoretical work on a remaining issue in multiscale atmospheric dynamics will be conducted. The feasibility of accurate and stable open boundary conditions for a model based on the well-posed reduced system for oceanography will be completed during the coming year.

GPS tomography package to handle the GPS operational dataset available at Japan Tsukuba dense GPS network was prepared. Compared with the software developed at the Japan MRI, the numerical results obtained from the FSL-developed tomography package were acceptable. Based upon the discussions at the Kyoto GPS workshop, FSL, MRI and the University of Kyoto formed collaboration to conduct future GPS tomography research on theoretical and operational experiments.

2002-2003

Continued participation in the Global Air-ocean IN-situ System (GAINS) support included several demonstration test flights this past year. GAINS is a long-duration stratospheric platform, instrumented for environmental sensing through a combination of dropsondes, XBTs and chemistry particulate, in=situ and remote sensors.

In support of the U.S. Fire Consortia for Advanced Modeling of Meteorology and Smoke, CIRA researchers created one 12-km western U.S. and two 4-km Rocky Mountain and Southwest region windows of LAPS and MM5 forecast runs on the iJet supercomputer to provide experimental real-time fields. Collaborating with the U.S. Forest Service Rocky Mountain Research Station, the team created web displays of several fire weather indices, PBL mean wind, and an interactive point forecast.

CIRA has installed a Data Processing and Error Analysis System (DPEAS) at NESDIS/OSDPD. This 8-node PC system is processing AMSU data and is demonstrating the use of PCs to perform real-time satellite data processing for significantly lower cost than conventional methods.

Developed a CD-ROM of over 60,000 IR images of Atlantic and Eastern Northern Pacific tropical storms. These data are being used for tropical storm research such as improvements in the Dvorak intensity estimation algorithm.

The WRF Standard Initialization package was significantly enhanced to better process various datasets required for the initialization of the WRF land surface packages. Additional flexibility was added to allow users to more easily use separate input datasets for the initial, lateral and lower boundary conditions. Gridded fields that are on non-isobaric surfaces can also now be ingested. Mercator and Lambert FORTRAN map projection routines were simplified and standardized.

The GLOBE program initiated in 1995 continues to grow and now includes over 13,000 schools in 102 partner countries, with 23,000 teachers having attended GLOBE workshops and GLOBE students having reported data from 9.7 million measurements worldwide. Science protocols now include Atmosphere/Climate, Hydrology, Soil, Land Cover/Biology, Phenology as well as several special observations such as hummingbird behavior, budburst and lilac phenology.

The Advanced Computing group initiated an investigation into how grid technology can be utilized by the atmospheric and ocean research communities. The project's goal is to determine the feasibility of running a coupled model on the grid with one model, e.g., atmospheric, running on one machine and the other, e.g., ocean, running on a second machine at another facility.

After successfully applying the wavelet transform data compression technique to satellite imagery, the wavelet compression technique, including a user-defined "precision control," was further modified to address 3-D gridded model fields. Early results with temperature fields indicate 2 to 6 times higher compression ratios compared to typical lossless codes with the same precision requirements.

2003-2004

Our climate modeling efforts (Northwest Mexican monsoon and Great Plains Precipitation) found that soil moisture anomalies had a greater impact than SST anomalies on monsoon circulations and precipitation.

Support of the U.S. Fire Consortia for Advanced Modeling of Meteorology and Smoke continued with enhanced fire weather products including a "Critical Fire Weather Index." Plots of surface latent heat flux forecasts and solar radiation observations were created to help diagnose and improve surface relative humidity forecasts.

Successfully implemented at CIRA and NESDIS/OSDPD a Total Precipitable Water product that combines AMSU and SSM/I sensor data from all the NOAA and DMSP satellites with these sensors.

Began simulation studies in support of NPOESS sensor risk reduction. Demonstrated a method for combining a numerical cloud model with an observational operator to produce synthetic NPOESS imagery.

Series of eddy resolving simulations (ERS), and large eddy simulations (LES) of smoke-cloud interactions were performed to demonstrate the relative importance of various factors responsible for cloud suppression in the biomass burning regions of Amazonia.

Completed the development of our Regional Atmospheric Modeling and Data Assimilation System (RAMDAS).

Developed a Southern Hemisphere tropical cyclone model now installed at the Joint Typhoon Warning Center.

Applied ensemble data assimilation and model error method to NASA's GEOS column precipitation model.

A specialized version of the Display-3D (D3D) interface for AWIPS was implemented for display of 3D lightning data at Cape Canaveral.

Novel visualization of global weather phenomena and in-the-round visualization of other planets and moons in our solar system were developed for the Science on a Sphere display platform.

The Virtual Institute for Satellite Integration Training (VISIT) has issued over 12,000 training certificates.

2004-2005

- Modeling studies have been completed on GCM sensitivities to cloud feedback, specifically shallow convection. The model sCAM has been used with several tropical data sets taken during BOMEX, ASTEX, and DYCOMS I and II. Year-long simulations have revealed several biases in the NCAR Community Atmosphere Model (CAM) including: anomalous precipitation patterns associated with the Asian Monsoon. The bottom line will be improved parameterizations in these climate models for precipitation and convection.
- CIRA has made further progress in using redundant ISCCP data to shed

light on the datasets' accuracy of cloud cover trends.

• Comprehensive model sensitivity studies have been performed on North American drought, floods and El Nino seasons using the monsoon convection as a telecommunication mechanism between monsoonal surges in Northern Mexico and convection in the central U.S.

• A prototype NOAA computational grid has been developed as part of an effort to explore the feasibility of combining geographically distributed computing resources into a single virtual resource (a computational grid). It includes processors located at the Forecast Systems Laboratory in Boulder, Colorado, the Geophysical Fluid Dynamics Laboratory in Princeton, New Jersey, and the Pacific Marine Environmental Laboratory in Seattle, Washington. A rudimentary grid-scheduler was developed to allow users to submit jobs from nodes anywhere on the grid. The coupling of atmospheric and oceanic models across the TeraGrid for climate applications is in progress.

• The Range Standardization and Automation (RSA) project was upgraded to a whole new set of IBM hardware and a new operating system (Advanced Server 2.0). This project is aimed at providing high-resolution analyses and forecasts to support space center activities at Cape Canaveral and Vandenberg AFB. Utilizing LAPS and the MM5 mesomodel, the RSA system creates high-resolution analysis and forecast products that support operations from the next few minutes to 24 hours in advance. The product set merges with the NOAA and USAF product streams for display on AWIPS. CIRA's efforts combined with those of other team members led to FSL and the LAPS branch being recognized with the 2005 NOAA Technology Transfer Award.

• A method to improve ensemble-based forecasts of maximum daily 1-hr and 8-hr averaged ozone concentrations was developed and evaluated. The method minimizes least-square error of ensemble forecasts by assigning weights for its members. Investigation showed that the magnitude of a weight does not necessarily correspond to the quality of the ensemble member. Maximum benefit in performance of the ensemble is achieved when weights are calculated daily, suggesting in a certain way the value of persistence as a forecasting tool.

• First year of proof-of-concept testing of local data assimilation and NWP within a NWS Forecast Office produced favorable results. Satellite, radar, and other local data were used for real-time initialization of the WRF model on a Linux cluster.

• Additional enhancements were implemented for the specially configured mesoscale ensemble forecast system comprised of MM5 and WRF model runs developed to support the Road Weather Maintenance Decision Support System (MDSS) for the FHA. New domain and products improve the input that provides forecast winter road conditions and recommended treatment options for road maintenance personnel.

• Display of the upstream contributing area (area of rainfall runoff) and downstream flow path (potential Flash Flood track) from an arbitrary large scale (small) FFMP watershed was added to the Flash Flood Monitoring Program (FFMP). This display improves the NWS forecaster's comprehension of the hydrologic processes and impact features involved in flash flood forecasting.

• Our work with the DoD on soil moisture is converging with NOAA's activities. We are currently finishing up a soil moisture data assimilation system that uses WindSat 6 GHz radiometer data as well as satellite IR and SSMI data. The 6 GHz channel provides deeper penetration and the modeling aspect should allow soil moisture analysis deeper than any sensor data can hope to achieve without a modeling component. The Backus-Gilbert work reported in the Satellite Applications section is a key element of this work.

• A breadboard etalon spectrometer and prototype analysis algorithm was developed to measure CO^2 remotely. This project, closely linked to the NASA OCO mission is an early development effort that could lead to a NOAA operational mission for the measurement of CO^2 sources and sinks at very high resolution.

• Improved statistical hurricane intensity forecasts developed. SHIPS improved by using satellite data and analysis shows eastern Pacific intensities improved significantly.

• A cross sensor blended total precipitation product (SSMI and AMSU) has been developed and delivered to OSDPD.

• A two dimensional Backus-Gilbert filter as been developed for general use to any satellite sensor and specifically for the WindSat data. This technology is critical to all passive microwave data utility within the modeling community. These data must be screened for RFI prior to model assimilation to be of any use over land.

• QuickSCAT data has been used to measure Gulf (Baja) surges as part of CIRA's multi-faceted work on the North American Monsoon Experiment.

• Series of eddy resolving simulations (ERS) and large eddy simulations (LES) of smoke cloud interactions were performed to demonstrate the relative importance of various factors responsible for cloud suppression in the biomass burning regions of Amazonia. The vertical distribution of smoke aerosol in the convective boundary layer was found to be crucial to determining whether cloudiness is reduced or increased. The study also pointed out the importance of coupling aerosol radiative properties and a surface soil and vegetation model to the microphysical-dynamical model. Under polluted conditions (associated, e.g., with biomass burning smoke), the surface flux response to the aerosol may be the single most important factor in cloud reduction.

• A major finding in the comparison of VIRS IR rain estimates to TRMM measurements was found. Results indicate the Iris hypothesis is not supported by the data. No trend indicating changes in precipitation efficiency was found in the 18-month period of study.

• During the past year, support of the RUC development continued, both at NCEP and at FSL. A new version of the operational RUC was implemented at NCEP on 28 June 2005, with increased horizontal resolution, down to 13km, several new data sources, and improved surface, precipitation and cloud forecasts. The RUC was also used extensively for data impact studies, most recently evaluating wind profilers, lidar and ACARS moisture observations.

• CIRA scientists collaborated on the design and development of a prototype WRF Portal – a Java-based GUI front end for running WRF. The design incorporates a mySQL database, Java application, and communication protocols between the client side application, WRF Portal, and server side workflow manager/job scheduler.

• The GLOBE Systems Team comprised of 8 CIRA researchers continued to provide website, database, and data acquisition support to the Program's worldwide users now located in 109 countries. There are now more than 13 million observations in the GLOBE database collected by students in over 16,000 schools since the Program's inception in 1995. The Program received the Goldman Sachs Foundation Prize for Excellence in international education (media and technology category) in November 2004.

• Science on a Sphere™ was installed this past year in its first permanent science museum location at the Nauticus Museum in Norfolk, VA. SOS continues in use at the Science Fiction Museum in Seattle. A full set of Jupiter's Galilean satellites is now available for display. Photo-mosaics of several Saturnian satellites were updated by reprojecting and overlaying recently taken Cassini flyby images. Maps of five Uranian satellites were added as well as one for Neptune. Some image processing was performed to add a high-resolution Voyager mosaic to a pre-existing map of Neptune's moon Triton.

• Satellite utility and educational efforts have been very active. Coordination with WMO on the role of satellite meteorology, investigations of improved spatial, temporal, and spectral data, Costa Rica training, and training sessions at the AMS Satellite Conference in 2005 have been conducted or are underway.

• The SHyMet training course, a collaboration between CIRA and CIMMS to develop a distance learning course on satellite hydrology and meteorology, is well underway. Currently NWS SOS's feedback is being incorporated into the program.

• The VISIT program has fulfilled all goals identified in 1998. This accomplishment has been validated from feedback from VISIT participants and students. 15,000 training certificates have been awarded and 15 teletraining courses have been developed. More and more NOAA offices are using VISIT.

• AHPS Regional Excellence Award received by Central Region for Climate Services Division's work on improving delivery of hydrological products. CIRA's sociological work (Dr. Deo) was critical to the improved understanding of customer needs, clear message generation, and the optimization of the process via workshops, focus groups, and prototype designs.

• The inventory of Tropical Cyclone IR imagery has grown to 336 storms in the 1995-2004 timeframe with 93,700 images to assist storm track, intensification and general research efforts.

• Delivered a new IT computer system based on DPEAS to OSDPD that saved them approximately $7M compared to standard IT systems for the processing of multi-platform data. If scaled to the 55 NPOESS EDRs, the savings would be approximately $385,000,000.

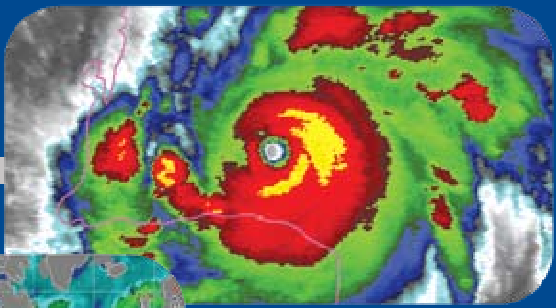
• The CloudSat Data Processing Center (DPC) was completed (hardware and software) during this period. CIRA DPC personnel are now awaiting the expected 20 April 2006 launch. The DPC's functions include data ingest from the USAF satellite earth station network, archive, production of standard products, distribution of products to the CloudSat science team members, and outreach to the broader science community. Please view the DPC website for the latest CloudSat updates. For product information http://cloudsat.atmos.colostate.edu/data/data.html and for the DPC http://www.cloudsat.cira.colostate.edu/

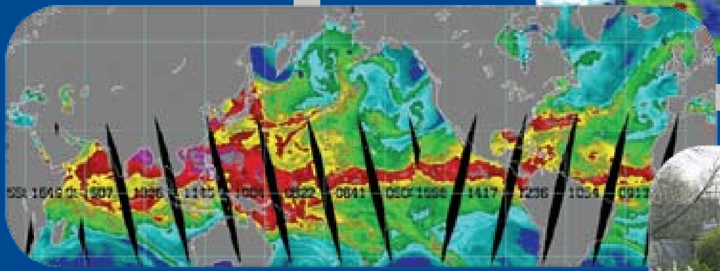
Acronyms

ADEOS	Advanced Earth Observing Satellite
AMSU	Advanced Microwave Sounding Unit
AVHRR	Advanced Very High Resolution Radiometer
AWIPS	Advanced Weather Interactive Processing System
AWRP	Aviation Weather Research Program
CALIPSO	French/NASA Lidar Satellite Comanifested with CLOUDSAT
CG/AR	Center for Geosciences/Atmospheric Research
CHANCES	Climatological and Historical Analysis of Cloud for Environmental Simulations
CLEX	Cloud Layer Experiment
COCORAHS	Collaborative Community Rain and Hail Study
COMET	Cooperative Program for Operational Meteorology, Education and Training
CPC	Climate Prediction Center
CSU	Colorado State University
CTOP	Cloud Top Height Algorithm
D3D	Display 3 Dimensions
DMSP	Defense Meteorological Satellite Program
DoD	Department of Defense
DOMSAT	Domestic Communications Satellite
DPC	Data Processing Center
EMDS	Emergency Management Decision Support
EPA	Environmental Protection Agency
ERBE	Earth Radiation Budget Experiment
ESRL	Earth System Research Laboratory
ETL	Environmental Technology Laboratory
FAA	Federal Aviation Administration
FHA	Federal Highway Administration
FSL	Forecast Systems Lab (became ESRL/GSD in 2005)
FX-NET	FSL X-Window Network
GAINS	Global Air-ocean In-situ System
GEOs	Geostationary Satellites
GEWEX	Global Energy and Water Cycle Experiment
GLI	Global Images (sensor)
GLOBE	Global Learning and Observations to Benefit the Environment
GOES	Geostationary Operational Environmental Satellite
GOES-R	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
GSD	Global Systems Division
HES	NOAA Satellite Sensor – Hyperspectral Environmental Suite
IHOP	International H2O Project
IMPROVE	Interagency Monitoring of Protected Visual Environments
INSAT	Indian Geostationary Satellite
ISCCP	International Satellite Cloud Climatology Project
JTWC	Joint Typhoon Warning Center
LAPS	Local Analysis and Prediction System
LDAD	Local Data Acquisition and Dissemination System
LEOs	Low Earth Orbiters

MM5	NCAR / Penn State Mesoscale Model
MODIS	Moderate Resolution Imaging Spectroradiometer
NASA	National Aeronautical and Space Administration
NATO	North Atlantic Treaty Organization
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NDIC	Natural Disaster Information Cards
NESDIS	National Environmental Satellite, Data and Information Service
NESS	Original name for NESDIS
NEXRAD	Next Generation of Radar
NHC	National Hurricane Center
NIFC	National Interagency Fire Center
NIMBUS	Networked Information Management Client-Based User Service
NOAA	National Oceanic and Atmospheric Administration
NOAA SOCC	NOAA Satellite Operations Control Center
NOAAPORT	NOAA Communications System Support NWS and AWIPS
NPOESS	National Polar Orbiting Environmental Satellite System
NPS	National Park Service
NREL	National Renewable Energy Laboratory
NRL	Naval Research Laboratory
NWP	Numerical Weather Prediction
NWS	National Weather Service
NWSFOs	NWS Forecast Offices
OEM	Office of Emergency Management
OGP	NOAA Office of Global Programs
OSDPD	Office of Satellite Data Processing and Distribution
PACE	Prototype Aviation Collaborative Effort
PMEL	Pacific Marine Ecology Laboratory
POWS	PROFS Operational Workstation
PROFS	Prototype Regional Observing and Forecast Service
RAID	Redundant Array of Independent Disks
RAMM Branch	Regional and Mesoscale Meteorology Branch
RAMS	Regional Atmospheric Modeling System
RAMSDIS	RAMM Advanced Meteorological Satellite Demonstration and Interpretation System
RASS	Radioacoustic Sounding System
RHR	Regional Haze Rule
RMTC	Regional Meteorological Training Center
ROL	RAMSDIS Online
ROMS	Regional Ocean Modeling System
RPO	Regional Planning Organization
RUC	Rapid Update Cycle
SMS	Scalable Modeling System
SOS	Science on a Sphere
SSM/I	Special Sensor Microwave Imager
ST5D	5-Day Statistical Typhoon Intensity Prediction Scheme
STIPS	Statistical Typhoon Intensity Prediction Scheme
TAQ	Temperature and Air Quality Study
TOGA	Tropical Ocean and Global Atmosphere Experiment
TPW	Total Precipitable Water
TRaP	Tropical Rainfall Potential
UAV	Unmanned Aerial Vehicle
VAX	Old Computer used at CIRA (32-bit computing architecture)

VIEWS	Visibility Information Exchange Web System
VIRS	Visible and IR Sensor on the POES Satellite
VISIT	Virtual Institute for Satellite Integration Training
VMS	Operating System in VAX Computer
WFO	Weather Forecast Office
WRAP	Western Regional Air Partnership
WRF	Weather Research and Forecast Model
XBTs	Expandable Bathythermograph





Knowledge to Go Places