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It is my pleasure to welcome you to the SSEC booklet. This document will introduce you to the Center and to the nature of our endeavors by providing a collection of short articles that span many of our ongoing activities and accomplishments. The articles are grouped into the three major functions of our work:

- to Observe,
- to Analyze,
- to Apply.

My intent in this message is to give you just enough information about the Center to whet your appetite before you explore the booklet. We certainly encourage you to read the whole document, but it is also intended for browsing. If you pick a topic of particular interest, you will find cross references to other related topics and relevant web sites. I hope you come away with a new perspective and excitement about our work and, especially, about possible areas of collaboration.

Initially inspired by the historic development of space platforms in the 1960s, SSEC’s mission is to conduct atmospheric, oceanic, environmental, and astronomical research using space-based and space-age techniques to discover and apply the physical properties of our universe for the benefit of humanity. As envisioned by its founders, Professors Verner Suomi and Robert Parent, SSEC is driven by the pursuit of science and its applications. The Center maintains a diverse and skilled team of people. Together, we strive for end-to-end involvement: converting ideas to concepts; developing designs; fabricating hardware and/or software systems; and, finally, producing results and products that make a difference.

Our work has many direct societal benefits. Our techniques and products derived from satellite data have improved hurricane predictions substantially and have had a positive impact on global forecasts from weather prediction models. As the launch of MODIS and the first high spectral resolution sounder (AIRS) signaled a new era of remote sensing, we have played a major role in product development and performance validation. The Center has continued involvement with the development of new polar and geosynchronous sounding instruments (CrIS and GIFTS). Additionally, we have continued our contributions to polar weather monitoring and research, and have started to apply satellite products to help improve aviation safety and to address environmental concerns. We also have provided a new home for the National Science Foundation’s Ice Coring and Drilling Services team.

As we look to the future, we expect further progress. Already, we have started to develop the next version of our renowned data analysis and visualization system (McIDAS-V) to handle the new flood of satellite data. We plan to find new applications for data from the advanced instruments that will soon orbit the Earth. As we continue to progress technologically, we will substantially improve weather and climate nowcasts and forecasts that have a crucial part in public safety and in industry. In new spaceflight science missions, we hope to participate in an x-ray astrophysics experiment, a cloud ice water content experiment, and a benchmark climate observing initiative. Formed through a Memorandum of Understanding among the University of Wisconsin-Madison, the National Oceanic and Atmospheric Administration (NOAA) and the National Aeronautics and Space Administration (NASA), our Cooperative Institute, CIMSS, put us in a position to make these and many other advances happen.

I want to thank all of the members of the SSEC team for their professionalism and effectiveness in making the many achievements described in this document a reality. I am proud of what we have accomplished together and excited about what the future has to offer.

-- Hank Revercomb
SSEC is a research and development center in the UW-Madison Graduate School. Pursuit of our mission includes the following:

- lead development of advanced space-based instrumentation for observing the Earth’s atmosphere, oceans and land surface, other planetary atmospheres, and astrophysical phenomena;
- lead and conduct research programs that improve our understanding of atmospheric, oceanic, environmental and astronomical sciences;
- facilitate the transfer of knowledge to operational observing and forecast systems;
- support campus research initiatives with technical, administrative and management expertise;
- support the UW educational mission by involving undergraduate and graduate students in the research process.

All of our activities are conducted with a commitment to education and public outreach, diversity, and free and open dissemination of knowledge. The SSEC Strategic Plan, available on our web site, provides more detail.

Director Hank Revercomb leads SSEC with the assistance of three Executive Directors: John Roberts for administration, Fred Best for technology, and Tom Achtor for science. Professor Steve Ackerman directs SSEC’s Cooperative Institute for Meteorological Satellite Studies (CIMSS). The SSEC Council, a group of senior scientists and UW-Madison faculty members, advises the team of Directors. Connections with the Department of Atmospheric and Oceanic Sciences permit SSEC/CIMSS to support graduate student research for more than ten students each year. The experience and affiliation with a research center provides an excellent path for young scientists entering geophysical fields.

Principal Investigators are the cornerstone of the Center. Principal Investigators supported by Project Managers lead the several hundred active SSEC projects. Each Principal Investigator is responsible for, and in charge of, all aspects of her/his research project. SSEC supports the Principal Investigators by providing the people, and the facilities and services to conduct their research effectively and efficiently. Critical to this process is the support of a talented, diverse scientific staff, and a highly trained professional administrative and technical staff.

Much of the Center’s success can be attributed to our “team” approach to research. The key elements that make this approach work are our people, our operating philosophy, our organizational structure, and our facilities and service centers.

SSEC has approximately 250 people with a wide range of professional specialties: a variety of scientific disciplines, science support, engineering, software development, electronics, quality and safety, instrument fabrication, human resources, purchasing, management and administration.

Our operating philosophy is that all SSEC projects will succeed. Equal commitments are made to projects led by internal Principal Investigators and from other Campus departments. To ensure that success, and the long term health of the Center, the fiscal and human resources of the Center are shared among all SSEC projects.

SSEC is a matrix organization. We have pools of talented people in many specialties available to support research projects. This structure allows Principal Investigators and Project Managers to use percentages of people’s time as needed without the responsibility for their future funding. More importantly this arrangement also allows the people with the desired talent to flow towards problems as they arise, solve the problems, and then move back to other projects. We have found this method to be an extremely efficient and cost effective way to do business, and to develop and maintain a talented and diverse staff.

SSEC has a first class research library, a state-of-the-art data center, a first rate machine shop, a class 1000 clean room, and many other research tools and facilities noted in this booklet. The service centers include professional staff in human resources, accounting, billing, purchasing, technical computing, travel, software development, safety, quality assurance, instrument fabrication, library science, and technical and financial management. The goal for these team members is to keep the Principal Investigator doing as much science and as little administrative work as possible.

This philosophy and organizational structure creates a “community” attitude within SSEC and the cooperation among the people that make up SSEC enables a positive, productive and exciting workplace.

--John Roberts, Fred Best and Tom Achtor
SSEC gathers information about different aspects of the Earth and its atmosphere by creating and using precise, accurate observational instruments. These instruments consistently raise the bar for remote sensing technology. SSEC also partners with government and industry to develop tools for planetary exploration and deep space measurements.
The Center’s leadership in remote sensing instrument design, development, and fabrication began with its founders, Professors Verner Suomi and Robert Parent. In 1958, Suomi designed and carried out the first space-based weather experiment, which studied the radiation budget of the Earth. In the 1960s, Suomi and Parent led a group of university, industry and government scientists and engineers in designing the spin-scan cloud camera, which, in 1966, flew onboard the first U.S. geostationary environmental satellite. This instrument revolutionized remote sensing of the Earth and other planets in our solar system; the spin-scan camera is the basis for instruments in use today. Suomi also conceptualized and SSEC played a prominent role in building the first atmospheric sounding instrument in geostationary orbit, the VISSR Atmospheric Sounder (VAS), launched in 1980. This instrument provided temperature and water vapor information throughout the depth of atmosphere.

During the 1980s, SSEC researchers fostered the evolution of high spectral resolution sounding instrumentation with the introduction of the High-resolution Interferometer Sounder (HIS). The SSEC interferometer program expanded through the 1990s with the development of the ground-based Atmospheric Emitted Radiance Interferometer (AERI) and the Scanning High-resolution Interferometer Sounder (Scanning HIS) aircraft instrument. SSEC’s expertise in interferometry has allowed the Center to play a major role in the design of operational space-based interferometer sounders within the U.S. and internationally.

SSEC also designs and deploys various instruments to test concepts and techniques for future space-based technology. By deploying these instruments on ground or aircraft platforms during field experiments, government organizations save tens of millions of dollars in the development of the best instruments for launch into space.

SSEC also has a long history of developing instruments and techniques that help ensure high quality data. The accuracy of environmental products derived from remote sensing data depends on reliable calibration. The SSEC blackbody program is crucial to its high quality calibration technology and techniques. SSEC has made significant contributions to the Earth-observing community through its development of interferometer calibration techniques and through its technologically advanced calibration blackbody radiance sources.

Our engineering team also supports NASA space-flight programs. Historically, SSEC has joined with government and industry to develop instrumentation for planetary exploration and deep space measurements, including the development of one of the original Hubble Space Telescope instruments, the Galileo Entry Probe’s Net Flux radiometer, and a Space Shuttle science mission, the Diffuse X-Ray Spectrometer.

Besides building and deploying its own instruments, SSEC advises government and industry on large instrument programs. For example, SSEC scientists have been involved with the definition of requirements and technical specifications of imaging and sounding instruments for the U.S. operational geostationary (GOES) and polar orbiting (POES) programs, and with the NASA Earth Observing System (EOS) satellite suite. The technical knowledge gained in developing our own instrument fleet helps us support the large, operational government programs that benefit all U.S. citizens and many in the rest of the world.
Even before results from the first geostationary sounder demonstrated Verner Suomi’s vision of measuring the Earth’s temperature and water vapor from a fixed vantage point 36,000 km above the Earth [17], SSEC unknowingly embarked on a long, fascinating journey of innovation. It began when a talented band of NOAA researchers came to Wisconsin to work with a team at SSEC in preparation for that first geostationary atmospheric sounder, known as VAS, which launched in 1980. Leading the way was another visionary, William Smith, who brought a unique background in atmospheric sounding from polar-orbiting satellites.* With the aid of SSEC’s new meteorological data processing system [22], the joint force of NOAA and SSEC researchers not only generated the first products from VAS but also began to investigate ways of measuring and modeling high spectral resolution radiation from the Earth’s atmosphere. Almost three decades later, this research continues to shape the Center and atmospheric science as a whole.

The Earth-emitted radiation at satellite altitude is shaped by the quantum mechanical properties of the trace gases molecules making up the atmosphere, and carries information about the vertical distribution of temperature and atmospheric composition. Applying the best existing models of these effects, researchers realized that the vertical information contained in atmospheric soundings could be improved by a factor of three if instruments observed broad regions of the emitted spectrum with the detail needed to characterize individual trace gas absorption lines.

With this foundation, SSEC launched the development of high spectral resolution measurement systems that could provide a revolutionary advance for research and for future operations. The promise of more rapid and more accurate warnings of the onset of severe storms, and overall improvements to long-term weather forecasts remains strong motivation for this research. [58]

By 1981, a team led by SSEC researchers had developed an advanced geostationary sounder concept called the High-resolution Interferometer Sounder (HIS). The primary goal of the HIS was to get much more detailed information about the vertical structure of the atmosphere, its vertical resolution, than was available from the existing instrument, which used a filter wheel to provide less than 20 discrete spectral channels. The HIS was based on a Michelson Fourier Transform Spectrometer (FTS) that could effectively provide more than 2000 spectral channels—a vast increase in information leading to better temperature, water vapor and trace gas soundings.

In order to further demonstrate that the HIS concept could provide the desired advanced measurements of the atmosphere from space, SSEC led the development of an aircraft instrument. Starting in 1985, the HIS aircraft instrument flew on the NASA U-2 (and later the ER-2) high-altitude airplane that simulates space operation by flying at 70,000 feet—above most of the atmosphere. This instrument successfully demonstrated interferometer technology and data processing techniques that could be employed on future geostationary and polar satellites to obtain the high vertical resolution atmospheric temperature and moisture profiles needed for improving both regional and global scale weather forecasts. Following the feasibility demonstration, the HIS aircraft instrument became a base for wide-scale atmospheric

* William Smith was the Principal Investigator for early sounders and for the HIRS, which still flies on NOAA operational satellites, who worked closely with the sounding pioneers at NOAA (Dave Wark) and NASA (Rudy Hanel) to realize the concept discovered by Louis Kaplan in 1959.
research and its success spawned other advanced FTS-based instruments for applications in space, on aircraft, on the ground and at sea.

In 1990, SSEC was asked by the European Meteorological Satellite organization (EUMETSAT) to provide an FTS-based satellite instrument design for a polar orbiting satellite. The project depended on SSEC’s experience gained from designing the HIS geostationary concept and flying the HIS aircraft instrument. While a successful design was developed, it was not chosen to fly on a European mission. However, the design has become the basis for the U.S. National Polar-orbiting Operational Environmental Satellite (NPOES) System’s Cross-track Interferometer Sounder (CrIS), which is currently under construction.

In the early 1990s, SSEC also started its development of the Atmospheric Emitted Radiance Interferometer (AERI) for the Department of Energy’s (DOE) atmospheric radiation measurement program. The AERI needed to provide high accuracy up-looking measurements of spectral infrared radiation at several surface sites around the world to support the global climate research program. This same instrument demonstrated a new and powerful ability for characterizing boundary layer changes by providing a continuous measurement of the vertical temperature and moisture structure of the lower atmosphere. The AERI can also be used to forecast the initiation of severe weather and the development of fog. [59] SSEC also developed a Marine AERI (M-AERI) to ride aboard ships and precisely (0.2°C) measure ocean surface temperature in support of a global climate analysis program. An AERI in SSEC’s mobile ground-based observatory called the AERIbago makes similar observations to map land surface temperature and emissivity for satellite validation programs.

In the mid-1990s, with funding from DOE, and later NASA and NOAA, SSEC developed a next generation FTS-based aircraft instrument called the Scanning HIS. By continually scanning side-to-side across the flight track, this instrument can generate images from the scene below with 2 km spatial resolution, simulating future satellite imaging and sounding instruments. The instrument can also look up at the sky to sense the stratosphere. The Scanning HIS was engineered to have state-of-the-art performance and to be very robust, reliable and well-calibrated, and to have low maintenance needs in the field. The instrument is designed to fly on four aircraft platforms: the NASA DC-8, ER-2, WB-57, and the Scaled Composites Proteus. The Scanning HIS has successfully demonstrated the capabilities that can be realized from future advanced imaging sounders and, due to its high accuracy and reliability, the Scanning HIS has also been used extensively to validate measurements from existing satellites. The absolute agreement between the Scanning HIS and the first high resolution sounder, AIRS (aboard the NASA Aqua platform), is quite spectacular. One of the future sounder instruments that benefited from Scanning-HIS experience is the Geostationary Imaging Fourier Transform Spectrometer (GIFTS) for which SSEC has played a key role in both the instrument development and in defining the algorithms and methods for performing the data processing.

-- Fred Best and Hank Revercomb

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**Point and Click: Web Spotlight**

Check out AERI at:  
http://cimss.ssec.wisc.edu/aeri/

And S-HIS at:  
http://deluge.ssec.wisc.edu/%7Eshis/
In the field

From Antarctica to the Bahamas to right in our backyard, field campaigns take SSEC personnel and instruments around the globe. For one notable experiment, a crew of SSEC scientists, engineers and students headed to the southern United States with a plethora of scientific expertise and a suite of instruments ready to measure the state of the atmosphere.

This field campaign, the International H2O Project (IHOP 2002), drew scientists from agencies and universities in the U.S., Canada and Europe to sites in Kansas, Oklahoma and Texas.

A couple of SSEC employees drove from Wisconsin to Oklahoma in a Winnebago converted into a mobile weather lab called the AERIbago. The AERIbago is in part named for one of the instruments on board – the AERI. For IHOP, researchers combined measurements from the AERI in the ‘bago with those from a small group of AERIs already in place in Oklahoma as part of the Department of Energy’s long-term Atmospheric Radiation Measurement Program.

In addition to the instruments in the AERIbago, SSEC gathered data with its Scanning HIS. Unlike the ground-based AERI, the Scanning HIS takes measurements while aboard aircraft flying at high altitudes. SSEC personnel also provided support for NASA’s interferometry instrument.

While operating the Scanning HIS and the AERI, SSEC also provided field program meteorologists on-site access to innovative satellite products from GOES, such as Total Precipitable Water (TPW), Lifted Index (LI) and Convective Available Potential Energy (CAPE). The IHOP field program provided excellent opportunities to evaluate the utility of these satellite products for use in severe weather forecasting. Field experiments such as IHOP yield detailed data sets that provide opportunities for re-examination back at home as case studies of “interesting weather days.”

As is typical for SSEC’s field work, efforts at IHOP spanned both the science and engineering aspects of the campaign. The information gathered through IHOP continues to improve the accuracy of measurements of temperature, moisture and rainfall as well as how these properties change over time. These data sets will be essential in demonstrations of the potential benefit of future satellite instrument systems to detect the precursors of severe thunderstorm development by monitoring temperature, moisture, and wind information. [33] Corresponding instrument development will improve measuring capabilities, which will ultimately advance the understanding of Earth’s environment and create new opportunities for scientific exploration through new instrument technology.
Although SSEC’s team at IHOP devoted most of their time and energy to research activities, some found adventure. One group chased a thunderstorm across the Southern Great Plains. In Oklahoma, the huge hail storm pelted the storm chasers. Much to the delight of this weather-obsessed group, relatively large hail stones blanketed the landscape completely. During field campaigns, SSEC researchers and technicians spend long days gathering data and operating instruments, but they also explore their surroundings and frequently enjoy the experience.

Field experiments have an important place in the research cycle. Scientists use field experiments to learn more about the atmosphere in specific places, verify the quality of satellite data, and make fine-scale adjustments to in situ and remote sensing instruments. SSEC’s participation in a spectrum of field experiments extends from the ground with instruments such as the AERI to the clouds with airborne instruments such as the Scanning HIS to space with satellite instruments and data assimilation techniques. “Some of our best work gets done at these field experiments because you have no other distractions that you normally have ... in the office and you’re working with all these different people and everybody’s really excited about their data,” said Steve Dutcher, a CIMSS researcher. “The collaboration with the different groups and universities is really beneficial.” Each year brings new collaborations and new adventures as SSEC researchers head into the field in service of scientific and technological progress.

--Jen O’Leary

Point and Click: Web Spotlight

For a summary of SSEC field programs and links to sites that detail specific experiments, please visit:

http://www.ssec.wisc.edu/experiment/
To gather useful information about weather and climate, remote sensing instruments require a high level of accuracy. This accuracy can be achieved by having the instrument periodically view two reference sources of different, but known, light intensity (or radiance). The instrument uses these values to calibrate measurements of unknown radiance. The higher the accuracy of the radiance sources the more accurate the instrument's measurements can be. SSEC maintains a tradition of developing highly accurate infrared calibration sources, known as blackbodies, for remote sensing instruments that observe thermal emission from the atmosphere and the Earth's surface.

SSEC started developing blackbody calibration sources in the 1970s to support laboratory testing of the Net Flux Radiometer instruments built at SSEC for NASA's Pioneer Venus Mission. In a controlled laboratory environment, these blackbody sources provided known values of energy emitted in rays or waves, called radiances, to instruments that measure emitted radiation. Laboratory testing of these instruments, known as radiometers, with blackbodies helped researchers determine how to properly convert the signal sent back from Venus into a thermal infrared radiance.

Developing well-characterized radiance references has received ever higher priority as greater absolute calibration accuracy is required to improve remote sensing of the Earth in our efforts to understand weather and climate. For example, even 0.1 K changes per decade can be significant for climate studies. In addition, more accurate observations are essential to assessing and improving the radiative transfer models used in forecast models and for remote sensing retrievals.

To advance the performance of infrared remote sensing instruments, SSEC has developed several infrared spectrometers that incorporate blackbody calibration sources as a fundamental part of the instrument to provide self-calibration during normal operation. These infrared spectrometers, used primarily for measuring the intensity of the Earth’s atmospheric radiation at different wavelengths, include the Scanning HIS, which gathers measurements by looking down from aircraft; and the ground-based AERI. These instruments use two blackbodies operating at different temperatures to establish a calibration scale for the measured atmospheric infrared radiance.

More recently, SSEC has been responsible for developing the on-board calibration system for NASA’s Geostationary Imaging Fourier Transform Spectrometer (GIFTS) – a demonstration of advanced technology for future weather satellites. For its calibration, GIFTS uses two blackbodies operating at two different temperatures in combination with views of deep space.

Blackbody design has improved steadily from the days of Pioneer Venus through the more modern GIFTS project. Over this time SSEC has developed the design capabilities, fabrication techniques and laboratory calibration capabilities needed to provide state-of-the-art blackbody calibration sources to the atmospheric science community.
Blackbody basics

A blackbody calibration source outputs a precisely known radiance that can be periodically viewed by an instrument designed to make accurate quantitative measurements of radiant intensity in the energy spectrum. A blackbody calibration source used for critical atmospheric measurements typically consists of a blackened light-trapping cavity with a viewing aperture that sustains a constant known temperature, usually between -60°C and +60°C.

In a high quality infrared blackbody source, almost all of the light energy that is emitted at the aperture originates from within the controlled cavity. Only 0.1% of what leaves the aperture is reflected light energy that originates from the uncontrolled environment outside the cavity (the blackbody cavity in this example is said to have an emissivity of 0.999). This kind of blackbody performance is achieved by using a highly absorbent black paint in combination with a special cavity geometry that causes any light entering the blackbody aperture to bounce several times before it re-emerges from the cavity.

Blackbodies for a new spaceflight instrument

To support advanced weather forecasts, temperature measurements of the atmosphere from space must be determined with an uncertainty that does not exceed 1 K. For the GIFTS instrument to make these kinds of measurements the absolute temperature of the blackbody cavity must be known to within 0.1 K and the cavity emissivity must be known to within 0.2% (assuming the cavity emissivity is 0.996).

The blackbody system delivered for the GIFTS Engineering Development Unit significantly exceeds these requirements, and serves as a prototype for future climate missions that have more stringent calibration performance requirements. For this system, the spectral emissivity of the delivered blackbodies is better than 0.999 with an absolute uncertainty of better than 0.1%, and the absolute temperature measurement uncertainty is less than 0.06 K.

New developments

To support key future climate monitoring applications, SSEC is developing new techniques for in-flight verification of blackbody emissivity and temperature measurements that will further reduce overall measurement uncertainty. As the Center did for GIFTS, the new techniques will exceed current standards and will set a new benchmark for calibration accuracy.

--Fred Best

A GIFTS blackbody, that serves as an on-board radiance standard, is shown without its casing in the photo on the left. The cut-away figure on the right illustrates the key components of the blackbody, including: 1-inch entrance aperture, blackened cavity, heater, and temperature sensors. The GIFTS blackbody design builds on the Center’s strong heritage of developing and calibrating infrared instruments for atmospheric observations.
Making the invisible visible

Conditions in the lowest kilometer of the atmosphere can change very rapidly and have a significant impact on the Earth and its inhabitants. In an effort to improve measurements of this layer of the atmosphere, called the convective boundary layer, a group at SSEC designs and builds innovative laser instruments known as Light Detection And Ranging instruments, or lidars.

The faint green light coming from the top of the building is the lidar’s laser.
SSEC lidars measure the properties of cloud particles and aerosols by emitting laser pulses that change direction, or scatter, when they collide with objects. Portions of the laser beam bounce back to the instrument, which then analyzes how the beam has changed and determines how long the beam took to return. The changes to the beam provide information about the particles’ properties and the time measurement indicates how high in the atmosphere clouds and aerosols are located.

The precision and advanced optical elements of SSEC lidars allow these instruments to directly observe the type and size of a cloud particle. SSEC lidars provide information that allows researchers to ascertain whether a cloud consists of ice, water, or a mixture.

Since 1967, the SSEC lidar group has developed a series of increasingly complex instruments. For example, the Volume Imaging Lidar (VIL) uses computer-controlled scanning that, with continuous pulses, creates an image of a large volume of sky at one time. Averaged wind measurements can be accurately deduced from the VIL images, providing important, but often elusive, information for numerical models. VIL scans are analyzed for wind speed and other parameters extracted from extremely dense data, and transformed into images of elements such as plumes of warm air and wispy cirrus clouds. Until the 1990s, no other lidar approached the VIL’s four-dimensional imaging capability.

The lidar team’s other system, the High Spectral Resolution Lidar (HSRL), can “see” even more than the VIL because the beam of light returning to the instrument can be split to help distinguish the effects of backscattering from those of the beam’s extinction. Splitting the beam provides a more accurate characterization of individual objects within its view.

The Arctic HSRL (AHSRL), an automated, more complex version of the HSRL, was first used operationally in November 2004. The instrument participated in the Department of Energy’s Mixed-Phase Arctic Cloud Experiment (M-PACE), a month-long study of Arctic clouds. Data retrieved during that study is used to augment climate models. Before its first trip to the far north, the Arctic HSRL was used to calibrate the lidar on NASA’s ICESat as it flew above UW-Madison’s Atmospheric, Oceanic and Space Sciences building.

The AHSRL returned to the Arctic in July 2005 at Eureka Base, a Canadian research outpost on Ellesmere Island, for NOAA’s Study of Environmental Arctic Change (SEARCH) program that studies Arctic climate change in detail. Eureka is the northernmost point from which to track geostationary communications satellites. These ‘comsats’ are the conduit for software, diagnostics and data to and from SSEC. The SSEC lidar is automated but is monitored closely via the Internet and its observations are transmitted by satellites. A web-based real-time data display enhances the AHSRL by making the data easily accessible and available free of charge over the Internet.

The HSRL remains one of the most technically advanced lidars in the world and is the first of its kind. Only a global view would make these lidars more useful, which would require HSRLs to be mounted on satellites. The next step towards achieving this goal is the creation of an aircraft model.

Work has begun on a version of the Arctic HSRL that will fly on a new airborne research platform called the High-performance Instrumented Airborne Platform for Environmental Research, or HIAPER. The National Science Foundation funds this work. Based at the National Center for Atmospheric Research (NCAR) in Colorado, HIAPER cruises at an altitude of more than 41,000 feet, which gives the instrument the ability to conduct research near the tropopause. It also can cover 6,000 nautical miles in one flight, the next best thing to a satellite orbit around the Earth.

--Ed Eloranta and Terri Gregory

Before heading to the Arctic, this lidar was tested in the penthouse of the AOSS building and gathered data through a skylight.
The SSEC Ice Coring and Drilling Services (ICDS) team provides support for NSF-sponsored research on glaciers both in the polar regions (including the great ice sheets of Antarctica and Greenland) and at high-altitude sites (such as at 7,000 m on the Tibetan plateau). Ice cores from regions so cold that surface snow does not melt even in midsummer contain a wealth of paleoenvironmental information both in the ice crystals themselves and in the air bubbles that are trapped between them. As the snow continually piles up on the surface, the older layers beneath, buried ever deeper, gradually change into ice. The greater the depth within the ice from which a core comes, the older the environmental record it contains. 800,000-year-old ice has recently been recovered from the base of the Antarctic ice sheet, but most coring projects are much more limited in scope, collecting ice cores that are merely a few hundred years old.

With about a dozen full-time engineers and several seasonal drillers, ICDS maintains and operates a stable of drills, and develops new systems when needed, to provide the best possible ice cores from all depths. The group’s noncoring drills provide access to the interior and beds of ice sheets and glaciers for such purposes as embedding instruments, collecting gas samples, setting off seismic charges, and studying subglacial processes.

A particular focus of ICDS activities is the development of a new-generation Deep Ice Sheet Coring (DISC) drill to provide cores down to the rock bed in Antarctica. It is capable of coring through 3,800 m of ice and includes a navigation package that monitors the straightness of the hole, allowing preventative measures to be taken if drift occurs. Other design improvements over existing drills are: much faster trip times in and out of the hole, streamlined operations at the surface, the capability to recover multiple cores over depth intervals of particular scientific interest (“replicate coring”), and to sample the subglacial rock. The DISC drill will in part support a deep ice coring program on the West Antarctica Ice Sheet (WAIS) that will develop interrelated climate, ice dynamics, and biologic records to help understand interactions among global Earth systems. Particularly, the WAIS Divide program aims to develop detailed climate records for the most recent 40,000 years and beyond.
ICDS also supports scientists from Boston University and the University of Maine in studies of ice in Antarctica’s Dry Valleys, the coldest desert on Earth. Boston University studies buried ice that may be the oldest on the planet or maybe relatively recently frozen groundwater. This group uses ICDS to drill holes through different places in the Mullins Valley Glacier, possibly drilling past an occasional rock and downward through the ice to 20 meters. This experience will help ICDS to learn more about the debris content in these glaciers to help determine specifications for a dedicated “dirty-ice drill” that can penetrate ice with certain amounts of debris.

Scientists from the University of Maine collect high-resolution ice core records from this cold, arid place to help interpret interannual to decadal-scale climate variability during the last 2000 years. In particular, they seek to test hypotheses related to ocean and atmosphere teleconnections (e.g. the El Nino Southern Oscillation and the Antarctic Oscillation) that may be responsible for major late Holocene climate events.

ICDS also works with the multidisciplinary International Trans Antarctic Scientific Expedition (ITASE) that endeavors to increase understanding of environmental change in Antarctica over the last two centuries to 1000 years. For ITASE, ICDS drillers have collected almost 40 ice cores in West Antarctica.

For the IceCube project, a neutrino telescope set in a cubic kilometer of ice at the South Pole, ICDS designed the Enhanced Hot Water Drill (EHWD). The EHWD will drill up to 80 holes, each about 0.5 m in diameter and 2400 m deep, which house sensor strings. ICDS staff continue to help with construction of the drill and the drilling itself. IceCube is an international collaboration of physicists headquartered at the University of Wisconsin-Madison.

For these and all NSF sponsored projects, ICDS provides the drills and extracts the ice cores from Antarctica and other cold places that will yield a better understanding of the Earth’s climate.

-- Charles Bentley, Don Lebar and Terri Gregory

Point and Click: Web Spotlight

http://www.ssec.wisc.edu/icds/
The first space-bound instrument designed and built at SSEC was the Flat Plate Radiometer. Professor Suomi developed the concept for this instrument, which was first launched aboard a U.S. polar-orbiting satellite in 1959. By making measurements in the solar and long wave portions of the spectrum, SSEC’s flat plate radiometers provided the first observations of the exchange of energy between the Earth and space—called the Earth’s radiation budget.

Another spaceflight project continued SSEC’s quest to gather information about the energy in the sky. In 1975, NASA launched the Orbiting Solar Observatory-8 (OSO-8), which housed the instrument for the Soft X-ray Background Radiation Experiment. Led by Professor William Kraushaar, members of UW-Madison’s Department of Physics devised the experiment while SSEC engineers developed and built the instrument, which consisted of three proportional x-ray counters. The maps generated from this experiment provided the first comprehensive survey of the low energy x-ray sky.

Beyond constructing instruments to observe the Earth and sky, SSEC has also developed instruments to investigate other planets. SSEC’s participation in NASA’s Pioneer Venus Mission is one example. For this mission, SSEC designed and assembled three heat flux sensors called Net Flux Radiometers. Launched in 1978, the sensors rode on small probes protected by conical heat shields. The data from SSEC’s net flux radiometers contributed to the first exploration of the atmosphere surrounding Venus to the planet’s surface. (pictured top right)

In another effort to gather data about space, SSEC collaborated once again with the Department of Physics for the Diffuse X-ray Spectrometer (DXS) experiment. Traveling aboard Space Shuttle mission STS 54, the DXS collected data from January 13 to 19, 1993. Even the limited amount of data collected on the eight-day shuttle flight provided sky maps of low-energy x-rays at the highest available resolution and made it necessary to correct existing models describing interstellar space. (pictured left)

SSEC’s longest spacecraft development project began in the fall of 1977 when the High Speed Photometer (HSP) was selected to be one of the Hubble Space Telescope’s five initial instruments. HSP was developed and built by SSEC in collaboration with Professor Robert Bless of UW–Madison’s Space Astronomy Laboratory. This instrument took precise measurements of variations in visible light at speeds up to 100,000 observations per second. The Hubble Space Telescope went into space in 1990. The photometer operated until 1993 when it was removed to make room for corrective
SSEC engineers designed and built this instrument for the Soft X-ray Background Radiation Experiment. The HSP provided the first high resolution light curves of a supernova remnant and even years later was providing archived evidence that confirmed the existence of black holes.

In addition to these major instrument development programs, the SSEC spacecraft hardware development group has been involved in many other mission collaborations.

- The two-part Galileo mission to Jupiter (orbiter and atmospheric entry probe) carried an SSEC instrument to measure local radiative heating and cooling of the atmosphere during the probe’s descent. This Net Flux Radiometer began its development at the Martin-Marietta aerospace company under direction of NASA’s Ames Research Center and was later modified, calibrated, and successfully operated under the direction of SSEC’s Dr. Lawrence Sromovsky.

- SSEC worked with UW’s Space Physics group to build an Adiabatic Demagnetization Refrigerator (ADR) for NASA’s Goddard Space Flight Center. For optimal operation, the ADR uses salt crystals at its center to keep a detector at extremely low temperatures required. It is used on ASTRO-E, a collaboration of NASA with Japan’s space agency.

- SSEC’s control system for the WIYN Telescope on Kitt Peak introduced a capability for remote observation and control. WIYN is a consortium of Wisconsin, Indiana, and Yale universities and the National Optical Astronomy Observatories. SSEC completed the design for and constructed the control system, making it possible for astronomers to observe without being present at the telescope.

- Blackbody calibration cavities developed for the Geosynchronous Imaging Fourier Transform Spectrometer have achieved exceptional performance levels. [10, 71] SSEC scientists and engineers devised and created this unique calibration system.

SSEC has a history of successful spaceflight instrument development programs spanning nearly four decades and looks forward to applying this rich heritage to the challenges of the future.

--Evan Richards and Terri Gregory
Spanning generations
Working with geostationary satellites

Beginning with the vision of Professor Verner Suomi to watch the Earth’s weather from space, SSEC has kept at its core a desire to exploit the capability of continually monitoring the Earth’s atmospheric system from the geostationary perspective. At the unique orbit of 36,000 km above the equator, geostationary satellites rotate around the Earth in 24 hours, continually poised above the same location, constantly monitoring the Earth and its weather within the approximately one third of the globe that they see below.

This image is from 23 August 1985 and shows tropical storms Humberto, Iris, Karen and Luis.
One can extract much information from the geostationary sentinels in the sky beyond the most basic applications of just “seeing” the land and water, and includes a variety of clouds ranging from hurricanes and extratropical cyclones to severe convective storms, fog, and cirrus streaks. In the late 1970s, SSEC used its Man-computer Interactive Data Access System (McIDAS) to track cloud features within a sequence of geostationary satellite images to determine the wind within which the clouds were moving. SSEC researchers first performed this quantitative analysis during the First Global Atmospheric Research Program (GARP) Global Experiment (FGGE) from 1978-79. The analysis was human and keyboard intensive, and initially limited to just one visible and one longwave infrared window channel. This pioneering effort of measuring “cloud drift winds” has evolved into a mature process, now accomplished objectively with little human or keyboard input. The modern process utilizes water vapor spectral bands to determine wind vectors in regions without clouds, and has become an essential component in tropical storm forecasting.

Another even more ambitious application of remote sensing measurements from geostationary orbit is the generation of vertical profiles of the atmosphere’s thermal and moisture fields. Beginning with GOES-4 (Geostationary Operational Environmental Satellite) in 1980, an infrared sounding instrument was added to each spacecraft. With pioneering efforts led by Bill Smith, Kit Hayden, and Paul Menzel, SSEC began to successfully generate atmospheric profiles by using mathematical methods to retrieve temperature and moisture parameters from the observed radiance data in just 12 infrared bands. Since the resulting retrievals did not provide significantly and consistently improved depictions of the atmosphere, relative to other data sources routinely used by National Weather Service (NWS) forecasters at the time; the development of improved sensors remained critical. In 1994, the current suite of operational geostationary sounders was introduced with GOES-8, providing more channels, better spatial resolution, less instrument noise, and much more flexible scanning scenarios. Several other products are extracted from the vertical temperature and moisture profiles that are also useful to forecasters, including total precipitable water vapor and several atmospheric stability products.

Research efforts at SSEC continue to obtain the best information possible from the vertically limited resolution of the current sounders. Software designed through a collaboration between SSEC and NOAA/NESDIS researchers to process retrievals continues to be incorporated into NOAA operations, distributing the latest GOES retrieval profiles and derived product imagery to forecasters in NWS field offices.

While it remains important to glean the most valuable information from current GOES retrievals, the latest effort for improving geostationary sounding is the development of the hyperspectral sounder. High spectral sounding will significantly improve vertical resolution and provide much greater coverage for future operational missions.

Although clouds prevent full atmospheric profiling beneath them when using infrared sensors, clouds themselves are important to forecasters and atmospheric scientists. In a complementary sense, cloud retrievals of height and amount are also generated from geostationary satellite data. Since the early 1990s, the NWS has used such satellite cloud information to supplement surface-based observations from hourly surface station reports.

The assimilation of cloud information acquired by satellites has improved significantly. The CIMSS Regional Assimilation Model, an experimental numerical model, includes explicit cloud physics elements. Cloud parameters from GOES (cloud-top pressure, effective cloud amount, cloud identification) were used to tune the cloud physics, convective parameterization, and the grid-scale precipitation. CRAS modelers developed a technique to initialize three-dimensional cloud fields for the model.

As a part of the GOES-13 post-launch NOAA Science Test, in which SSEC scientists participated, the satellite provided continuous “full disk” images every 30 minutes for two consecutive days. The current operational GOES full disk imaging interval is only once every 3 hours. GOES-13 6.6µm “water vapor channel” imagery (above) showed cloudiness as well as non-cloudy water vapor circulations within the middle troposphere.
The GOES platform can also be used to observe the initial stages of deep convective clouds. As cumulus clouds grow, many simply dissipate while others may grow into towering cumulonimbus. A technique to track developing cumulus clouds over time and identify those likely to develop into thunderstorms is useful to forecasters. Even though the current GOES satellite program is in a mature stage, developing techniques such as this convective initiation scheme continue to extract added benefit.

Another successful application of GOES data has been the detection and description of fires, as well as of the ensuing smoke and aerosol output, especially over large otherwise data-void regions of the Earth. Pioneering work at CIMSS investigated biomass burning over South America in the 1980s. The fire and smoke monitoring capability from geostationary orbit has evolved into a real-time tool, covering much of the Western Hemisphere.

The international suite of geostationary satellites offers a unique and powerful capability to frequently monitor the Earth and its atmosphere. Ask any forecaster today to do their job without satellite data, and one would be hard pressed to find willing volunteers. From observing severe thunderstorms every few minutes, to seeing the diurnal signal in prescribed agricultural burning in remote Amazon regions, to depicting the wind fields around tropical storms several times a day, to showing the fluid continuity in the global dynamic patterns so dramatically portrayed in water vapor imagery, the geo sentinels in the sky are invaluable. SSEC has helped lead the way, and continues to advance their applications.

--Gary Wade

### Point and Click: Web Spotlight

CIMSS research meteorologists maintain a blog that contains interesting and relevant satellite images. Each post features at least one image with an explanation of the scientific or social significance.

Please visit the CIMSS Satellite Blog at: http://cimss.ssec.wisc.edu/goes/blog/

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### Facilities

SSEC is housed in a 15-story building on the University of Wisconsin-Madison campus. SSEC provides the full range of capabilities and facilities necessary for the design, analysis, development, and testing of scientific instruments, including (but not limited to):

- the Man computer Interactive Data Access System (McIDAS), an interactive hardware and software computing system designed primarily for the analysis and display of weather and climate data;
- a Center-wide network of computing clusters and workstations, including a subset of systems focused on calibration, retrieval and display of advanced sounder data sets;
- the facilities and staff necessary to design and manage large-scale software projects to meet data processing and visualization needs;
- sophisticated electronics modeling and layout design capability along with fully equipped electronics assembly and test laboratories;
- an extensive machine shop suitable for manufacturing of high quality products compatible with space qualification standards;
- a quality assurance system that ensures that products exceed customer and end user expectations;
- sophisticated mechanical and thermal design and modeling capability;
- mechanical assembly areas, electronics board assembly and test labs;
- electro-optical design and analysis capability;
- numerous temperature test chambers and thermal vacuum test chambers;
- a Class 1000 clean room (less than 1000 particles larger than 0.5 microns per cubic foot of air space), including Class 100 laminar flow benches;
- a state-of-the art temperature metrology lab used primarily for calibrating blackbody radiance standards;
- an off-site warehouse facility that provides the capability to construct and test ice coring and drilling systems.
The Rooftop Instrument Group (RIG) is a collaboration with the Department of Atmospheric and Oceanic Sciences that provides:

- temperature
- dew point temperature
- wind direction and speed
- pressure
- precipitation
- solar radiation
- precipitation
- solar radiation

The instrument group includes: pyranometer, wind monitor, temperature and relative humidity probe, pressure sensor, and rain gauge.

SSEC’s mobile weather lab, the AERIbago, is a modified 1994 Winnebago designed to deploy multiple weather instruments easily and quickly. The AERIbago contains:

- an Atmospheric Emitted Radiance Interferometer to obtain hyperspectral radiances including retrieved temperature and moisture profiles;
- a ceilometer that measures the altitude of the base of overhead clouds;
- a surface weather station mounted on top of the ‘bago to measure wind speed and direction, temperature, pressure, and relative humidity;
- a Vaisala balloon launching system to retrieve vertical profiles of temperature, humidity, and wind;
- a Global Positioning System receiver that enables wind direction and water vapor measurements;
- (coming soon) a microwave radiometer;
- (coming soon) an advanced lidar.

Find real-time RIG data on the web at:  
http://rig.ssec.wisc.edu/
Step Two:

This image depicts cloud top pressure data from the sounding instrument aboard GOES-11 and -12. The text running down the left side of the page is a portion of the code used to turn the GOES observations into an image of cloud top pressure over the U.S. The image along the right side of the facing page is a cluster of processors that SSEC researchers use to run more complicated algorithms.
Since its creation in 1972, the SSEC Data Center has cultivated the technology and skills to acquire, distribute and archive real time data from U.S. and international environmental satellites. The Data Center helps SSEC manage the large amount of data acquired via the “antenna farm” on the building’s roof. The Data Center plays an essential role in SSEC research, providing scientists with access to data in real time and to its archives for retrospective studies.

The ability to interact with and visualize data is essential to deriving maximum benefit from the measurements. SSEC invented the first such computer system for this purpose. The Man-computer Interactive Data Access System (McIDAS) revolutionized the use of meteorological data. SSEC scientists are combining the legacy of McIDAS with the new, powerful multi-dimensional imaging power of VisAD to create a new data manipulation and visualization system for the next generation of environmental satellites and forecast models.

SSEC also works with scientists around the globe to develop techniques to extract essential information from each observation and to combine the observations for use in numerical prediction models through a process known as data assimilation. Along with steadily improving techniques, recommendations from SSEC founded in data assimilation studies have contributed to the preparation of numerical prediction models for new satellite instruments that will deliver even greater quantities of data than the current instruments. After assimilating the data, SSEC researchers develop radiative transfer models to simulate how energy moves through the atmosphere.

Beyond research and technological advancement, SSEC organizes workshops to help others learn how to handle the deluge of data gathered by remote sensing instruments. These workshops develop skills throughout the world for the next generation of scientists.
The SSEC Data Center is a unique facility that provides access to, maintenance for, and distribution of real-time and archived geophysical data to researchers around the world. These data include weather satellite and radar data, in-situ observational reports, and gridded numerical forecasts. The Data Center receives data in real time from most geostationary and polar-orbiting satellites operating for the United States and internationally. The Data Center also serves as a direct broadcast reception facility for NASA’s Earth Observing Satellites Terra and Aqua, receiving data for much of North and Central America. This accessible wealth of data is a critical resource to SSEC as well as to our research collaborators, commercial companies, organizations, and individual researchers worldwide.

SSEC established its Data Center in 1972 to support users of the new McIDAS software program. Its satellite data archive extends back almost that far, to the Global Atmospheric Research Program’s Atlantic Tropical Experiment in 1974. The Data Center began routinely storing U.S. geostationary satellite data in 1978 and has continued to do so through the present.

From 1979 through July 2005 the SSEC Data Center was partially funded by NOAA to continue the GOES archive and to provide that data to the customers of NOAA’s National Climate Data Center. The SSEC Data Center maintains one of the largest online GOES data archives in the world. Much redundancy is built into the Center’s computer system, so data are seldom lost.

The Data Center also provides data to scientists around the world and to organizations with unique, very specific needs. For example, Honeywell Aerospace contracts the Data Center to provide weather information that are transmitted to the cockpits of commercial airlines. Using Honeywell software, pilots can view products that contain information about clouds, winds, turbulence, and storm activity. As a self-supporting facility, SSEC’s Data Center sells customized data products to museums and commercial companies.

The most recent addition to the Data Center is a large data storage system. In January 2006, the Data Center began archiving all GOES data onto this RAID-based system as the Center receives it from satellites. The staff of the Data Center has also started to transfer past GOES data from magnetic tapes to the new online storage system. As a part of this process, the staff verifies and updates the data and inventory. Eventually, the Data Center will have a complete archive online, extending back to 1978—a feat requiring about 400 terabytes of storage space.

A significant feature of the Data Center’s storage system is that it stores raw satellite data. Because the data are not processed in any way, a user can apply a single calibration factor across time or across generations of satellites. Preserving and making the data accessible as raw data means that it is available for customized processing.

Through antennas and over the Internet, SSEC can receive data from new satellites from the moment they start transmitting useful data. The Data Center began receiving real-time data from the European geostationary satellite, Meteosat-8 (Meteosat Second Generation, MSG), on March 15, 2004. Of the three sites attempting to receive the data, SSEC was the only one able to do so when the transmission began from the U.S. ground station on Wallops Island, Virginia. Less than a month later on April 8, 2004, the Data Center began archiving the MSG data.

The Data Center’s broad base of capabilities and its staff’s expertise facilitate much of the research at SSEC. The Data Center is an invaluable resource both to the scientists and engineers at SSEC, and to the international science community.

--Dee Wade and Terri Gregory

Point and Click: Web Spotlight

Visit the Data Center’s web site: http://www.ssec.wisc.edu/datacenter/
Visualizing the future of satellite data

From SSEC’s earliest one-workstation Man computer Interactive Data Access System (McIDAS), a software package to process remote sensing data, SSEC researchers have sought to revolutionize how satellite data is visualized and accessed. That innovation and vision continue as we seek to develop a new generation of data analysis and visualization tools.

The Legacy of McIDAS

McIDAS was initially developed in the 1970s to enable interactive tracking of cloud features using geostationary satellite imagery, from which information about wind speed and direction was derived. It quickly became the software of choice for weather satellite data analysis and visualization around the world. McIDAS is still used in weather observation and forecasting, climate studies, and meteorological support for environmental, agricultural, commercial, and public service applications. McIDAS aids researchers from a variety of disciplines who work with satellite and other remotely-sensed data. This software package is also used at approximately 100 universities nationwide. While useful for research purposes, much of McIDAS’s strength lies in its ability to routinely generate products for time-critical applications at operational weather service sites, not only in the United States but at several international locations as well. Since the late 1970s, NOAA and NASA have used McIDAS in their major centers. Today, McIDAS provides the foundation for NOAA’s real-time distribution of satellite imagery to the National Weather Service forecast offices.

From its inception, McIDAS was known for its flexibility and myriad capabilities. This sophisticated package has allowed users to visualize and manipulate geophysical data in a wide variety of formats. McIDAS processes data from geostationary and polar orbiting meteorological satellites, NEXRAD radar, surface and upper-air observations, numerical model forecasts, NOAA environmental data and information, and other sources. An intuitive and interactive Graphical User Interface (GUI) accommodates users from novice to expert.

McIDAS evolution was always an ongoing process. Since 1973, the system has undergone progressive upgrades to adapt to new data sources and evolving user requirements. Through the years the software has kept pace with the ever-changing computing environment, while maintaining its unique identity. McIDAS-X, the version designed for Unix-based computers, has been in use since the 1990s. Very few software packages developed 30 years ago are still used today.

Measurement technologies planned for future operational weather satellites are ushering in a new era, requiring a more powerful and more versatile software environment for large volume satellite data processing and visualization. This new visualization system will need to combine satellite data with other sensor data, observations, and model output in not only meaningful displays, but also quick computations without concern for sampling, unit, or file format issues. Again SSEC leads the way, leveraging the expertise and experience gained with McIDAS, as well as other software, to transform it into a modern, powerful data manipulation and display system for the meteorological instruments of the future.

A New Foundation: VisAD

SSEC developers have looked in-house and elsewhere to establish the best possible foundation for the next evolution of McIDAS. The new McIDAS will be based on VisAD (Visualization for Algorithm Development) and HYDRA (HYperspectral viewer for Development of Research).
Applications) software developed at SSEC, as well as the Integrated Data Viewer (IDV) software developed by the Unidata Program Center in Boulder, CO. Unidata provides a community of users (primarily educators and researchers) with access to data and visualization software to explore Earth-system phenomena.

Initially led by Bill Hibbard, SSEC developed its VisAD software library to help scientists view and interact with their data in three dimensions. Among its many attributes, and in contrast to current McIDAS-X, VisAD has a consistent way of representing data, units, and navigation, as well as a built-in approach for estimating errors when combining disparate data types with different errors or sampling. Based on the VisAD library, the HYDRA application aims to address the needs of scientists worldwide when they use newer satellite sensor technologies that contain hundreds or thousands of spectral channels.

The Unidata community has borrowed from and built upon the success of VisAD to create the IDV, a Java-based application for analyzing and visualizing data. The IDV reference application showcases the potential of using the VisAD library as the basis for geosciences applications and also provides a rich library for application development.

Because VisAD, HYDRA and IDV are Java-based, they operate independently of computing platform and operating system, thus removing a major restriction to software and hardware evolution. In addition, all three are open source software, which allows users to freely use, modify, and redistribute source code. These features will all be part of the new McIDAS-McIDAS-V.

The Next Generation: McIDAS-V

SSEC visualization scientists have laid the foundation for this evolution to preserve existing McIDAS software capabilities (and millions of lines of heritage code written by SSEC and other McIDAS users) while also creating new, powerful data processing and visualization capabilities. McIDAS-V will extend McIDAS capabilities into the 3-D and hyperspectral domains. The combined use of Java and VisAD is already well supported by the international community and has proved capable of dealing with large, complex data sets; in addition, it opens up new avenues to explore nontraditional display and analysis paradigms. New techniques for interacting with colleagues are also possible using the collaboration capabilities built into the VisAD and IDV libraries.

Emphasis on interdisciplinary research as well as new instruments and technologies continue to bring challenges in visualization. SSEC remains on the forefront, imagining the possibilities and building the future.

--Tom Whittaker, Leanne Avila, and the McIDAS team
As part of its commitment to education, SSEC provides opportunities for new and future scientists to interact with those more experienced in the field. SSEC’s main educational goal is to spread environmental awareness and, in particular, to emphasize the role satellite-based remote sensing observations can play in observing the Earth. In this spirit, we seek to encourage and support researchers on both ends of the knowledge spectrum, from those first learning about the benefits of remote sensing to those who already understand and are seeking to improve upon the techniques used to interpret the data. Many of SSEC’s recent efforts have focused on the needs of two groups:

- the high spectral resolution community, particularly young researchers, looking to discuss high-spectral data analysis and the characteristics of instruments that take such measurements
- graduate students seeking to learn more about remote sensing

Technological advancements have greatly improved the spectral resolution available on meteorological instruments, leading to the availability of more detailed information about the Earth and its atmosphere. Learning to apply this high spectral data is critical to an improved understanding of atmospheric processes. To continue to develop and strengthen the high spectral resolution community, SSEC/CIMSS hosts workshops that bring both young and more experienced scientists together to discuss new data, techniques and results. Scientists from Europe, Asia, and the Americas converge on a chosen location such as Madison, Wisconsin, or Ravello, Italy, alternating between the U.S. and Europe, and devote a few days to sharing ideas and asking and answering critical questions.

SSEC’s remote sensing workshops share a similar purpose, but provide a broader and more fundamental perspective to the graduate students attending the course. SSEC lecturers travel around the world conducting week-long workshops to present the principles and applications of remote sensing. Over several days, the graduate students listen to lectures and participate in lab exercises to put into practice what they have learned. From China to South Africa to New York City, SSEC/CIMSS scientists have brought greater understanding of the technology, the applications, and the benefits of remote sensing measurements of our Earth. Through these efforts SSEC fosters a new generation of scientists, who will help to carry our work forward.

Leanne Avila

In a center with many separate research projects, SSEC’s computing environment is naturally very diverse and presents a challenge to a technical computing support team of about a half dozen full-time staff and several students. Together they provide consultation and implementation on system design, networking infrastructure, and full support for Unix and PC computing. The Technical Computing (TC) group serves all of SSEC’s staff of more than 200 with more than 700 individual networked computers. TC strives to provide support invisibly, freeing researchers to pursue science as their wide-ranging computing needs are met behind the scenes.

SSEC relies on TC to coordinate all computing tasks and requests. TC engages in a plethora of support activities including: infrastructure support and planning, computer purchasing assistance, answering computer support questions, system configuration and setup, repair, installing applications, system design for proposals, and SSEC network support. Involvement with computing projects ranges from minimal assistance to fully managing projects, based on the needs of the research project. Ultimately the TC group helps SSEC minimize costs while maximizing computer processing power and efficiency.

Scott Nolin
To understand simple as well as more complex aspects of the Earth's weather and climate, researchers need to describe how energy moves (in other words, how radiation is transferred) through the atmosphere. Computer models, specifically Radiative Transfer Models (RTMs), help to meet this challenge. At SSEC, researchers develop and use RTMs for various weather and climate applications, from understanding the effects of greenhouse gases, to the role clouds play in climate change, to the basic physical processes occurring in the atmosphere.

Using information about the state of the Earth's surface and atmosphere, RTMs calculate what a satellite would observe from the top of the atmosphere or what a ground-based instrument would see from the Earth's surface. The calculations depict how much electromagnetic radiation passes through an area or how much an area emits. Such a quantity is called a “radiance” or “brightness temperature.” RTMs facilitate many uses of satellite data including data assimilation techniques that contribute to improved weather forecasts, emissivity studies, the retrieval of cloud and aerosol information, and simulations of performance characteristics of future satellite instruments.

RTMs fall into two general categories: computationally slower but highly accurate models called “line-by-line” models, and fast models. Line-by-line models use a database consisting of measurements of molecular emission and absorption over a wide range of frequencies or wavelengths under various atmospheric and laboratory conditions. Computations with such models are typically performed at very high spectral resolution—i.e., using a very small increment of frequency or wavelength to cover the specified spectral range. These models most accurately represent the true absorption and emission characteristics of the atmosphere. Using line-by-line models, SSEC researchers conduct a variety of studies, including those to improve understanding of important greenhouse gases such as carbon dioxide and water vapor. As part of this effort, precise field observations of the Earth's surface and clear sky atmospheric conditions, impossible to reproduce in the laboratory, are compared to measurements taken with radiation sensors. SSEC researchers also endeavor to further develop and validate the accuracy of the line-by-line models.

Radiative Transfer Models translate atmospheric properties such as pressure, temperature, gases and particles, into how much energy passes through the atmosphere. This image shows a test run of a clear sky model for GIFTS—a technology demonstration for future satellite instruments.
Fast RTMs are much faster computationally than the line-by-line models because they operate at instrument resolution rather than the very high spectral resolution of the line-by-line models, and the highly complex calculations intrinsic to those models are replaced by simpler parameterizations. This simplification is usually accomplished by statistically regressing line-by-line model calculations against atmospheric profile values; the training set of profiles spans a large range of clear sky atmospheric conditions. The result is faster computation but with a loss of accuracy. CIMSS researchers are actively developing new fast model parameterizations for both clear and cloudy sky applications. Clear sky fast RTMs are developed using various techniques for many infrared and microwave aircraft and satellite sensors. These instruments include: broadband to hyperspectral resolution sensors, in geostationary and polar orbit, aircraft- and ground-based, and from the microwave to near infrared.

Clear sky conditions present certain challenges that either type of model must address. For example, retrieving vertical profiles of temperature and moisture from the atmosphere can become complicated because different profiles can produce very similar radiance measurements. To manage this problem, retrieval schemes provide what is called a “first guess” profile to the RTM, and adjust that profile until the model’s calculated radiances match the observed radiances within a specified tolerance. Adjoint models, which calculate how sensitive model radiances are to atmospheric state parameters, are used to adjust the profile guesses efficiently. Fast models are used to retrieve temperature and moisture profiles because rapid convergence to the solution profile is essential for using radiance data in numerical weather prediction models, where timeliness is critical to accurate forecasting.

SSEC scientists have also been involved in developing new fast RTMs for use in cloudy conditions. Clouds can have a net radiative warming or cooling effect; the outcome depends on subtle differences between the largely canceling effects of warming due to longwave energy absorption and cooling from shortwave reflectance. The outcome of this energy transfer is important in climate studies because clouds play a key role in global climate change.

Two specific examples of cloudy RTMs are the FIRTM2 and the Successive Order of Interaction (SOI). Developed in collaboration with other research centers, the FIRTM2 is a two-cloud-layer RTM capable of handling both single layer and overlapping cloud situations. The model uses a pre-computed library of cloud reflectance and transmittance values in order to speed up calculations. In contrast, the SOI computes multiple cloud scattering. The SOI model effectively reduces computational time by calculating the radiance fields for entire cloud layers instead of thin layers of the atmosphere as is common with other techniques. The model allows for adjusting the accuracy and speed by varying the number of streams reserved in calculations.

New RTMs will allow us to take full advantage of the increasing number of satellite observations, improving our ability to predict weather with numerical models. Our major challenge lies in cloud modeling, finding accurate yet fast computational methods. SSEC is making impressive strides toward modeling clouds using a number of different approaches. RTMs have been and will continue to be an important tool for understanding atmospheric processes, assisting in weather predictions, and addressing climate change questions.

-- Leslie Moy and Hal Woolf
Bad things can happen when weather forecasts go awry. Bikers find themselves unexpectedly drenched by a downpour; students are disappointed when an anticipated blizzard fails to deliver a big snowfall; and, much worse, lives are lost as tornadoes tear through communities or hurricanes pound the coasts with surprising intensity. As new measurement technologies provide an impressive amount of data about the atmosphere, scientists from SSEC and around the world work to develop techniques to use this data to improve forecast quality not only for weather but for other aspects of the atmosphere as well.

**Understanding data assimilation and numerical weather prediction**

Numerical weather prediction (NWP) models have two basic components. First, observational data about the Earth’s surface and the atmosphere fit together to create a depiction of the initial state of the surface and atmosphere. Second, from these initial conditions, prediction models generate forecasts of future conditions. More accurate initial conditions lead to more precise forecasts.

At SSEC, several research groups study the process of assembling observations to depict the state of the Earth’s surface and atmosphere—a process called data assimilation. Data assimilation studies at SSEC have contributed to improved use of satellite data. In addition to the role of research, improved computer technology has allowed models to be more realistic with incorporation of sophisticated dynamics and more complex physical processes that more accurately describe the state of the atmosphere. With increasingly powerful technology, modelers discovered that they needed more atmospheric information and more accurate processing techniques.

A major factor in the improvement in numerical weather prediction was the expanded use of space-based measurements. Modelers began to incorporate observations from satellite instruments into weather prediction models in the 1970s. In the late ‘80s, scientists at CIMSS began to assess the potential value of using satellite observations to derive the initial conditions for numerical weather prediction models.
Today, all major operational numerical weather prediction centers rely on satellite observations to control the growth of errors in their prediction systems. While in situ observations continue to contribute information to the initial state, satellite radiance data currently constitute the largest single observation type used in assimilation systems.

Assessing the impact of satellite data on weather prediction models

One facet of data assimilation work is to evaluate the impact of various types of data on forecasts generated by numerical models. By conducting experiments that add and remove different types of data from the initial conditions, researchers can tell which products improve the quality of a forecast.

Since 1996 scientists at CIMSS have been involved with assessing the potential value of observations from the atmospheric infrared sounder on GOES. Observations of vertically-integrated water vapor were first evaluated using the CIMSS Regional Assimilation System (CRAS). Initial experiments demonstrated the spatial and temporal benefits of using the observations. Next, with guidance from the National Centers for Environmental Prediction (NCEP), assimilation experiments were conducted using integrated water vapor retrievals in the NCEP Eta Data Assimilation System (EDAS). These experiments contributed to the operational use of GOES sounder observations in the EDAS.

By 1999, forecast models began to use more precise information in cloud prediction. Initially, forecasts of clouds did not use any cloud observations from satellite instruments. Using the CRAS, CIMSS scientists demonstrated that cloud information from the GOES sounders could be used to improve the numerical prediction of clouds. This work led to collaboration with the Mesoscale Analysis and Prediction System group at the Earth System Research Laboratory (ESRL) in Boulder that developed the Rapid Update Cycle (RUC) forecast model. The GOES sounder cloud information is currently being used to initialize clouds in the operational RUC.

More recently, the focus of the satellite impact studies at CIMSS has undergone a transition from regional models to global models. The NCEP Global Forecast System (GFS) has now become the primary model studied, with scientific direction, funding and computer resources supplied by the Joint Center for Satellite Data Assimilation (JCSDA).

The Atmospheric InfraRed Sensor (AIRS) sensor samples information at nearly 100 times the spectral resolution as other current infrared sensors. CIMSS scientists, under the direction of the JCSDA and NCEP obtained and tested these data for potential implementation in the NCEP GFS. The initial tests were run at the operational resolution of the time, covered seasonal time periods and used 152 channels. Significant improvements in temperature, moisture and wind fields were obtained in the model initialization. The subsequent forecasts also showed significant improvements out to 7 days, with an additional 12 hours of forecast skill demonstrated in each the Northern and Southern Hemispheres. Ongoing tests continue at CIMSS to improve data assimilation techniques for AIRS at higher spectral resolution than are currently used operationally by NCEP.

Experimental model demonstrates how satellite data improves forecasting

Throughout recent hurricane seasons, the CIMSS experimental numerical weather prediction model showed surprising skill, accurately forecasting the major hurricanes that struck the United States. This accuracy emerges from a progression of refinements to the model, as well as routine comparisons of the forecasts generated by the model with satellite observations. The CIMSS Regional Assimilation System (CRAS) tests ways to incorporate satellite observations into numerical weather forecasts.

In 1995, explicit cloud physics elements were added to the CRAS. Cloud parameters from GOES (cloud-top pressure, effective cloud amount, cloud identification) were used to tune the cloud physics, convective parameterization, and the grid-scale precipitation. CRAS modelers developed a technique to initialize three-dimensional cloud fields for the model. This technique improved the prediction of not only clouds, but also other forecast parameters such as precipitation, surface temperature, and dew point.

CRAS uses moisture and cloud data from GOES sounders to initialize those fields for forecasts. Including cloud and moisture fields within the CRAS allows the model to better predict the paths of hurricanes. During hurricane season, the CRAS generates forecasts for the hurricane path prediction project. This CIMSS project uses the CRAS to analyze how satellite observations influence forecasts of a hurricane’s path.

The CRAS contributes to several modeling studies in addition to the hurricane path prediction project. These include satellite data assimilation research, land surface energy and water budget studies, and analyses of short-term weather forecasts known as nowcasts. Modelers also use the CRAS in support of field experiments. Year round, the CRAS produces daily
72-hour forecasts for North America, Antarctica, and the Northeastern Pacific region. As this experimental model improves, modelers will increasingly rely on the CRAS to assess the potential value of observations from satellites for numerical weather prediction.

Modeling on a global scale

Weather, air quality and climate prediction continue to be key scientific challenges, particularly as concerns of human impact on the Earth’s climate continue to grow. To investigate these challenges, SSEC’s Isentropic Analysis and Modeling group developed, maintains and uses a global numerical model, called the UW Hybrid Isentropic Coordinate Model.

Most numerical models of the atmosphere employ a coordinate system that is based on atmospheric pressure as the vertical coordinate. Research by the Isentropic Analysis and Modeling group, and others, have demonstrated decided advantages for simulating characteristics of movement of water in all its forms and chemical transport in models where the vertical coordinate is based on potential temperature (entropy). This is called an isentropic coordinate system. The fundamental importance of these processes to weather and climate prediction and air quality prediction provided the impetus for development of the UW Hybrid Isentropic Coordinate Model.

This model has been used to demonstrate the increased accuracy in modeling hydrologic processes and trace constituent transport provided by a model based on an isentropic coordinate. The capability of the UW hybrid model to perform robust climate simulations has also been documented.

In daily numerical weather prediction, the UW model has been used to produce seven-day global forecasts for a period of more than two years. Comparison with similar results from the National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS) revealed similar capabilities between the two models in terms of a commonly used measure of model performance. These results documented the capability of models based on a potential temperature vertical coordinate to provide accurate weather prediction. NCEP and several other large operational/research centers are currently developing numerical models based on an isentropic coordinate.

Depicting how chemicals move through the atmosphere

In a collaborative effort between scientists at NASA Langley and the Isentropic Analysis and Modeling group, the Real-time Air Quality Modeling System (RAQMS) has been developed. RAQMS combines the UW Hybrid model with a chemical modeling system developed at NASA Langley. RAQMS predicts the global evolution of meteorological variables (weather) and 55 chemical constituents that are important for understanding and predicting atmospheric processes and air quality. This effort includes research in the assimilation of satellite observations of ozone and other chemical observations to provide increased accuracy in the transport of air pollution and the prediction of air quality.

RAQMS continues to be used in basic research to increase understanding of the chemical composition of the atmosphere and to advance the prediction of air quality. While ozone in the stratosphere (the layer of the atmosphere above the troposphere) plays a critical role in shielding the Earth’s surface from the sun’s harmful ultraviolet radiation, ozone in the lower troposphere is a pollutant that can cause serious health problems and economic damage. Accurately assessing air quality is a priority of NOAA and offers the potential to alleviate economic and health concerns from air pollution by providing lead-time to initiate mitigation procedures.
Observations are essential to weather forecasting and our understanding of the atmosphere, but these observations must be as reliable as technology will allow. To assess the accuracy of sensor measurements and the algorithms that create products from these measurements, SSEC researchers conduct a wide array of validation activities. The overall objective of these activities is to measure and describe the accuracy and performance of the various sensors and derived products when they are deployed in the field or into space.

There are many different approaches to validation. The most common is the comparison of derived products with more accurate independent data sets. For example, the accuracy of satellite sounding products is assessed via comparison with corresponding measurements from other instruments. In one validation study, CIMSS researchers compared the precipitable water product created using GOES sounder data to measurements from radiosonde and a microwave radiometer. The combination of radiosonde data and observations from the microwave radiometer demonstrated the ability of the GOES sounder to capture fluctuations in precipitable water in between radiosonde launch time. The validation of satellite products leads to more accurate data that improve forecast models.

SSEC also actively engages in this approach by developing and deploying both ground- and aircraft-based measurement suites for validation field campaigns. Prominent examples of SSEC instrument suites include the mobile weather lab in the AERIbago, the rooftop measurement instruments, the High Spectral Resolution Lidar (HSRL), and the aircraft based Scanning High-resolution Interferometer Sounder (Scanning HIS).

Other validation methods include analysis of sensor data to check for rationality and internal consistency. For example, researchers analyze satellite data to check for biases which are dependent on the sensor scan angles. Another approach uses derived products in numerical model analyses and forecasts to determine the impact and value of the products. An SSEC validation study using this method demonstrated that data from the Advance Microwave Sounder Unit (AMSU) increase forecast skill in the northern hemisphere by about 12 hours in five-day forecasts and 18 hours in the southern hemisphere.

Validation studies help determine the proper use of products derived from satellite data, identify problems in sensor design and/or product algorithms, and provide feedback into the further development of sensors and algorithms. These efforts also provide fundamental climate information including data on long-term trends. By participating in validation efforts, SSEC contributes to improved accuracy of data sets and the continued advancement of atmospheric remote sensing techniques and technology.

-- Dave Tobin

RAQMS is also used in NASA and NOAA field experiments. In the field, RAQMS forecasts of both weather and chemical composition are used to help determine the optimum deployment of experiment resources to achieve the goals of the experiment. For example, RAQMS forecasts are used to help determine the optimal flight plan of instrument-laden aircraft in order to maximize sampling of targeted air pollution, provide validation for remotely sensed satellite data and ensure a safe flight. Due to the limited resources and the amount of time available, accurate planning is crucial to the success of these experiments.

-- Todd Schaack, Tom Zapotocny and Bob Aune

SSEC validation efforts include ground- and aircraft-based instruments. This image shows the Scanning HIS before being integrated into NASA’s WB-57 for a validation experiment.
To say that satellite meteorology is a data rich environment is a vast understatement. When he described receiving and processing satellite data, SSEC’s founding director Verner Suomi would say we were “drinking from a fire hydrant.” And he was speaking in the infancy of the satellite program. More than 30 years later, weather satellites provide more information with larger, vastly improved instrument suites.

On the ground, researchers develop software and visualization tools to use the data, steadily more complex with each new generation of satellite instruments. SSEC develops many of these software tools to make it possible for scientists around the world to drink from the fire hydrant without drowning.

One such tool is the direct broadcast data processing software package. NOAA launched its first operational polar orbiting satellite in 1978. That satellite and all those that followed have had the capability to directly broadcast measurements as it orbits the Earth, transmitting data to ground stations equipped with receiving equipment. To spread the message about this great new data opportunity, the International TOVS Working Group was formed with Bill Smith, former CIMSS Director, as one of the first Co-chairs of the group. To support ITWG international cooperation, scientists at CIMSS developed a software package in 1985 to enable scientists around the world to process data transmitted from the satellite to local direct broadcast receiving stations. The International TOVS Processing Package (ITPP) worked on the satellite direct broadcast data, producing calibrated, navigated radiances for imaging, and then applied retrieval algorithms to create temperature and moisture vertical profiles and other useful products. The ITPP was used by many operational and research centers around the world.

The next significant improvement in imaging and sounding capability came in 1998 with the launch of the NASA Earth Observing System (EOS) Terra satellite. A 36 channel imager, the MODerate-resolution Imaging Spectroradiometer (MODIS), flew on Terra and on the next satellite, Aqua. Also on Aqua was a high spectral resolution sounder the Atmospheric InfraRed Sounder (AIRS). A new direct broadcast software package was developed at CIMSS to take advantage of improved instruments on the spacecraft. This software package, the International MODIS/AIRS Processing Package (IMAPP), required yet more complex algorithms to process the data.

Beyond managing the data, the processing software also enables the continuous development of new ways to use the data. IMAPP fosters the rapid improvement of retrieval algorithms and other applications of EOS data in a variety of global weather, process studies, and climate applications. IMAPP developers stress scientific integrity, ease of use and reliability. The package includes a single set of software to navigate and calibrate the data as well as to create science products; users do not need to develop product-specific software themselves.
Work on these software packages has enabled SSEC/CIMSS scientists to play and active, exciting, and rewarding role within the international community. These efforts have also resulted in numerous and fruitful global connections—from visiting scientist exchanges to research collaborations to graduate students from other countries conducting research with CIMSS scientists. Many long-term partnerships have grown out of common interests and goals.

Next for the Direct Broadcast program is the development of a similar package for the forthcoming NPOESS program. Working with scientists from the NPOESS Integrated Program Office (IPO) and NASA, many of the IMAPP scientists at CIMSS are turning their expertise to create the International Polar Orbiter Processing Package (IPOPP). The IPOPP will provide freely available software to process and create products for NPOESS and other satellites that will orbit the Earth in the early decades of the 21st century.

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Kathy Strabala, Terri Gregory and Tom Achtor
Step Three:
SSEC uses its instruments to make measurements and its innovative software tools to analyze these data. SSEC research enhances understanding of the Earth and its atmosphere, the other planets in our Solar System, and the cosmos. Our scientists apply measurements from the international array of geostationary and polar-orbiting environmental satellites, aircraft, and ground-based remote sensors and other data to play a major role in our nation’s remote sensing research and development.
With various techniques and areas of expertise, SSEC researchers have contributed to methods for using satellite observations to estimate the intensity of tropical storms, and to identify and monitor regions of biomass burning. NOAA has incorporated these methods into operational forecast models to improve the timeliness and accuracy of their forecasts and public warnings.

SSEC scientists also develop ways to use satellite observations to assist pilots and farmers. In support of aviation weather programs with the FAA and NASA, research groups at SSEC use satellites to locate areas of turbulence, icing, and restrictions to visibility, such as fog and low clouds. GOES measurements are also used in a land and atmosphere forecast model to support agriculture. This research is a part of an experiment to provide farmers in the upper Midwestern United States with environmental information about their crops and the biophysical condition of their fields to help in decision making for planting, watering, applications of fertilizer, pesticides and herbicides, and harvesting.

In support of the Polar Orbiting Environmental Satellite (POES) program, CIMSS and their NOAA collaborators use the global data received from the NOAA operational satellites to create a global cloud cover climatology. CIMSS scientists have assembled 15 years of global cloud information to study regional, seasonal and global trends. High-resolution NOAA POES data also aids in the study of the weather and climate of the polar regions.

While most SSEC research focuses on Earth, SSEC planetary researchers use data from numerous NASA missions to discover important atmospheric features of the planets in our solar system. Currently, scientists are utilizing data from high-resolution ground-based telescopes and from the Hubble Space Telescope to study the seasonal cycle of Neptune and cloud features on Uranus. The Venus Express mission is providing data that center scientists will use to study the Venusian atmosphere. Studying atmospheres of planets in our solar system increases our knowledge of Earth’s circulation.

All of these activities have an ultimate goal of providing improved weather forecasts and severe weather warnings to the citizens of the United States and the world.
D \text{uring the summer and fall of 2005, residents along the}
shores of the Atlantic Ocean and Caribbean Sea found
themselves facing destructive winds and massive flooding
from a record-breaking number of tropical cyclones – Dennis,
Katrina, Rita, and Wilma, to name just a few. Throughout
the life cycles of these storms, the CIMSS Tropical Cyclone
Research Group provided a continuous stream of unique data
and products derived from satellites to assist forecast meteor-
ologists in assessing each storm, and in particular its inten-
sity.

Decisions concerning how much coastline to evacuate and
how far inland storm surge flooding may extend are based
on the expected landfall strength of a storm. Determining a
storm’s current intensity is a critical part of forecasting the
cyclone’s strength. By comparing current intensity changes
forecasters are able to determine short-term intensity trends.
Rapid changes in intensity can be especially problematic since
they are the most difficult to forecast. For example, in 2004,
Hurricane Charley unexpectedly strengthened from a Catego-
ry 2 to a Category 4 hurricane in a matter of hours just prior
to making landfall on Florida’s west coast. Intensity changes
like those seen in Hurricane Charley represent a potentially
deadly situation if insufficient warning has been given to
the public. Tools that allow forecasters to monitor intensity
changes are crucial to the forecasting process.

By developing innovative techniques using satellite data to
study and monitor tropical cyclones, the Tropical Cyclone
Research Group contributes to more accurate analyses of trop-
ical cyclones approaching landfall and, consequently, more
effective warnings for the public. Two of the group’s major
research techniques focus on intensity: the Advanced Dvorak
Technique and a microwave data analysis method.

\textbf{Advanced Dvorak Technique}

Since the launch of the first meteorological satellite, tropi-
cal cyclone forecasters have depended on satellite imagery to
detect and track storms in regions where accidental discovery
of hurricanes by ships at sea was the rule. Initial attempts to
determine the intensity of these storms resulted in the Dvorak
Technique; this highly subjective method relied on forecasters
who evaluated sequential visible and infrared channel imagery
to relate the development and evolution of cloud patterns
and features to storm intensity. In the mid-1990s CIMSS
researchers sought to create an objective, computer-based ver-
sion of the Dvorak Technique with the goal of producing an
improved operational analysis tool.

By 1998, the CIMSS Tropical Cyclone Research Group had
developed the prototype version of the Objective Dvorak
Technique (ODT). Key to the ODT’s success was the ability
to objectively determine the storm’s current intensity estimate.
The significance of this improvement, as explained by re-
searcher Tim Olander, is that “a user in Miami will obtain the
same result as a user in Hawaii on the same storm at the same
time.” After an extensive evaluation by users in the tropical
cyclone research community, major tropical weather forecast-

(left to right) Hurricane
Wilma – 2005, MODIS;
Hurricane Charley -- 2004,
GOES-12 visible; Hurricane
Katrina -- 2005, composite
ing offices worldwide began using the technique, including the National Hurricane Center in Miami, FL; the U. S. Air Force Weather Agency in Omaha, NE; the Joint Typhoon Warning Center in Pearl Harbor, HI; and the Australian Bureau of Meteorology.

Over the years, the ODT has proven to be a very successful method for monitoring tropical storms. On numerous occasions, the National Hurricane Center has credited the ODT and recognized CIMSS for assisting their forecasts. CIMSS researchers remain in close contact with the forecast specialists, and, as in the case below, alert them to significant storm intensity changes detected with the ODT technique. In 2005 the National Hurricane Center upgraded Hurricane Rita to a category 4 storm based directly on ODT input at a critical time during which very rapid intensification was indicated by the satellite technique and a reconnaissance plane was unable to take measurements from inside the hurricane due to mechanical problems; a later reconnaissance plane confirmed the accuracy of the ODT analysis.

The CIMSS team continues to improve the ODT, extending its capability to operate over the entire storm life cycle at all intensities and to remove the final subjective aspect of the ODT – the manual selection of the storm center. As a result of these enhancements, early in 2005, the method was renamed the Advanced Dvorak Technique (ADT). Statistical analysis shows that the ADT estimates are comparable, if not superior, to those intensity estimates obtained with the operational Dvorak Technique.

An Advanced Microwave Approach

Traditional infrared and visible satellite imagery may not always provide the full picture of a tropical cyclone. High cloud cover can often mask the inner structure of the storm and prevent an accurate determination of the storm's intensity. The launch of the Advanced Microwave Sounding Unit (AMSU) aboard a polar orbiting satellite (NOAA-15) in 1998 represented a significant improvement in monitoring tropical cyclone intensity and structure. AMSU allows us to "see" through the clouds into the heart of the storm.

In 2001 an AMSU-based intensity technique developed at CIMSS began running in an operational mode and estimates of tropical cyclone intensity were distributed to the National Hurricane Center; the computer code for this method was later transferred to the Center, allowing them to run their own analyses. Because the AMSU instrument measures temperatures that are directly associated with intensity, the method is in many cases more accurate than the Dvorak method, which relies on pattern recognitions that are not as closely related to intensity. In 2002 the AMSU-based technique became global – estimates of intensity are produced for every tropical cyclone in the world and distributed to forecast agencies worldwide.

However, no single tropical cyclone intensity analysis technique is without some error. Operational hurricane forecasters often subjectively combine multiple sources of data to make a best guess of the storm's intensity. An effort is underway at CIMSS to combine the best of the available techniques into a satellite-based "consensus" estimate. Knowledge of the strengths and weaknesses of the ADT and AMSU-based techniques is used to give weights to each method. The weighted methods are then combined, resulting in an intensity estimate that is superior in skill to the individual techniques. The CIMSS consensus intensity technique is objective and based on robust statistical analysis of the individual members of the consensus. Currently only the ADT and AMSU techniques are used. Future techniques based on microwave imagers will provide an additional piece of the current intensity question.

With each hurricane season comes new challenges and opportunities to improve the way storms are monitored and analyzed from satellites. The examples cited above are just two of the methods being pioneered at CIMSS. Throughout the year you will find the CIMSS Tropical Cyclone Group working hard to develop and improve the necessary tools to aid forecasters worldwide in making critical decisions, from upgrading storm intensity to warning the public to evacuate.

-- Chris Velden, Tim Olander, Derrick Herndon and Leanne Avila

Point and Click: Web Spotlight

The Tropical Cyclones team maintains a large web presence. Imagery and detailed forecast data make their web site a popular stop for those seeking information about hurricanes. The site received three million hits in one day during Hurricane Ivan in 2004.

Visit the CIMSS Tropical Cyclones web site at: http://cimss.ssec.wisc.edu/tropic
Hazard satellite products to navigate weather hazards

Hazard-related thunderstorms, turbulence, and volcanic ash cost the aviation industry many millions of dollars annually in lost time, fuel, and efficiency through delayed, cancelled, and rerouted flights, as well as accidents. Increased skill in forecasting and detecting these hazards would help to minimize their impact. Traditionally, satellite data have been underutilized to support forecasts of aviation weather hazards, especially over the data-poor oceans where satellites can have a significant impact. A CIMSS team called the Satellite-based Nowcasting and Aviation Application Program (SNAAP) formed to specifically focus on the 0-2 hour short-term nowcast time window relevant to the aviation weather nowcasting problem.

The team has been primarily funded by the Advanced Satellite Aviation-weather Products (ASAP) initiative, created by NASA’s Langley Research Center to provide satellite-derived meteorological products and expertise to weather researchers in the Federal Aviation Administration (FAA). Along with the University of Alabama in Huntsville, the Massachusetts Institute of Technology, and the National Center for Atmospheric Research (NCAR), CIMSS provides satellite-derived information to Product Development Teams (PDT) established by the FAA within the Aviation Weather Research Program.

Satellite-derived products offer value-added information for forecasting and nowcasting aviation hazards such as those caused by low ceiling or visibility, convection (thunderstorm development), turbulence, icing, volcanic ash, and wind shear. Much of the satellite data is infused into each team’s unique system for diagnosing a particular hazard. The three primary aviation hazards serving as the focus for the CIMSS ASAP group are convection, turbulence, and volcanic ash.

By monitoring rapidly developing thunderstorms with geostationary satellite instruments, scientists focus on classifying towering cumulus clouds, high resolution satellite-derived winds, and infrared cooling rates. This information reveals locations of future strong thunderstorm cells up to 45 minutes before mature thunderstorms are detected by conventional radar.

Turbulence, a common and significant aviation hazard, can be caused by several sources. Convection, type of terrain, and upper tropospheric instability on the synoptic-scale can all lead to turbulence in both cloudy and “clear-air” conditions. SNAAP researchers are analyzing infrared satellite data over spectral, temporal, and spatial domains to provide insight as to how satellite instruments can best help identify turbulent regions in the atmosphere. SNAAP provides the FAA Turbulence team with fields of “interest” based on pattern recognition and water vapor and ozone gradients. The SNAAP team uses satellite infrared imagery to aid in

MODIS water vapor imagery shows mountain waves across Colorado. Time-matched pilot reports of turbulence are plotted here, with values 1-2 as light, 3-5 as moderate, and 6-8 as severe turbulence. Vertical motions associated with mountain waves produce periodic fluctuations in the upper-level water vapor field. These vertical motions in clear-sky can adversely impact commercial flights, as they cannot be visually observed by pilots. MODIS water vapor channel brightness temperatures along the arrowed cross-section are shown within the right panel.
Volcanic ash has caused several nearly catastrophic commercial airline engine failures and has damaged windshields with scoring. Tracking the horizontal location and altitude of post-eruption ash plumes until the cloud disperses is critical to aviation safety. While geostationary sounder and imager instruments offer relatively good temporal resolution for monitoring airborne ash from volcanic eruptions, their large fields of view and limited global coverage over volcanically active regions act as disadvantages.

In contrast, polar-orbiting satellite instruments such as the AVHRR and MODIS provide high spatial resolution and better global coverage. To offset their poor temporal sampling, at any given time several polar-orbiting satellites are available, each capable of detecting volcanic ash with fairly frequent time intervals at higher latitudes. This ongoing study will help determine how best to automate current and future polar and geostationary satellite instrument capabilities to better monitor volcanic ash (both the horizontal and vertical extent) in the atmosphere. Our work has focused on optimizing conventional techniques for volcanic ash detection to reduce false alarm rates and improve ash cloud identification and height estimates using automated techniques.

Top left panel contains a true color image of the Manam volcanic eruption on 24 October 2004, top right image shows an aerial view of the ash cloud. Bottom two images show the improved volcanic ash detection methodology (left image) with ash indicated by red area and ash/ice mixture indicated by green area over the traditional method on the right.

identifying upper tropospheric fold events that can contribute to clear air turbulence. In addition, SNAAP researchers are correlating water vapor and infrared imagery showing mountain waves to provide an objective method for detecting mountain wave turbulence. Satellite data also indicate the presence of infrared wave signatures of severe convection, and correlations between these signals and downstream convectively-induced clear air turbulence are being studied.

The results of our satellite product research are finding pathways into operational forecasting. The satellite-derived convective product is being used by the FAA Convective PDT to improve nowcasting of thunderstorms at O’Hare and Dallas/Ft Worth airports. The satellite-derived upper tropospheric and convectively induced clear air turbulence interest fields will be tested by the FAA Turbulence team as a way to improve their Graphical Turbulence Guidance product. Finally, satellite-derived volcanic mask and ash height algorithms will be integrated into NOAA’s operational Clouds from AVHRR data stream and SSEC’s International MODIS and AIRS Processing Package. Future work includes development and transition of aviation hazard interest fields using future operational hyperspectral imager and sounder data available from instruments such as CrIS/VIIRS and the GOES-R suite which should provide higher temporal, spatial, and vertical resolution.

--Wayne Feltz

Point and Click: Web Spotlight
http://cimss.ssec.wisc.edu/snaap/
Each year, wildfires and those caused by human activity destroy countless resources and vast amounts of property, and significantly impact the environment. According to the National Interagency Fire Center, over 77,000 fires raged across the United States in 2004. Suppressing these fires cost federal agencies almost 900 million dollars. In spite of such efforts, over six million acres were destroyed. Researchers have been working on techniques to detect fires earlier, particularly in remote locations where detecting fires by conventional methods is far more difficult. Using satellites to detect and monitor biomass burning has contributed to more effective fire monitoring and improved understanding of environmental consequences.

The Biomass Burning Group within CIMSS developed a product that uses satellite data to detect fires, monitor diurnal variations, and analyze consequent environmental effects. The fire product, called the GOES Wildfire Automated Biomass Burning Algorithm (WF-ABBA), serves numerous government groups as well as a broad community of scientists.

The WF-ABBA went into operational use in 2002 when NOAA incorporated the fire product into the Hazard Mapping System. This interactive processing system provides a wide variety of users with fire products derived from satellite data. From November 2002 to October 2003, CIMSS’s fire product detected over 17,500 fires. This accounts for 20 percent of the fires detected by the Hazard Mapping System in that year, a higher percentage than the other satellite data algorithms in the system.

In addition to detecting fires, the fire product is being evaluated as an ancillary data set to assist the U.S. Environmental Protection Agency in enforcing the Clean Air Act. As a part of the Clean Air Act, the EPA issued a mandate regarding concentrations of fine particulate matter (PM$_{2.5}$). The impact of emissions from biomass burning constitutes a large variable in the equation to determine whether a region meets the EPA’s PM$_{2.5}$ standards.

GOES addresses BURNING concerns

The WF-ABBA uses satellite data to detect fires, monitors diurnal variations and assesses consequent environmental effects. This image depicts several active fires in Central America.
In 2001, the CIMSS Biomass Burning Group finished reprocessing GOES fire data back to January 2000. The data reflect the extensive use of fire for deforestation and agricultural management in South America. For example, thousands of fire pixels appear along the area in Brazil where frequent, widespread deforestation takes place. The data also show distinct burning patterns along rivers and areas of recent road construction. A comparison of the data shows that most fires in the Southern Hemisphere occur between 20°S latitude. 2002 saw the largest number of fires with a decrease in 2003 and an increase in 2004. The group hopes to reprocess data back to 1995 with an improved version of the WF-ABBA, which will allow them to create a more accurate trend analysis. Please refer to the legend on the facing page.

The Biomass Burning Group works with the air quality community to determine the effects of biomass burning on the environment. If a region does not meet the standards set forth in the PM$_{10}$ mandate, regional governments must prove that the pollutants came from somewhere else or they are required to impose costly regulatory changes on local industry. Satellite monitoring techniques like the fire product help verify where pollutants originate. After using the WF-ABBA fire product to monitor the origin of pollutants such as aerosols, scientists then use transport models to forecast how the particulate matter will travel and its ultimate destination.

The United States Navy also uses the WF-ABBA fire product for real-time aerosol monitoring and modeling. The fire product allows the Navy to identify smoke sources, and to assess and predict the characteristics of smoke plumes. Such plumes can affect visibility in a naval operations area.

The Biomass Burning Group also actively participates in planning and assessing future polar and geostationary satellites' ability to monitor and characterize fires. They work with fire modelers both in the field and in the lab to better understand how instrument design changes will affect their ability to detect fires effectively and to make recommendations based on these studies.

In addition to assisting short-term forecasts and monitoring and working on the future of fire detection, the Biomass Burning Group is also aiding the investigation of the long-term impacts of these fires and aerosols. Using the most recent version of the WF-ABBA, the group is reprocessing GOES data from 1994–present. Doing so will provide a consistent, long-term database for researchers studying characteristics and effects of biomass burning, consequences of land use, and global climate change.

Biomass burning is a source of atmospheric aerosols and trace gases that can affect global climate, but current research does not reveal the extent. As of 2006, the WF-ABBA fire product only provides information about the Western Hemisphere. The CIMSS team plans to expand the WF-ABBA fire product to new international satellites and to create a long-awaited global geostationary fire monitoring system. Such a system would facilitate research on global change including the impact of changes in land use and land cover as well as the effects of socioeconomic factors. Like many aspects of research, a global fire monitoring system evolves through collaborative efforts with other universities and government organizations.

-- Elaine Prins, Chris Schmidt and Jen O'Leary
Polar research: Braving the elements in pursuit of science

Ice covers 97 percent of Antarctica. Elevations reach above 4000 meters in places and temperatures can dip below -80 degrees C, with monthly mean winds speeds reaching over 40 meters per second. The Antarctic Meteorological Research Center and the Automatic Weather Station program both continue to advance the study of weather on the highest, coldest, driest, and windiest continent on Earth.

The Antarctic Meteorological Research Center

Dr. Charles Stearns founded the Antarctic Meteorological Research Center (AMRC), which combines multiple polar-orbiting and geostationary satellite images over Antarctica into a single composite image. The images present a view of all weather systems and their motion over the entire Antarctic continent and southern oceans (from the South Pole to about 40°S latitude). Stearns demonstrated their value while providing weather forecasts for research ships operating in the Antarctic region. He recognized their potential value in forecasting for Antarctic air travel as well. SSEC uses its Man computer Interactive Data Access System (McIDAS) software to generate these unique mosaics. [24]

To this day, the Antarctic composite image remains the hallmark product of the Antarctic Meteorological Research Center. With support from the National Science Foundation’s Office of Polar Programs, the original mission of the AMRC was to collect, distribute and archive all Antarctic meteorological data for the meteorological community. Since its inception, the AMRC mission has expanded to include research in observational meteorology, stewardship of Antarctic meteorological data, expert assistance to the Antarctic community, and educational outreach. Recent efforts include the monitoring of spectacular calving of Antarctic tabular icebergs – the world’s largest.

The calving of tabular icebergs from the Ronne and Ross Ice Shelves, in 1998 and 2000 respectively, sparked a collaboration between the University of Chicago, Northwestern University, and University of Wisconsin-Madison to learn more about the Earth’s largest icebergs. Drawing upon the experience of both the Automatic Weather Station (AWS) and AMRC projects, iceberg monitoring efforts have included the deployment of AWS units on the large tabular icebergs in the Ross Sea off the coast of Antarctica, and over 5 years of nearly daily iceberg tracking from satellite observations. Project scientists hope to gain a better understanding of iceberg movement.

Antarctic Automatic Weather Station Program

In January 1980, Stearns established the Antarctic AWS project, marking a significant milestone of modern meteorological observing of the Antarctic. Occupying and maintaining staffed sites to collect meteorological observations is expensive, and feasible locations may not be appropriate for the collection of meaningful data. The capabilities of an automatic weather station allow for the retrieval of important weather information without requiring a person on duty at each site. For more than 25 years, these stations have provided an invaluable resource for researchers and forecasters, as well as the general public, by gathering important meteorological information about Antarctica.

With funding from the National Science Foundation’s Office of Polar Programs, the AWS project places units in remote areas of Antarctica to support meteorological research and operations. Any one station may contribute to several experiments and all contribute to operations. The units help prepare weather forecasts for aircraft flights to and from New Zealand and within Antarctica.

The development of low power computer components in the 1970s and the Argos Data Collection System (DCS) on NOAA’s polar-orbiting satellites made possible low-power AWS units capable of operating in the extreme Antarctic climate. These components allow for longer operational use, reducing the number of repair visits to the sites. At the end of the 2004-2005 field season, just under sixty stations were operating in the Antarctic.

-- Matthew Lazzara

Point and Click: Web Spotlight

Many real-time products are available on the AMRC/AWS web site, including: AWS observations, Antarctic composite images, numerical weather prediction displays, images from AWS web cams, and movies and animations.

Check out the weather in Antarctica at: http://amrc.ssec.wisc.edu/
Looking at weather in polar regions from space

Information about the weather at the poles enhances researchers’ understanding of many meteorological phenomena across the globe, but the weather itself makes it difficult to gather data. Satellites provide one way around the inclement conditions. CIMSS’s polar satellite meteorology group develops new techniques to gather satellite data about the polar regions and to put it to use.

Using data from a polar-orbiting satellite to calculate the speed, height and direction of winds in the Earth’s polar regions, the group’s polar wind product allows forecasters to fill in several gaps in satellite observations and significantly extend the accuracy of mid-range forecasts. Forecast models depend on millions of atmospheric observations to create a picture of current conditions. Plugging actual data into some of the holes cuts off errors that accumulate when a model has to rely on previously generated predictions to complete the picture. Adding polar wind data makes three- to ten-day forecasts more reliable by filling in some of the data holes in forecast models.

Forecasters who use polar wind data need the most recent observations for their models; the information ceases to be useful after only a few hours. SSEC/CIMSS scientists recently traveled to Antarctica to help install a system to receive data directly from a satellite instrument, the MODerate-resolution Imaging Spectroradiometer (MODIS), at McMurdo Station. The system provides real-time data about meteorological conditions in Antarctica. In addition to generating data more quickly for assimilation into numerical weather prediction models, the direct broadcast system gives forecasters in Antarctica a source of accurate, timely information without an intermediary.

While the team helps improve forecast model predictions, they also analyze present and historical data to understand trends as well as current conditions in polar areas. CIMSS researchers studied changes in cloud cover from 1982 to 1999 as well as differences in surface albedo, or reflected light, and temperature. The study found a complex interplay of cloud cover with a variety of factors. The results of this study helped researchers incorporate cloud information into models that predict global climate change.

A CIMSS research team conducted another climate change study that looked at the cloud cover over the Arctic and the distance the ice from the continent extends into the sea. Despite setting a record low in ice extent in summer 2005, the researchers determined that the increased cloud cover during the summer months of the last decade actually moderated the effects of higher temperatures.

--Jen O’Leary and Jeff Key
A historic event in remote sensing programs at UW-Madison occurred in 2006 when the Environmental Remote Sensing Center (ERSC) joined SSEC. Established in 1970, ERSC was one of the first geospatial remote sensing research facilities in the world. ERSC is focused on developing cutting-edge Earth remote sensing and geospatial technologies to bring about a better understanding of environmental systems. The new partnership adds a talented team of scientists conducting research in and applying geospatial remote sensing data to SSEC’s atmospheric and Earth science research programs. The combination provides a broad range of space, time and spectral scales to remote sensing research and enables unique collaborations among distinct research communities.

ERSC research projects range from rapid-response detection of the destructive swath of tornado damage, to the global assessment of large lakes, to the mapping of invasive species in Wisconsin’s wetlands. Scientists at ERSC specialize in bringing together a diverse set of geospatial tools to study the environment. Among these tools are: advanced remote sensing systems (e.g., high spatial resolution satellite imagery, interferometric radar, and space-based laser altimetry), field data collection tools (GPS and field spectroradiometer), and information systems, such as geo-databases and web mapping services, for efficient access to high volumes of spatial data.

WisconsinView

ERSC is the lead organization and founder of the WisconsinView program, a statewide consortium of agencies and educational institutions that supports the remote sensing community through data distribution, educational programs, and research activities. WisconsinView is part of AmericaView Inc., the nationwide consortium. Since August 2005 the data portal for statewide 1-meter resolution true-color aerial photography and 30-meter multi-spectral Landsat imagery has attracted over 2,700 individual registered users.

On campus and across the region, ERSC is a leader in developing open source web-mapping services that enable the display and analysis of environmental systems and permit the integration of wide ranging data sets in a geospatial context. ERSC scientists are active participants in the development of the Great Lakes Observing System that seeks to integrate ground-based observations with satellite data.

This false-color Landsat-7 image shows an area of southern Burnett county in northwest Wisconsin as it appeared on May 18, 2001, one month before a powerful (F3) tornado struck the village of Siren and other parts of the county.
Studying lakes from space

Researchers at ERSC also use remote sensing to study lakes in Wisconsin and around the world. Lakes provide many environmental and economic benefits. They are an important source of water for domestic consumption, wildlife habitat, agriculture, industry, fisheries, and a wide array of other uses. At the same time, lakes are robust indicators of regional-scale dynamics in both climate and human activity. With increases in global population and development, demand on the world’s lake resources is expected to increase dramatically during the 21st century.

In Wisconsin, ERSC has worked with the state Department of Natural Resources to develop periodic assessments of water clarity in over 7000 lakes statewide. A network of citizen volunteers collects field measurements of lake clarity, timed to coincide with the overpass dates of the Landsat-5 and -7 satellites. These field observations are then used to calibrate and validate models, which are in turn used to estimate water clarity on the thousands of lakes that are not routinely sampled in-situ.

Globally, the ERSC team uses a variety of sensors to monitor environmental conditions in lakes. They are testing the use of satellite laser altimetry for remote measurement of changing water levels in lakes. By combining these data with other satellite measurements of a lake’s surface area, it is possible to calculate changes in the volume of water stored in the lake. ERSC researchers are also using sensors such as MODIS, Landsat, and ASTER to look at in-lake conditions such as water clarity, chlorophyll concentration, and suspended solids—parameters that affect the usability of lake water and the costs associated with water treatment.

Education and Outreach

Geospatial technologies enable even our youngest citizen scientists to see the world from new perspectives. And seeing is just the beginning.

While we often use virtual Earth and other visualization technologies to introduce new learners to our world, we focus outreach efforts on engaging people in authentic explorations of their own. The ERSC team puts the Wisconsin Idea into practice by delivering geospatial tools and remote sensing data to people in schools, museums, visitor centers and their homes, all across the state and beyond.

In education, students are challenged to move from exploration into problem solving and analysis. With support from NSF, the research-based Mapping Technology Experiences with Alaska's Cultural Heritage (MapTEACH) project supports innovative educational experiences for rural and remote secondary students. Students use GPS, GIS and remote sensing to investigate their local geological and cultural landscapes.

The US Department of Labor recently recognized geospatial science as one of three top-priority fields for research and education in the 21st century. While the geospatial science and atmospheric science communities have worked side-by-side for decades, the potential for collaboration has only begun to be tapped. As new members of the SSEC community, the scientists and educators at ERSC are excited about pursuing cross-cutting research opportunities.

--Jonathan Chipman, Tim Olsen and Sam Batzli
To predict the weather, forecasters rely on models that simulate the physical processes taking place in the atmosphere. Environmental models use a similar approach to look at what occurs at the surface of the Earth. CIMSS scientists are actively involved in developing tools and techniques to study environmental issues, from water resource management, to agricultural land management, to climate monitoring. Working with scientists in the University of Wisconsin-Madison’s Soil Sciences Department, CIMSS researchers have developed two computer models to assist in this environmental monitoring: PALMS and ALEXI/DisALEXI.
Modeling for land management

Agriculture takes a heavy toll on the land, but farmers can minimize negative effects through good land management. Computer models assist farmers in this effort by providing valuable information about what is happening to the soil, the plants, and the air near the Earth’s surface. Researchers within CIMSS maintain and improve a model designed specifically for agriculture called the Precision Agricultural-Landscape Modeling System (PALMS).

PALMS is intended to help farmers manage their land in more efficient, profitable, and sustainable ways. For example, by running PALMS simulations with different tillage types, a farmer can explore how tillage can make the soil moisture, and therefore crop yield, more or less uniform across a field. PALMS can also estimate how much soil nitrogen was absorbed in last year’s crop, so that the farmer can apply only as much fertilizer as is necessary to each part of the field.

PALMS also helps assess the impact agriculture has on the environment, such as how much eroded soil and phosphorus ends up in surface waterways. Subsequently, researchers can use information from PALMS to determine which management techniques might best reduce sediment and phosphorus runoff, and so prevent harmful algal blooms in lakes and rivers. For example, using PALMS, farmers can determine how best to place strips of vegetation to act as buffers, and reduce the amount of sediment and phosphorous that flows into nearby waterways. The amount of runoff varies around the edges of a field; areas with a high amount of runoff require wider buffers to minimize the impact. PALMS helps to pinpoint those areas.

Using hourly surface weather observations and field management information, PALMS simulates heat, water, and material transport. The model runs on individual farm fields, which are broken up into small grid cells (e.g., 10 meters by 10 meters). At each individual cell, a model is used to calculate the vertical exchange of water, energy, and mass. Grid cells are linked horizontally through runoff. In this way, PALMS simulates interactions among the soil and plants in different parts of the field. PALMS calculates a wide variety of variables in and on the soil (soil moisture, soil temperature, runoff, and phosphorous loss), for plants (photosynthetic rate, leaf area, leaf temperature and wetness), and inside the plant canopy (air temperature, humidity, wind speed, and evaporation).

PALMS allows farmers and other members of the agricultural community to better understand the physical processes affecting their livelihood, and to join productivity and profitability with environmental issues.

Monitoring water in all its forms

As concerns increase about world population growth and climate change, our need to accurately monitor Earth’s water resources becomes more critical. Observing the movement of water in all its forms can help us to detect significant changes in this valuable resource. To improve models of the hydrological cycle and water resource management practices, scientists have devised new methods for mapping surface energy transfer over time and detecting where soil is experiencing stress due to a lack of moisture. Such information will also improve numerical weather prediction and global climate models. Relating these observations on different scales (global, continental, watershed) is equally important for researchers to understand whether events are part of a large-scale pattern or isolated incidents.

To best assess Earth’s water supplies, remote observations, such as those provided by satellites, are frequently required. Water loss to the atmosphere, or evapotranspiration, is one...
process in the hydrological cycle that researchers monitor using satellite data. To remotely assess both meteorological and agricultural drought conditions, CIMSS researchers are collaborating with UW-Madison soil scientists and researchers at the USDA Agricultural Research Service to develop the Atmosphere-Land Exchange Inverse (ALEXI) model. This model maps evapotranspiration and soil moisture stress across continents. Moisture stress measurements modeled by ALEXI correlate with previous precipitation patterns and with local soil moisture measurements. Among its many uses, ALEXI can help farmers monitor crop health by tracking soil moisture conditions. Researchers are also evaluating the effects of assimilating ALEXI soil moisture predictions into hydrologic models and the effects of the predictions upon mesoscale forecast models.

The ALEXI model uses infrared remote sensing data, in particular surface temperature, short- and long-wave radiation derived from GOES data, and vegetation cover information from high-resolution, polar-orbiting satellite data. ALEXI is executed daily, in near-real time, over the continental U.S. at a spatial resolution of 10 km.

At times, scientists need to examine changes on a smaller scale than is possible with ALEXI. CIMSS researchers have adapted ALEXI to create a complementary model to help validate energy transfer (or flux) estimates at a higher resolution. Direct, quantitative validation of flux estimates at ALEXI’s 10-km resolution is difficult because most standard flux measurement techniques sample a surface footprint on the order of 100–1000 m. To solve this problem, CIMSS scientists developed the DisALEXI model, which breaks down, or disaggregates, 10-km ALEXI predictions to the 1–1000 m scale to compare directly with ground- or aircraft-based flux measurements. The model uses high-resolution surface temperature and vegetation cover information from aircraft or satellites such as Landsat, the Advanced Spaceborne Thermal Emission and Reflection radiometer, and the MODerate-resolution Imaging Spectroradiometer (MODIS).

Combined, ALEXI and DisALEXI provide a means to scale discrete flux measurements. Researchers compare flux data available from a network of towers to the model data using satellite measurements. A good comparison suggests that the model represents the true, full two dimensional distributions of land surface fluxes well, allowing researchers to extrapolate from the point measurements from the towers to larger spatial scales on the order of watersheds, continents, or the globe to better assess the large-scale water, carbon, and energy budget. The ability to map fluxes at multiple resolutions with a common model framework also helps to provide spatial context to a field experiment by highlighting the scale of interest. Scientists can see how their measurements either fit ongoing trends or appear to be isolated events.

Environmental issues continue to confront us. The challenge is to face the issues with the proper tools and information. CIMSS researchers continue to meet this challenge by improving PALMS, ALEXI, and DisALEXI and making their products available in an effort to help themselves and others understand environmental change and answer critical questions effectively.

-- Christine Molling, Martha Anderson and Leanne Avila

Researchers set up monitoring stations on individual farms around Wisconsin to help assess the impact of agriculture on the land. These measurements contribute to the numerical models developed by CIMSS researchers in collaboration with UW-Madison’s Department of Soil Sciences.
Whether a health or safety issue or simply a factor contributing to quality of life, air quality is receiving more attention from the public, and how we monitor it is becoming a growing research area at SSEC. Currently, agencies such as the Environmental Protection Agency create a picture of national air quality conditions through a sparse network of ground stations, and the air quality conditions aloft are largely ignored. However, the shape and size of smoke and dust plumes (whether due to natural causes or human activity) that are transported across the country vary far more than the ground network is able to report.

Infusing satellite Data into Environmental Applications (IDEA) seeks to expand the application of MODIS satellite imagery into the field of operational air quality forecasting. Because MODIS provides information about air quality conditions higher in the atmosphere, beyond the reach of the ground station network, IDEA can help to provide a more complete picture of air quality throughout the United States. As an experimental service, the products created through the IDEA project are updated daily on the web as part of a complete aerosol forecasting tool. One of IDEA’s most valuable products is a near real-time satellite product of total-column aerosol concentrations over the U.S. presented as a complement to model and in-situ information. Other products include trajectory forecasts, regional plots of the MODIS aerosol product, and composite maps of MODIS aerosol and model fields.

IDEA also uses MODIS data to produce correlation maps that distinguish concentrations of aerosols, which take the form of smoke and haze, versus surface particulate matter such as soot and larger dust particles. In addition, IDEA scientists are creating a time series of MODIS aerosol values and surface particulate matter concentrations for every surface station in the U.S.

SSEC researchers are working to ensure not only that air quality forecasters will find the products useful, but also that they learn how to best use them. We solicited feedback from air quality forecasters from across the country, and worked with the Wisconsin Department of Environmental Quality to learn about possible local applications of the project. In addition, SSEC researchers created an online training module to teach the air quality forecasters how to use IDEA products to complement the current set of models and surface measurements. Another key effort involves streamlining the processing software to make the products available earlier in the day to improve forecasting potential.

NASA and NOAA have responded positively to the IDEA project. NOAA is pursuing the project for integration into a future operational air quality forecasting system while NASA is funding a three-year multi-university project to create a national three-dimensional air quality monitoring system that will include support for an expanded form of IDEA at SSEC.

--Tony Wimmers
Clouds modify the amount of solar heating and thermal cooling of the Earth system. Since clouds vary greatly over the Earth, researchers must look at all clouds in all places to understand their effect on weather and climate change. Scientists at SSEC use satellite observations to study the global distribution of clouds and how these distributions change with time. Researchers also study the effects of volcanic eruptions, El Niño and jet contrails on cloud cover.

Clouds by the numbers

One group of SSEC scientists analyzed two sources of satellite data to study trends in global cloud cover for the last two decades in the 20th century: data from the International Satellite Cloud Climatology Program (ISCCP) and from the High Resolution Infrared Radiometer Sounders (HIRS). ISCCP has collected the largest global cloud data set using visible and infrared measurements from an international suite of weather satellites; however, the ISCCP reliance on measurements from the visible portion of the energy spectrum limits its ability to detect high, thin ice clouds, or cirrus. Multispectral infrared measurements from NOAA’s polar orbiting HIRS have been used to enhance detection of cirrus both day and night.

Scientists perform analyses on the HIRS data using a method called CO$_2$ Slicing to determine global cloud cover. The name alludes to how each of the instrument’s sounding channels views a different vertical layer of the atmosphere. Clouds are detected and their heights estimated by the amount that each CO$_2$ channel is affected by the clouds.

Studies of HIRS cloud data have revealed a number of trends, and in some cases have found surprising results. The globally averaged frequency of cloud detection (excluding the poles where cloud detection is less certain) has stayed relatively constant at 75% over the 20-year study period. In addition, scientists have discovered that clouds can be found most frequently in two locations: (1) the Inter-Tropical Convergence Zone (ITCZ) in the deep tropics where trade winds converge and (2) the middle to high latitude storm belts where low pressure systems and their fronts occur.

The most significant feature gleaned from this data study may be that the globally averaged cloud cover changed very little in spite of dramatic volcanic and El Niño events. During the four El Niño events, winter clouds moved from the Western Pacific to the Central Pacific Ocean, but their global average in the tropics did not change. El Chichon in southeast Mexico and the Philippines’ Pinatubo spewed volcanic ash into the stratosphere that did not dissipate completely until a year or two later, but cloud cover was not affected significantly.
In addition to looking at overall cloud cover, scientists are reviewing trends in high clouds. High thin clouds capture some of the Earth's infrared radiation similar to the effect of CO$_2$, which means they contribute to global warming in the same manner. High clouds in the upper troposphere (above 6 km above the Earth) are found in roughly one-third of HIRS measurements, indicating a small increasing trend of approximately two percent per decade. [56]

One notable change in high cloud cover occurs during the northern hemisphere's winter season. Increases have occurred in most parts of the world except the tropical South Pacific, Atlantic, and Indian Oceans south of the ITCZ where decreases in high clouds have been found. While jet aircraft have been suspected of increasing cirrus cloud cover due to their contrails, the HIRS data do not reveal such a trend. While increases in high clouds occur in areas of high air traffic, such as central and western North America and Europe, they also occur in areas of rare air traffic, such as the Southern Ocean around Antarctica. Larger weather systems appear to be the major cause for high cloud cover changes during northern hemisphere winters.

While total cloud cover stayed relatively steady over the two decades included in the analysis, the small increase in high clouds is worth monitoring, particularly given their role in trapping the Earth's infrared radiation. Clouds do not appear to be off-setting global warming by increasing their reflection of incoming solar radiation; instead they may be enhancing global warming with a modest increase in high thin ice clouds.

**Different approach to clouds … different answers?**

Another group of scientists in SSEC is using a different approach, or rather satellite instrument, to tackle some of the same research. The Advanced Very High Resolution Radiometer (AVHRR) is the visible and infrared imager on NOAA’s Polar Orbiting Environmental Satellites (POES). The AVHRR has flown on the POES platform since 1979 and is expected to fly until 2012. Traditionally, NOAA has used the AVHRR to generate imagery, sea surface temperature, oceanic aerosols, and a picture of vegetation health. More recently, NOAA has sought to increase the use of AVHRR for quantitative remote sensing. The Clouds from AVHRR-Extended (CLAVR-x) project is an example of NOAA's modernization of AVHRR processing.

Designed as NOAA’s newest AVHRR cloud processing system, CLAVR-x has been further developed into a system to reprocess climate data called PATMOS-x for AVHRR Pathfinder Atmospheres-Extended. Because the CLAVR set of algorithms is time and spacecraft independent, it is suitable for decades-long climate studies and has been adapted to reprocess the AVHRR data record. A major CLAVR-x modification was an increase in the number of ancillary data types used in PATMOS-x to improve the ability of its products to be useful in climate studies.

PATMOS-x builds on the original PATMOS program of the 1990s, but with significant improvements. PATMOS-x generates more cloud products, including: cloud mask, cloud type, cloud amounts by layer, cloud optical thickness, particle sizes and cloud-top heights. To increase the diurnal resolution of the climate records, PATMOS-x also uses data from AVHRRs on all the NOAA satellites. By using a common processing path, PATMOS-x developers can generate multiple products on the same grid. While the spatial resolution (0.5 degrees) is coarser than that typically offered by other climatologies that focus on surface products, having cloud, aerosol, surface, and radiometric products together allows for a more thorough diagnosis of any one time-series of data.

The graph above illustrates a current weakness in cloud climatologies—their inability to agree. The time series shows the amount of high clouds in the tropics from several sources, including PATMOS-x. The UW/HIRS climatology uses HIRS data to estimate cloud top pressure and emissivity using the CO2 slicing method. The International Satellite Cloud Climatology Project (ISCCP) is a cloud climatology based mainly on geostationary imager data supplemented by AVHRR data. The Aqua data comes from the MODIS instrument and is produced using algorithms also developed at SSEC/CIMSS.
Global cloud cover statistics are crucial to the study of Earth's climate. A technique developed by a CIMSS team tracks cloud cover. The cloud-mask algorithm characterizes cloud cover using observations from the MODerate Resolution Imaging Spectroradiometer (MODIS), an imaging instrument flown on two of polar orbiting research satellites. SSEC has a direct broadcast system that obtains real-time MODIS data and access to global MODIS data, putting the CIMSS team in an opportune position to develop and test the cloud-mask algorithm.

The cloud-mask algorithm ranks each pixel in a satellite image based on the likelihood that the pixel depicts cloudy or clear conditions. The system uses four categories: clear, probably clear, probably cloudy and cloudy. These categories allow scientists to use the cloud information in research where this information is required for the algorithms to operate accurately.

In addition to providing a ranking system, other details, such as the surface type or the presence of snow or ice, are also included in the result. When the cloud-mask team was determining how to package the cloud-mask algorithm they considered that it had to be useful to a variety of researchers, the file size could not be too big, it could not use too much of a computer's processing power, and it had to be robust. The first two restrictions limited the cloud detection techniques they could consider.

Often it is imperative simply to determine if clouds are present in a satellite's field of view. Cloud retrieval techniques need to be employed on a data set that is cloudy, while others can only be used on a data set that is clear. It is extremely important for the cloud-mask to be as accurate as possible; otherwise it can cost researchers extra time redoing work, and even result in inaccurate final statistics.

When the SSEC first began developing a cloud-mask detection algorithm in the 1990s, scientists tested the

This set of images shows the high cloud amount derived from AVHRR observations over the Eastern Pacific from PATMOS-x. Data were derived from all July AVHRR observations from 1983, 1988, 1993 and 1998.
technique on instruments similar to MODIS but with fewer spectral bands. When MODIS became available, the results were greatly improved through the process of testing and validation. MODIS has 36 unique channels, allowing SSEC scientists to take advantage of each spectral band’s capabilities.

The MODIS group at SSEC coded the cloud detection algorithm in 1999 and has continued to make adjustments to improve the algorithm, which is also a key component to the IMAPP. [34] The cloud-mask team at SSEC uses their own investigations as well as feedback from users to identify regions where the mask is not performing optimally and to increase precision. The technique appears to be stable, accurate, and useful in a wide range of scientific disciplines.

--Kathy Strabala and Richard Frey

The MODIS cloud mask and other MODIS products are generated on-site at Tromsø, Norway. SSEC personnel helped install a direct broadcast processing system in Tromsø. This particular image was taken by Terra, a satellite in NASA’s Earth Observing System. As indicated by the legend in the lower right corner, the green areas represent clear skies and the white areas denote the presence of clouds.

This image is an example of a convective cloud mask, which was created using data acquired during a tornado in Wisconsin.
Clouds cover about 70 percent of the Earth at any given time. About 35 percent of the total cloud cover is made up of high-altitude, semitransparent ice clouds. Inferring the properties of these ice clouds, known as cirrus clouds, presents one of the most challenging research areas in remote sensing.

Semi-transparent ice clouds play a large role in the interactions between the Earth and the atmosphere. Most ice clouds let some sunlight through to heat the lower atmosphere and surface, but trap longwave energy emitted from the Earth, in what is called the greenhouse effect. Because cirrus clouds vary over much of the Earth, a proper representation in the numerical models of both the cloud’s radiative and microphysical properties has proven difficult. Each model uses a different representation, or parameterization, of the ice cloud properties. This inconsistency prevents various numerical models from reaching agreement, consequently limiting our ability to accurately predict the influence of cirrus clouds.

With the use of multispectral data from satellite instruments, a team of researchers at SSEC continues to learn more about this type of cloud. Long-term data from both NOAA and NASA satellites make it possible to discuss the variation of cirrus cloud properties over space and time. Studies using these data play a substantial role in establishing radiative and microphysical properties of ice clouds. This research serves as a reference to validate remote sensing methods used in field campaigns, present-day climate models, and assessments of future climate change.

Since 1999, the team at SSEC has contributed significantly to improved analyses of cirrus cloud characteristics. The team works closely with colleagues at various NASA centers, Texas A&M University, and the National Center for Atmospheric Research (NCAR). At SSEC, the goal is to continually improve historical, current and future satellite retrievals of ice cloud properties by transferring new research into operational use.
Researchers are developing cloud climatologies to track trends in ice cloud properties, such as ice cloud optical thickness and particle size. Currently, satellite imaging instruments generate the data that scientists use to develop most global cloud climatologies. For imagers such as the Advanced Very High Resolution Radiometer (AVHRR) and the Moderate Resolution Imaging Spectroradiometer (MODIS), these retrievals consist of simultaneous measurements of cloud reflectance in both the visible and near-infrared bands of the energy spectrum.

Recent research at SSEC demonstrated that it is possible to deduce the same properties using high spectral resolution infrared data from sounding instruments such as the Atmospheric Infrared Sounder (AIRS). Because the retrieval techniques using satellite imagers generally depend on measuring how sunlight interacts with cloud particles, retrievals are not as well refined for nighttime data. The use of high spectral resolution infrared sounding instruments, or spectrometers, allows the record to extend to both daytime and nighttime observations.

To retrieve the information from both imaging and sounding instruments, researchers use a set of theoretical calculations obtained from a radiative transfer model [28], which simulates what a satellite instrument should measure at the top of the atmosphere for a given set of conditions. Scientists compare the information, in the form of computed radiances, with actual measurements to infer various cloud properties. Then the challenge is to improve the process of comparing simulated to measured radiances. Researchers must account for improvements in satellite instruments over time, including better assessments of instrument characteristics that affect observations as well as advances in calibration techniques. Additionally, improvements to radiative transfer simulations better account for the way light interacts with ice cloud particles—a critical component of many satellite observations. Insight as to how ice clouds develop and relate with light emerges from analyses of data recorded during field campaigns, where a variety of measurements are recorded both from inside and outside the clouds. Through collaboration with other scientists, the team at SSEC hopes to improve the ability to capture global ice cloud characteristics from satellite data.

Semitransparent ice clouds remain largely enigmatic, but scientists continue to use remote sensing instruments to make progress dissecting and understanding this type of cloud. This research contributes to assessments of future climate change, and enhances other techniques used to predict and evaluate the interaction between the Earth and its atmosphere.

--Bryan Baum

These five images depict different shapes, or habits, of ice crystals that can be found in clouds. The top left is a group of bullets. The lower left image is a hexagonal plate. The next image to the right is a group of solid columns. The next image is a dendrite. The farthest right image is an aggregation of hexagonal plates and solid columns. The images come from a collection of ice crystal images taken by Wilson Bentley, America’s first cloud physicist. SSEC’s Schwerdtfeger Library maintains an online collection of Bentley’s images at: http://library.ssec.wisc.edu/library/bentley/
Scientists who rely on satellite remote sensing to conduct their research and seek to improve operational weather forecasting see hyperspectral resolution as a significant trend and opportunity for the future. Gathering observations over more of the electromagnetic spectrum and in greater detail will lead to unprecedented improvements to weather and climate applications. SSEC has helped lead the revolution by building aircraft and ground-based instruments that paved the way to hyperspectral resolution science from space. [6]

The first imaging and sounding instruments launched into space to view the Earth during the 1960s and 70s used innovative technology for the time. However, if these satellite instruments were to rival the accuracy of the radiosonde, improved spatial resolution and spectral resolution were necessary. Successful instrument programs at SSEC provided accurate observations and the algorithm techniques that demonstrated the relationship between high spectral resolution and higher vertical resolution sounding from instruments in space.

Both the polar orbiting and geostationary sensors available from the early 1970s through the year 2001 were limited in their vertical resolving capability. The broad spectral channels used in the infrared filter radiometers smeared the vertical resolution of the infrared data. One technique to improve vertical resolution uses a spectrometer with higher spectral resolution to resolve the gaseous absorption lines and thereby greatly improve the vertical resolving capability of the sensor. In order to demonstrate the measurement technique, an aircraft instrument was developed at SSEC with an interferometer spectrometer provided by BOMEM, Inc. of Quebec, Canada.

This instrument, the High-resolution Interferometer Sounder (HIS), and the next generation Scanning HIS flew aboard high-altitude aircraft to demonstrate greatly improved measurement capabilities while the Atmospheric Emitted Radiance Interferometer (AERI) looked up from the ground. SSEC and various collaborators conducted studies using these instruments with an important goal of designing similar high spectral resolution instruments for polar and geostationary orbiting satellites.
The polar orbiting designs reached fruition in the European Infrared Atmospheric Sounding Interferometer (IASI) instrument and in the Cross-track Infrared Sounder (CrIS) aboard the next generation U.S. polar orbiting satellite system. Both instruments have roots in HIS and Scanning HIS technology. The geostationary design evolved from Geostationary HIS to GIFTS, with a further technology infusion that included detector arrays to allow simultaneous field of view measurements, greatly increased data rates, and thus expanded areal coverage.

Hyperspectral measurements have refined how researchers use data from sounding instruments. For example, hyperspectral data influenced the improvement of satellite-derived temperature and water vapor profiles by contributing significantly greater vertical detail to the solution of a complex radiative transfer equation. New information includes sub-pixel observations from a co-located imager that helps assess partially cloudy fields of view. Hyperspectral measurements also provide details about the infrared optical characteristics of cloud radiation and contribute to improved global databases of surface characteristics (land cover, snow cover, infrared emissivity).

Hyperspectral measurement capabilities have also extended the application of sounding data to the environmental and climate impact of radiatively active trace gases. In addition to water vapor, this classification includes carbon dioxide, methane, carbon monoxide, and ozone. The typically broad spectral coverage of the infrared sounders also is being used to detect airborne particles (aerosols) such as the Saharan dust layer that blows off Africa and influences the intensity of hurricanes in the Atlantic, as well as plumes of ash and sulfur dioxide emitted by volcanoes that can cause a serious hazard to aviation.

A wide variety of weather-related products are also anticipated to be directly improved through the use of the hyperspectral satellite sounder data; in particular wind in height resolved layers in cloud free regions can be determined by tracking water vapor motion deduced from the time animation of retrieval sounding products.

--Tom Achtor

Science with AERI

Since its inception in the late 1980s, the AERI system has evolved into a completely automated continuously operating atmospheric profiling system used to provide information on boundary layer thermodynamics, cloud properties, aerosol properties, sea/land surface temperature/emissivity, and trace gas amounts. The passive remote sensing capability of the AERI instrument provides a unique portable, low energy, and autonomous meteorological solution for monitoring atmospheric stability, fog detection, cloud icing potential, and boundary layer turbulence. Using a new 20 second rapid sampling mode (the original sampling interval was 8 minutes), the AERI retrieves detailed observations of rapidly evolving/advecting cloud properties such as optical depth, emissivity, particle size, and phase. The utility of these rapid-sample observations is illustrated above, where the large variation in the retrieved optical depth from the rapid sampling system in the AERI Bago correlates very well with the reflectivity from a co-located cloud radar. New cloud and aerosol property retrieval applications developed by SSEC scientists for AERI measurements show promise of operational use in meteorological forecast offices and for short-term weather forecasts, or nowcasts, at airport terminals. Such applications also have potential for directly assimilating the AERI-observed downwelling radiances into numerical weather prediction models to complement the radiance measurements from high spectral resolution infrared satellite sensors.

--Wayne Feltz and Dave Turner
Revisiting Uranus from Earth

After a nine-year journey, the Voyager spacecraft arrived at Uranus in 1986. Led by SSEC’s founding director Verner Suomi, SSEC scientists attempted to measure the atmospheric circulation of Uranus by tracking discrete cloud features. But only eight suitable cloud targets were found in months of images, giving Uranus a reputation, from a weather perspective, as the most boring planet in the solar system. It almost made sense, given that Uranus was 19 times further from the sun than the Earth, and thus received 360 times less solar energy per unit area. Uranus also seemed to lack an internal heat source to power its weather. Perhaps there just was not enough energy to produce storms or the locally intense convection needed to make bright discrete cloud features.

Recent advances in adaptive optics (AO) have completely changed this 1986 picture of Uranus. To revisit Uranus without leaving the Earth, SSEC scientists are taking advantage of the Keck 2 telescope on Mauna Kea, Hawaii, which has the largest mirror on Earth (10 meters in diameter) and a superior AO system that achieves an angular resolution at near-Infrared (IR) wavelengths that is better than that of the Hubble Space Telescope. With Keck, we have been able to make images of Uranus that reveal far more cloud features and far more information about their vertical structure than Voyager obtained by traveling to the planet.

The Advantages of Near-IR Wavelengths

In addition to the excellent ground-based spatial resolution that can be obtained at near-IR wavelengths, this spectral region also improves the contrast between bright cloud features and the background atmosphere, which is darkened by methane and hydrogen absorption. By analyzing data from various near-IR wavelengths at which these absorptions differ in strength, we are able to place constraints on the vertical positions of cloud features, which also constraints the chemical composition of clouds.

The atmosphere of Uranus consists mostly of hydrogen, helium, and methane. Methane is a condensable substance in

Adaptive Optics
Untwinkle the Stars

Ground-based telescopes on Earth must look through an atmosphere with turbulence-induced density variations that distort the image (this is what causes stars to twinkle).
the cold atmosphere of Uranus and most bright cloud features are likely composed of methane ice. Deeper clouds are of less certain composition, and may include frozen hydrogen sulfide, and frozen ammonia.

**Uranus in Near-IR Color**

Each color image to the left is a composite in which near-IR images made with J (1.26 micron), H (1.62 micron), and K’ (2.1 micron) filters are assigned to blue, green, and red color components respectively. This roughly approximates the view that would be available to human vision if the response of the eye could be shifted to longer wavelengths beyond red (0.7 microns); the human eye can detect light only at wavelengths between approximately 0.4 and 0.7 microns.

The rings of Uranus appear red because the K’ image is boosted relative to the others to reveal atmospheric features that are strongly darkened by methane absorption in this band. When examined carefully, the left image reveals 13 cloud features and the right image displays over 18, for a total of 31 features in just two images, exceeding the total observed in all pictures obtained by Voyager, Hubble, and other telescopes up to the year 2000. The bright white feature in the right hand image is exceptionally bright in the K’ band, meaning it extends to a relatively high altitude, and is strongly variable, as is the unusually large complex of clouds associated with it, both having changed dramatically by our observing run in August 2004. The large complex, which extended over 80 degrees of longitude (30,000 km), is probably the largest group of atmospheric features ever seen on Uranus. The isolated relatively bright green cloud near the lower left limb in the right hand image is a very long-lived feature that oscillates in latitude.

**Seasonal Change on Uranus?**

Because the rotational pole of Uranus is tipped 98 degrees to its orbital pole (the Earth is tipped just 22.5 degrees), it has the largest fractional variation in seasonal solar forcing of any planet, though little seasonal response was expected because its cold atmosphere has a response time even longer than its 84-year orbital period. Yet, the northern hemisphere of Uranus, which is seen in the right color image emerging out of a long period of darkness, is not a mirror image of the southern hemisphere, indicating that there is some response to seasonal solar radiative forcing. The zonal wind speeds are asymmetric as is the cloud morphology. This asymmetry indicates a phase shifted response to seasonal solar forcing, which continued observations will help us to understand.

--- Larry Sromovsky

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On November 8, 2005 the European Space Agency (ESA) announced the successful launch of Venus Express. Arriving at the planet in April 2006, Venus Express will conduct the most extensive survey ever of the Venus atmosphere from polar orbit. The comprehensive instrument suite, including the Venus Monitoring Camera, the Visible and Infrared Thermal Imaging Spectrometer and Venus Radio Occultation Experiment, will collect data over a period of three Venus days (equal to two Earth years).

In addition to the European team members, a team of ten U.S. scientists, including SSEC planetary scientist Sanjay Limaye, will participate in analyzing these new observations, which will allow for global observations over an extended period of time with greater temporal and spatial coverage. The data will be analyzed at SSEC to gain an improved understanding of the solar thermal tides, large-scale planetary waves and other gravity waves that may be triggered by surface topography. These data will enable an increased understanding of atmospheric circulation mechanisms that contribute to the observation that high altitude cloud features move much faster than the surface rotation of the Venus atmosphere in the equatorial latitudes. In the coming years, you will hear much more from SSEC about Venus Express as SSEC will lead the mission’s Education and Outreach Program, sharing progress and exciting research with a worldwide community.

--- Sanjay Limaye
SSEC strives to communicate scientific results and related concepts in lively and engaging ways. Public information and education are integral to the Center and to the Wisconsin Idea--the belief that the University should benefit all of Wisconsin.

To foster space science education

SSEC’s Office of Space Science Education (OSSE) designs and implements Earth and space science education and public outreach programs in collaboration with scientific and educational agencies and other partners at the regional, national, and international level. These programs promote science, mathematics, and technology education using space science themes and include targeted efforts to support the unique needs of underserved communities.

OSSE fosters many efforts to bring science to a variety of audiences. Internationally, OSSE has had a leadership role in strengthening ties between India and the United States by representing UW-Madison in a research and education collaboration among India’s government, several Indian universities, three international corporations, and many universities in the U.S. For this initiative, OSSE focuses on pre-college science education and the need for improved education in rural India.

The European Space Agency also relies on the SSEC’s space science education expertise. OSSE leads the education and public outreach component in the U.S. for Europe’s Venus Express Mission. For this effort, OSSE is developing learning modules using data and images from the Venus Express spacecraft.

NASA enlists the talents and resources in OSSE to help the public learn about space science missions. OSSE is the education lead for Juno, the NASA New Frontiers Mission to Jupiter scheduled for launch in 2011. OSSE coordinates a nationwide program that directly engages students from rural communities in the mission’s science investigations.

On a regional level, OSSE is the GLOBE (Global Learning and Observations to Benefit the Environment) partner for Wisconsin and has trained K-12 teachers in the GLOBE protocols. Other programs conducted on a regional level include the “One Sky, Two Views” initiative supported by UW-Madison’s Baldwin Endowment to promote space science education within a cultural context for Native American communities. Additionally, OSSE’s Small Museum Program provides portable kiosks featuring current themes in space science for museums serving small rural and minority communities across the Midwest.

The images across the following pages represent the variety of SSEC/CIMSS education and outreach activities. For more information please visit: http://www.ssec.wisc.edu/outreach
Further atmospheric and Earth science education

SSEC supports a variety of forums that promote Earth science education—from workshops to online tools to scholarship opportunities. No matter what the medium, our outreach programs provide audiences of all ages with the resources and opportunities to learn more about remote sensing and the atmosphere of Earth and other planets. SSEC imagery is nationally and internationally renowned and widely utilized for educational purposes by other research centers, universities, and museums.

Research at the end of the Earth

SSEC’s Antarctic Meteorological Research Center (AMRC) engages in a variety of outreach activities highlighting the only continent with no nations: Antarctica. Through focused lectures and presentations, AMRC helps the public understand Antarctic meteorology and why we study it.

Every year, AMRC scientists visit numerous grade schools and middle schools. Frequently, the scientists dress a student in Extreme Cold Weather gear to demonstrate how inhospitable Antarctica is. The students usually find themselves swimming in the giant red parka. Parka and all, the gear weighs almost as much as a first grader.

AMRC also contributes to SSEC’s more general outreach activities. For example, an AMRC team member presents remote sensing applications in Antarctica to the high school students involved with the CIMSS annual workshop and the visitors to Grandparents University. Students and alumni are often amazed and fascinated by the significance of Antarctic research in global climate and atmospheric research.

On-line Training Resources

Beyond face-to-face educational opportunities found in workshops and tours, SSEC maintains a strong web presence. Reaching a broad audience, SSEC’s education efforts take advantage of the technology available on the web, showcasing materials and allowing people to interact with science information in a new, exciting way.

CIMSS collaborated with the National Weather Service and two other universities during the 1990s to develop and maintain an innovative online software program that facilitates professional training for weather forecasters. Known as VISITview, the distance learning program accelerates the transfer of meteorological research into operational use by teaching forecasters how to use new data sources and processing techniques.

VISITview connects students and instructors in real-time teaching and discussion sessions, enabling multiple users to view and respond to images and annotations simultaneously. Lesson topics include: satellite meteorology, severe weather, winter weather, tropical weather, lightning, climate, numerical weather prediction, and fire weather. Using VISITview’s “builder” tool, SSEC meteorologists and computer specialists continue to develop lessons for new and future satellites, satellite instruments, and data techniques to help prepare forecasters for the next generation of satellite data.

VISITview is also employed by the World Meteorological Organization for professional training. CIMSS also uses VISITview in an NSF funded distance learning course for high school teachers. Along with affording many instructional aspects similar to a traditional classroom for
teachers taking the course, VISITview enables content experts to make online follow-up visits to the classroom.

With support from NASA and NOAA, CIMSS has developed several online resources for K-16 audiences featuring highly interactive learning tools, including “Satellite Meteorology for Grades 7-12”, a comprehensive curriculum aimed at middle and high school students. Along with providing a dynamic learning experience for students, the course is an excellent resource for teachers which has been approved by NASA’s Education Product Review team and is listed on the NESDIS Education and Outreach home page.

“Satellite Observations in Science Education” is a CIMSS online course that combines learning activities with creative e-learning tools called reusable content objects (RCOs) to assist educators teaching remote sensing and satellite technology to high school and college level students. Collaborations on this project connected SSEC with the Federation of Earth Science Information Partners (ESIP).

CIMSS also hosts the Wisconsin Weather Stories (WWS) project made possible by the Baldwin Wisconsin Idea fund. WWS combines the efforts of K-12 classroom teachers, folklorists, and meteorologists to explore the science and stories of Wisconsin weather. The project was awarded the 2005 American Folklore Society’s Dorothy Howard Award for excellence in folklore educational resources.

Workshops at SSEC and Around the World

SSEC staff facilitates workshops on and off the UW campus to provide concentrated studies and allow for educational interactions between experts and workshop participants.

CIMSS offers two summer workshops each year, one for high school students and one for middle and high school teachers, sponsored in part by the Wisconsin Space Grant Consortium. The student-oriented resident workshop on Atmospheric, Earth, and Space Sciences has been offered since 1991 and features an exciting agenda in meteorology, astronomy, remote sensing, and geology. Several of the students from this workshop have become AOS majors and worked at CIMSS. Originally teachers could attend the student workshop, but in 2002 CIMSS developed a professional development experience solely for educators to provide the background necessary to incorporate remote sensing topics into science and technology curriculums.

SSEC has also been an active participant in Grandparents University. Each year the Wisconsin Alumni Association provides the opportunity for UW-Madison alums to return to campus with their grandchildren. Participants can choose from a variety of “majors” hosted by different departments within the university. SSEC provides both space exploration and satellite meteorology units.

Finally, SSEC researchers and computer experts have traveled to many countries, including Taiwan, China and Italy, to train other agencies how to process and visualize satellite and other meteorological data. Our goal is to enhance science literacy at all levels, facilitate the use of remote sensing data worldwide, and raise awareness and appreciation for the ubiquitous contributions of satellite technology to 21st century society.

--Rose Pertzborn, Margaret Mooney, and Leanne Avila
SSEC takes a multi-faceted approach to communicating with the public. Many specialized groups work together to provide the Center with comprehensive outreach and public information efforts. The Public Information Office supports SSEC by spreading knowledge of the Center through a variety of publications, both in print and online; a network of media contacts; and various projects.

Several publications come out of SSEC on a regular basis. Each month, the Public Information Office sends out *In the News*—an online newsletter containing the Center’s latest research developments, media appearances, outreach activities, and awards. *In the News* goes to local and national news professionals, UW-Madison communications specialists, a host of individuals from related organizations, and many others who have an active interest in the Center.

In addition to *In the News*, the Public Information Office publishes news releases, annual highlights, information on the Center’s individual research projects, content for a variety of SSEC web pages, and, this, the Center’s information booklet. These publications are only possible through the cooperation and support of SSEC’s talented writers and editors.

The Public Information Office also works with the media to tell the public about the fascinating scientific research and technological advances that occur at SSEC. In addition to appearances on CNN, the History Channel, and the Weather Channel, local and state TV, radio and print media outlets frequently feature SSEC’s work. In addition, the director of CIMSS and the chair of the AOS department answer questions about the weather as the Weather Guys on Larry Meiller’s Wisconsin Public Radio talk show.

When communicating with the public, researchers at SSEC strive to illustrate the scientific process as simply and clearly as possible and to make it interesting to a general audience. As most of the work at the Center is abstract and esoteric, explaining it is frequently a challenge.

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Jean Phillips, librarian for SSEC’s Schwerdtfeger Library, was awarded a 2006 Chancellor’s Award for Excellence in Service to the University. This campus research library is dedicated primarily to atmospheric sciences and provides many special services to its clients and to the public.

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Jen O’Leary
A Look to the Future

SSEC continues to carry the legacy of Verner Suomi into the future by nurturing new ideas and conducting pioneering research. Through our strong national and international research and engineering presence, we strive to enhance understanding of the environment of Earth, the other planets in our Solar System and the Cosmos.

Today SSEC has a prominent role in several emerging projects in the U.S. operational environmental satellite programs. Both the GOES and POES programs will deploy new, advanced systems between 2009 and 2014. SSEC enthusiastically supports the development of these systems through its instrument programs, its algorithm and product research, its data management and processing experiments, its validation expertise and its efforts to provide advanced applications to support new generations of technology.

SSEC has a key role in NPOESS.

Flat plate radiometer designed by V.E. Suomi and R.J. Parent for the first Earth Radiation Budget Experiment (ERBE) flew on Explorer 7.

ATS-I, the first geostationary satellite, launched in 1966 carried Suomi's Spin Scan Cloudcover Camera.

SSEC introduced the Man-Computer Interactive Data Access System (McIDAS).

SSEC's Cooperative Institute for Meteorological Satellite Studies formed in a Memorandum of Understanding between NOAA, NASA and UW-Madison.

Designed and developed at SSEC, the Missing Baryons Explorer will measure low-energy x-rays in space.

SSEC is a major participant in the GIFTS program, a demonstration of emerging technologies for geosynchronous orbit. GIFTS provides much faster and more accurate observations of the atmosphere than currently available using detector array technology combined with high spectral resolution interferometer. An advanced measurement system like GIFTS will greatly improve observations.

NOAA, NASA and UW-Madison.
especially in the mesoscale, significantly enhancing our severe weather detection and prediction capabilities. We aim to help expedite the integration of GIFTS-like capabilities into the international geosynchronous observing systems of the future.

We continue to explore new ideas in remote sensing that hold promise for the future. In one new project, SSEC researchers have been working with NASA and others on the design of an instrument to remotely measure the ice content of the upper atmosphere, an important missing component to complete our knowledge of the Earth’s hydrologic cycle. We are also working within the climate community to define small missions that can provide highly accurate, benchmark measurements from which to better assess climate change. Our first priority focuses on measuring more accurate and spectrally complete infrared emission spectra. In deep space, we continue to participate in the development of a measurement system to search for missing baryons (dark matter) that theory implies must be present but astronomers have yet to detect. Through these and other programs, our research philosophy to Observe, to Analyze, and to Apply will continue into the future in support of our goal to contribute to humanity’s knowledge and understanding of our world.

- - Hank Revercomb and Tom Achtor
The history of the U.S. geostationary environmental satellite program is one of slowly, but continuously evolving measurement capability. The program has achieved a near-continuous record of monitoring the western hemisphere of the Earth with an ever increasing number of spectral channels and finer spatial resolutions. The program began in the 1960s inspired by SSEC’s Professor Verner Suomi who invented the Spin Scan Cloud Camera, the primary instrument on the first U.S. research geostationary satellite. Over these 40 years, SSEC and CIMSS scientists have continued to develop and improve ways to more fully utilize satellite observations from the unique geostationary perspective, including looking ahead to the future of the geostationary satellite program.

GOES-R will provide many improvements over current geostationary satellites. Improved spatial resolution of the infrared window bands of the ABI demonstrated from MODIS data (a) for a convective cloud case. Note the colder cloud-top brightness temperatures and the sharper “Enhanced V” signature located over central Tennessee on 25 May 2000. Also of interest are the concentric anvil-layer waves observable in the higher spatial resolution IR data, associated with rapidly intensifying convection along the Missouri/Arkansas border region. These are not evident in (b), the current GOES imager data.

Currently, imagers on geostationary satellites offer five spectral bands. GOES-R will gather measurements in 16 distinct regions of the energy spectrum. These images are shown to the right. GOES-R will also have better spatial resolution, which will provide more detailed images. Shown to the right is a comparison of a current geostationary image (top) and a simulation of a GOES-R image (bottom). SSEC is contributing to the GOES -R risk reduction by defining instrument measurement requirements, researching methods of data system design, and creating preliminary algorithms to test data processing methods and the validation of meteorological and environmental products.
Beginning with the GOES-R satellite, expected to be launched around 2014, a new suite of instruments will observe the Earth environment from geostationary orbit. GOES-R will carry the Advanced Baseline Imager (ABI), a 16 spectral channel, high spatial and temporal resolution radiometer. Improvements over the current five channel GOES Imager include complete hemispheric coverage every 15 minutes with higher spatial resolution. The additional spectral channels will provide better capabilities for determination and/or detection of cloud properties, aerosols and dust, fog, surface emissivity, vegetation, snow cover, and volcanic ash. CIMSS, through its collaboration with NOAA, has been involved in choosing the new bands that need to be added based on their spectral characteristics. These enhancements will add considerable accuracy to the products retrieved from the current GOES Imager.

Future GOES planning includes an advanced hyperspectral sounder. The sounder should provide complete hemispheric coverage every hour at very high spectral resolution over the infrared spectrum. The high spectral resolution translates into improved vertical resolution and results in greater accuracy in derived products. Further, the GOES-R sounder scan pattern should be adjustable to allow for coverage over a smaller area more frequently during periods of severe weather. The spatial and spectral coverage will provide a true mesoscale measurement capability that will greatly enhance our ability to detect and forecast severe weather events.

SSEC/CIMSS is actively supporting the planning and development of GOES-R instruments, data processing, and algorithms. Through the GOES-R Risk Reduction program, the Algorithm Working Group (AWG) and other projects, we are supporting the definition of measurement requirements for GOES-R, creating simulation data sets from current research instruments, investigating methods of data compression to transmit the greatly expanded volume of data, and conducting data processing experiments to provide recommendations for data ingest, management, archive, and delivery. Our scientists are developing the prototype retrieval algorithms for vertical temperature and moisture structure, cloud and aerosol properties, trace gases, fire detection, and others. We are also conducting data assimilation experiments to determine optimal methods to effectively take advantage of the extremely large data sets as well as to provide an assessment of the impact of GOES-R observations on numerical weather prediction.

Through these efforts, SSEC/CIMSS scientists are playing key roles and providing essential input to the NOAA led program to develop and deliver the operational data processing algorithms to the responsible aerospace contractor selected for conducting GOES-R operational activities. SSEC/CIMSS researchers serve on several teams which comprise the GOES-R AWG, evaluating and selecting the best algorithms for operational products, and then working with industry to document and deliver that software to the operational data processing system. From instrument design to the impact on day to day weather forecasts, SSEC/CIMSS is providing ‘end-to-end’ support for the GOES-R program.

--Tom Achtor and Tim Schmit
A group of scientists at SSEC continues to contribute to preparations for the next generation of polar-orbiting environmental satellites. The National Polar-orbiting Operational Environmental Satellite System, or NPOESS, will provide a much needed upgrade from the United States’ current polar-orbiting satellite system, which has remained essentially unchanged since 1980.

SSEC is playing an important role in the NPOESS Preparatory Project (NPP), a joint NASA and NOAA Integrated Program Office (IPO) satellite mission that will provide a bridge from the current NASA EOS missions (Terra, Aqua and Aura) to the future NPOESS. To ensure that science products from NPP will be of sufficient quality to continue the climate record established by EOS, NASA has established five Product Evaluation and Algorithm Test Elements (PEATEs). NASA selected SSEC to lead the Atmosphere PEATE, while the Land, Ocean, Ozone, and Sounder PEATEs are all at NASA centers.

The Atmosphere PEATE utilizes SSEC expertise in several areas: science algorithm development, calibration and validation expertise from MODIS and AIRS; data acquisition, management and archiving capabilities of the Data Center; and hyperspectral data processing experience with high performance computing clusters. The Atmosphere PEATE will provide processing resources and product assessment tools for the NPP science team, of which several SSEC scientists are members.

The project requires adding significant computer processing and data storage capability in the SSEC Data Center to enable ingest of global observations from the NPP imager (VIIRS) and sounder (CrIS). The NPP archive is expected to grow at a rate of about 25 Terabytes per year. The project began with a demonstration of SSEC’s ability to ingest, store, and process proxy data sets, including those from MODIS and AIRS. A software data processing plan for algorithm evaluation has been established, and NPOESS operational algorithms and science team algorithms are being evaluated for accuracy to fulfill the requirements for climate data records. SSEC has already demonstrated the ability to reprocess MODIS data at a rate of 100 data days in 1 day in a mode similar to that expected for VIIRS.

SSEC also has a significant role in the development of a software package for real time Direct Broadcast (DB), an important data acquisition feature from polar orbiting satellites. Built on the legacy of the ATOVS and MODIS/AIRS processing packages (ITPP, IAPP and IMAPP), the International Polar Orbiting Processing Package (IPOPP) will provide users world-wide with software to transform the raw measurement data from VIIRS and CrIS into calibrated, navigated radiances and then on to environmental products. This effort is complemented by remote sensing education and training workshops that provide students and scientists with information on environmental satellite measurements, products and applications. Workshops have been conducted in Italy, Australia, China, Norway, South Africa, and Taiwan. A growing number of SSEC scientists are participating in these training workshops, which helps expand the number of users of these data.

NPOESS preparation efforts at SSEC will ensure that researchers and forecasters will benefit from the satellite system’s observations. The system will carry a number of advanced sensors to help scientists learn more about the Earth’s atmosphere. Measurements from NPOESS will improve scientific understanding of a variety of atmospheric processes including storm formation and development, and fog formation and dissipation.

--Liam Gumley
Environmental satellites are crucial to understanding and predicting weather and providing long term observations for climate studies. Geostationary satellites play a particularly vital role in the global space-based observing system by providing a high temporal and spatial resolution view over one area of the planet. Efforts to increase the spectral and spatial resolution of satellite-based atmospheric sounding instruments began more than twenty-five years ago with the goal of improving data accuracy and resolution. The Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS) represents a revolutionary step in satellite-based remote sensing of the Earth.

The GIFTS instrument enables hyperspectral measurements with innovative technological advances. Using a combination of a Fourier Transform Spectrometer (FTS) and Large Area Focal Plane Arrays (FPAs), GIFTS can measure the Earth emitted infrared radiance at the top of atmosphere from geostationary orbit at an unprecedented combination of spectral, temporal, and spatial resolution and coverage. From these measurements, thermal and gaseous concentration profiles, cloud parameters, wind field profiles, and numerous derived products can be retrieved. As experiments with these instruments have shown, hyperspectral observations from instruments aboard satellites will lead to unprecedented improvements to weather prediction and atmospheric analyses.

Hyperspectral satellite sounder data, such as the data GIFTS will provide, will have an impact on a wide variety of weather-related products. Observations of water vapor in the atmosphere constitute one example. With improved detection of water vapor, researchers will be able to generate wind measurements at different heights in cloud-free regions by tracking water vapor motion deduced from a time animation of sounding data products.

Significant collaborations among the funding agencies and those directly involved in instrument development have sustained the project and instigated preparations for the data and science that will follow. Along with NOAA, NASA and the Utah State University’s Dynamics Lab, SSEC has a strong presence in the GIFTS project.

SSEC engineers have developed the on-board calibration system for GIFTS; GIFTS uses two blackbodies operating at two different temperatures in combination with views of deep space. This blackbody system will allow for more accurate measurements from the instrument, thereby improving our ability to create useful science and products. [10]

SSEC has not only been involved in the design and development of the GIFTS instrument, but SSEC researchers have also been investigating the science and products that the new technology will afford. GIFTS will deliver an unprecedented amount of data, and SSEC researchers are looking at how best to process and archive the data. SSEC’s Data Center provides an excellent resource. Additionally, SSEC scientists have been developing and validating retrieval algorithms, conducting studies related to numerical weather prediction modeling and forward modeling, investigating how best to derive winds from satellite radiances using hyperspectral data, and examining topics such as visibility and stability for the study of convective weather phenomena.

GIFTS addresses and exceeds the requirements for the next generation of geostationary sounders. The technologies and techniques developed for GIFTS will inspire immense improvements to satellite-based remote sensing of the Earth and its atmosphere from geostationary orbit.

--Jen O’Leary

Thermal vacuum testing of the GIFTS Engineering Development Unit (EDU) was performed at the Space Dynamics Laboratory. In this image the EDU is in a thermal vacuum chamber to replicate space-flight conditions. An external scene mirror provided a means of directing the GIFTS field of view, allowing an upward-view into the Earth’s lower atmosphere. Radiometrically and spectrally calibrated measurements from an AERI allowed researchers and engineers to calibrate and validate the integrity of the GIFTS radiance measurements.
**Expanding SSEC’s instrument suite**

To piece together the complex picture of the Earth, researchers need a variety of accurate observations. Access to many instruments allows researchers to gather many types of data and to validate instruments that take similar measurements. SSEC recently won a Major Research Instrument grant from the National Science Foundation to add two more instruments to its fleet of instruments that measure the Earth and its atmosphere.

One of the new instruments is a lidar. As mentioned in a previous article [12], lidars measure the properties of cloud particles and aerosols by emitting laser pulses that change direction, or scatter, when they collide with objects such as cloud particles and pollutants called aerosols. Portions of the laser beam bounce back to the instrument, which then analyzes how the beam has changed and determines how long the beam took to return. The changes to the beam give researchers an idea of the particles’ properties and the time measurement indicates how high in the atmosphere clouds and aerosols are located. SSEC has had a significant role in lidar development.

The other instrument that will be acquired with NSF funding is an instrument that gathers information about the atmosphere in the microwave region of the electromagnetic spectrum. Microwave radiometers (MWR) are particularly useful for sensing water concentrations in the atmosphere. The MWR will gather data in three bands, rather than the standard two, making it more sensitive to the amount of liquid water in the atmosphere.

The two new instruments will enhance the measurements taken by the AERI and the other instruments aboard the AERIbago [20] and will provide excellent sensitivity to clouds with small amounts of both liquid water and ice. Together, these instruments will help to understand cloud processes and provide critical data sets needed by climate researchers to improve the radiative transfer in global climate models. The instruments will be easy to remove from the AERIbago and put on the roof of SSEC’s home in the AOSS Building on the UW-Madison campus, enhancing the suite of instruments already on the roof.

--Jen O’Leary

**Thin liquid water clouds:**

**Not a solved problem**

Thin liquid water clouds, i.e., clouds that have an integrated amount of liquid water (called liquid water path or LWP) less than 100 g / m², are prevalent around the globe. Furthermore, the radiative energy flux is very sensitive to small changes in the amount of liquid in the cloud when the amount is small, and climate researchers require accurate measurements of this geophysical parameter for thin clouds in order to improve radiative transfer in global climate models. However, a recent study led by SSEC demonstrated that there is a large disparity among over 15 different algorithms that attempt to retrieve the amount of cloud liquid water from ground- and space-based remote sensors. This is surprising because liquid water clouds are relatively easy to treat in radiative transfer models and thus the retrieval of liquid water cloud properties was considered a ‘solved problem.’

--Dave Turner
Real-time data products offered at:

http://www.ssec.wisc.edu/data/

In addition to real-time satellite imagery, SSEC also provides many real-time products to the public via the Center’s web site. These include: satellite composite images; Antarctic images, movies, and weather data; CRAS forecasts; fire monitoring satellite images; convective initiation assessments products; hurricane and tropical storm images; mesoscale winds; polar remote sensing products; sea surface temperature; IDEA air quality analysis and forecasting data and images; atmospheric profiles generated from lidar data; and many more.
<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADR</td>
<td>Adiabatic Demagnetization Refrigerator</td>
</tr>
<tr>
<td>ADT</td>
<td>Advanced Dvorak Technique</td>
</tr>
<tr>
<td>AERI</td>
<td>Atmospheric Emitted Radiance Interferometer</td>
</tr>
<tr>
<td>AHSRL</td>
<td>Arctic High Spectral Resolution Lidar</td>
</tr>
<tr>
<td>AIRS</td>
<td>Atmospheric InfraRed Sounder</td>
</tr>
<tr>
<td>ALEXI</td>
<td>Atmosphere-Land EXchange Inverse</td>
</tr>
<tr>
<td>AMRC</td>
<td>Antarctic Meteorological Research Center</td>
</tr>
<tr>
<td>AMSR-E</td>
<td>Advanced Microwave Scanning Radiometer</td>
</tr>
<tr>
<td>AMSU</td>
<td>Advanced Microwave Sounder Unit</td>
</tr>
<tr>
<td>AO</td>
<td>Adaptive Optics</td>
</tr>
<tr>
<td>AOS</td>
<td>Atmospheric and Oceanic Sciences</td>
</tr>
<tr>
<td>ARM</td>
<td>Atmospheric Radiation Measurement</td>
</tr>
<tr>
<td>ASAP</td>
<td>Advanced Satellite Aviation-weather Products</td>
</tr>
<tr>
<td>ASTER</td>
<td>Advanced Spaceborne Thermal Emission and Reflection Radiometer</td>
</tr>
<tr>
<td>ATOVS</td>
<td>Advanced TIROS Operational Vertical Sounder</td>
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<tr>
<td>ATOS</td>
<td>Applications Technology Satellite</td>
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<tr>
<td>AVHRR</td>
<td>Advanced Very High Resolution Radiometer</td>
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<tr>
<td>AWG</td>
<td>Algorithm Working Group</td>
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<tr>
<td>AWS</td>
<td>Automated Weather Station</td>
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<tr>
<td>CAPE</td>
<td>Convective Available Potential Energy</td>
</tr>
<tr>
<td>CIMSS</td>
<td>Cooperative Institute for Meteorological Satellite Studies</td>
</tr>
<tr>
<td>CLAVR-x</td>
<td>Clouds from AVHRR-Extended</td>
</tr>
<tr>
<td>CRAS</td>
<td>CIMSS Regional Assimilation System</td>
</tr>
<tr>
<td>CReS</td>
<td>Cross-track Infrared Sounder</td>
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<tr>
<td>DCS</td>
<td>Data Collection System</td>
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<tr>
<td>DisALEXI</td>
<td>Disaggregated Atmosphere-Land EXchange Inverse</td>
</tr>
<tr>
<td>DISC</td>
<td>Deep Ice Sheet Coring</td>
</tr>
<tr>
<td>DMSP</td>
<td>Defense Meteorological Satellite Program (USAF)</td>
</tr>
<tr>
<td>DXS</td>
<td>Diffuse X-ray Spectrometer</td>
</tr>
<tr>
<td>EDAS</td>
<td>Eta Data Assimilation System</td>
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<tr>
<td>EHWD</td>
<td>Enhanced Hot Water Drill</td>
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<tr>
<td>EOS</td>
<td>Earth Observing System</td>
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<tr>
<td>EPA</td>
<td>Environmental Protection Agency</td>
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<td>ERSC</td>
<td>Environmental Remote Sensing Center</td>
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<tr>
<td>ESA</td>
<td>European Space Agency</td>
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<tr>
<td>ESIP</td>
<td>Earth Science Information Partners</td>
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<tr>
<td>EUMETSAT</td>
<td>European Organisation for the Exploitation of Meteorological Satellites</td>
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<tr>
<td>FAA</td>
<td>Federal Aviation Administration</td>
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<tr>
<td>FGGE</td>
<td>First GARP Global Experiment</td>
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<tr>
<td>FIRTM2</td>
<td>Fast Infrared Radiative Transfer Model</td>
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<tr>
<td>FPA</td>
<td>Focal Plane Array</td>
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<tr>
<td>FSL</td>
<td>Forecast Systems Laboratory</td>
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<tr>
<td>FTIR</td>
<td>Fourier Transform Spectrometer</td>
</tr>
<tr>
<td>GARP</td>
<td>Global Atmospheric Research Program</td>
</tr>
<tr>
<td>GFS</td>
<td>Global Forecast System</td>
</tr>
<tr>
<td>GIFTS</td>
<td>Geosynchronous Imaging Fourier Transform Spectrometer</td>
</tr>
<tr>
<td>GOES</td>
<td>Geostationary Operational Environmental Satellite</td>
</tr>
<tr>
<td>GMS</td>
<td>Geostationary Operational Geostationary Meteorological Satellite (Japan)</td>
</tr>
<tr>
<td>HIAPER</td>
<td>High-performance Instrumented Airborne Platform for Environmental Research</td>
</tr>
<tr>
<td>HIRS</td>
<td>High-resolution Infrared Radiometer Sounders</td>
</tr>
<tr>
<td>HIRL</td>
<td>High Speed Photometer</td>
</tr>
<tr>
<td>HSRL</td>
<td>High Spectral Resolution Lidar</td>
</tr>
<tr>
<td>HYDRA</td>
<td>Hyperspectral viewer for Development of Research Applications</td>
</tr>
<tr>
<td>IASI</td>
<td>Infrared Atmospheric Sounding Interferometer</td>
</tr>
<tr>
<td>ICDS</td>
<td>Ice Coring and Drilling Services</td>
</tr>
<tr>
<td>IDEA</td>
<td>Infusing satellite Data into Environmental Applications</td>
</tr>
<tr>
<td>IDV</td>
<td>Integrated Data Viewer</td>
</tr>
<tr>
<td>IHOP</td>
<td>International H_0 Project</td>
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<tr>
<td>IMAPP</td>
<td>International MODIS/AIRS Processing Package</td>
</tr>
<tr>
<td>IPO</td>
<td>Integrated Program Office</td>
</tr>
</tbody>
</table>
IPOPP  International Polar Orbiter Processing Package
ISCCP  International Satellite Cloud Climatology Program
ITASE  International Trans Antarctic Scientific Expedition
ITCZ  Inter-Tropical Convergence Zone
ITPP  International TOVS Processing Package
ITWG  International TOVS Working Group
JSCDA  Joint Center for Satellite Data Assimilation
Lidar  Light Detection and Ranging instruments
MciDAS-V  Man computer Interactive Data Access System
M-PACE  Mixed-Phase Arctic Cloud Experiment
MODIS  MODerate-resolution Imaging Spectrometer
MSG  Meteosat Second Generation
MWR  MicroWave Radiometer
NASA  National Aeronautics and Space Administration
NCAR  National Center for Atmospheric Research
NCEP  National Centers for Environmental Prediction
NESDIS  National Environmental Satellite, Data, and Information Services
NOAA  National Oceanic and Atmospheric Administration
NPOESS  National Polar-orbiting Operational Environmental Satellite System
NPP  NPOESS Preparatory Project
NSF  National Science Foundation
NSMC  National Satellite Meteorological Center (China)
NWP  Numerical Weather Prediction
ODT  Objective Dvorak Technique
OSSE  Office of Space Science Education
OSO  Orbiting Solar Observatory
PALMS  Precision Agricultural-Landscape Modeling System
PATMOS-x  AVHRR Pathfinder ATMOSpheres - Extended
PDT  Product Development Team
PEATE  Product Evaluation and Algorithm Test Element
POES  Polar Orbiting Environmental Satellite
RAQMS  Real-time Air Quality Modeling System
RIG  Rooftop Instrument Group
RTM  Radiative Transfer Model
RUC  Rapid Update Cycle
SEARCH  Study of Environmental Arctic Change
SHEBA  Surface HEat Budget of the Arctic Ocean
Scanning HIS  Scanning-High resolution Interferometer Sounder
SNAAP  Satellite-based Nowcasting and Aviation Application Program
SOI  Successive Order of Interaction
SSEC  Space Science and Engineering Center
TC  Technical Computing
TIROS  Television InfraRed Operational Satellite
TPW  Total Precipitable Water
USDA  United Stated Department of Agriculture
VAS  VISSR Atmospheric Sounder
VIL  Volume Imaging Lidar
VIIRS  Visible/Infrared Imager and Radiometer Suite
VisAD  Visualization for Algorithm Development
VISITview  Virtual Institute for Satellite Integration Training
VIISSR  Visible/Infrared Spin-Scan Radiometer
WAIS-CORES  West Antarctica Ice Sheet Cores
WF-ABBA  Wildfire Automated Biomass Burning Algorithm
WIYN  Wisconsin, Indiana, and Yale Universities and the National Optical Astronomy Observatories
WMO  World Meteorological Organization
WWS  Wisconsin Weather Stories
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