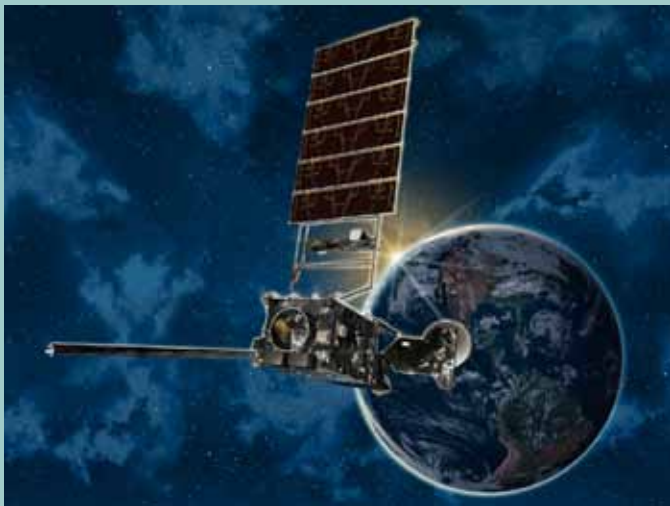


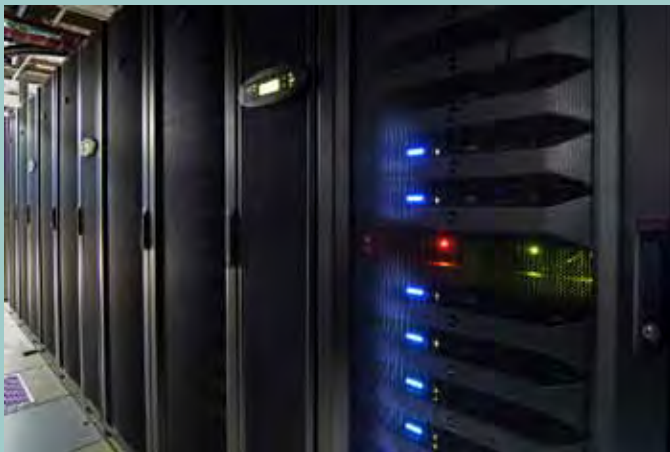
through the atmosphere

Spring/Summer 2011

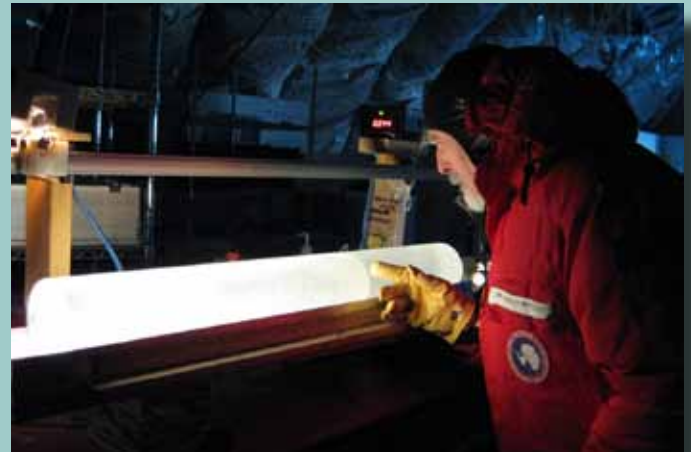


GOES-R Satellite

Multidisciplinary Approaches...



New Supercomputer



Ice Core Drilling Record

...Wide-Ranging Successes



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and more...

Director's Note

This Summer edition of our magazine features a smorgasbord of articles illustrating the breadth, and yet connectedness, of our SSEC activities. While there is no common theme, each provides an enticing vignette capturing some aspect of our multidisciplinary approach to science and engineering.

The issue begins with the story of our massive effort to get ready for the new GOES-R series of geosynchronous satellites. We are very proud of our work with NOAA, providing a major fraction of the algorithms and code for generating important products from the new system that is expected to fly in 2015.

We continue with a description of an exciting new super-computer facility that is being hosted in the Data Center computer room on 6th Floor. SSEC's hosting of this system came about as a result of our role as a Cooperative Institute for NOAA STAR and will be both a service to STAR and an asset to our growing modeling and data assimilation efforts.

There is also a very interesting story about our local (roof-top plus) atmospheric measurement

capabilities. Successful efforts to incorporate new, highly accurate instrumentation over the last several years have made SSEC an unusually capable, state of the art observing site. In addition to atmospheric science, the rooftop observations can provide entertainment. One of my own recent favorites is our images that monitor the progress of three baby red-tail hawks next door on Weeks Hall using a new rooftop webcam.

We then shift gears to climate science. This was a banner year for the Deep Ice Sheet Coring (DISC) drill team at the WAIS Divide in Antarctica, with new US depth records being set. Designed and built at SSEC, the drill provided over two miles of extremely high quality ice cores that will tell the story of the last ~40,000 years of the Earth's climate—a real tribute to the science and engineering skills of the team and to their perseverance in the exceptionally challenging polar environment.

A very different climate effort also hit a milestone this year. SSEC's new system for establishing a highly accurate temperature scale on orbit has passed a rigorous series of ground-based tests

with flying colors. The miniature phase change cells at the heart of the new system are also being prepared for on-orbit testing aboard the International Space Station later this year. Their ultimate climate application will be to serve as the key component of an On-Orbit Absolute Radiance Standard (OARS) for future high spectral resolution climate benchmark missions like CLARREO (2007 Decadal Survey).

An exceptionally successful outlet for sharing the marvels of satellite data with the public was also demonstrated this year at the Dane County Regional Airport. Live video, science on the sphere, 3-D imagery, and many other fascinating displays have drawn a great deal of acclaim from a wide range of appreciative viewers, including travelers, airport workers, and pilots as well.

This collection reminds us that our strength relies on being able to balance the use of measurement science, engineering, analysis, modeling, and computer sciences to achieve a wide range of fundamental and application-based goals.

Hank Revercomb
Director, SSEC

Through the Atmosphere

Spring/Summer 2011

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University of Wisconsin-Madison
Space Science and Engineering Center
Cooperative Institute for Meteorological Satellite Studies

GOES-R AWG - Benefits Today, Preparing for Tomorrow

It wasn't so long ago that a weather satellite would be launched and researchers would go to work developing products and doing science studies with the data flowing from it. These days researchers often know years in advance of the launch what will be possible to accomplish with the data, having conducted numerous research experiments using simulated data. Such work, both simulating and using the information, has been a focus at CIMSS. Scientists here, in collaboration with scientists within the government (such as the co-located NOAA/NESDIS team, the Advanced Satellite Products Branch (ASPB)), industry, and at other cooperative institutes, prepare for the next generation geostationary satellites, GOES-R.

Scheduled to launch in 2015, GOES-R will provide improved measurements from three new instruments: the Advanced Baseline Imager (ABI); Geostationary Lightning Mapper; and Solar UV Imager. At CIMSS, our primary interest is in the ABI, which will offer significantly better spatial and temporal resolution, and additional spectral channels, over that currently available with the existing GOES series. The ABI will feature 16 bands: 2 visible, 4 near-infrared, and 10 infrared.

The GOES-R procurement program is a partnership between NASA and NOAA. NASA runs the program to build the instruments and spacecraft, test and integrate all systems, and launch the satellite to geostationary orbit.

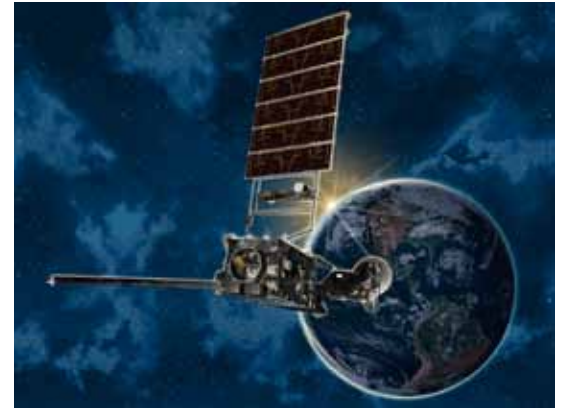
For GOES-R, NOAA has developed prototype software algorithms for the 60+ derived products and designed a framework for rapidly processing

the data as it is received from the spacecraft. A private sector company (Harris) will use that prototype to build the operational processing system and turn it over to NOAA to operate during the spacecraft lifetime.

CIMSS researchers have played a key role in scientific software development throughout the GOES-R program, from the development and testing of operational algorithms as a partner in the GOES-R Algorithm Working Group (AWG) to expanded research through the Risk Reduction component to educating and training end users through the Proving Ground. In fact, CIMSS/ASPB were key during the ABI instrument formulation phase, moving the ABI from 8 to 16 spectral bands and defining many key features.

A host of algorithms are being prepared from the GOES-R data, most derived from the ABI data. These products cover many phenomena, including weather, oceanographic, hazards, land and cryosphere. The full list of the GOES-R products can be found at: <http://www.goes-r.gov/>. Products include: imagery, clouds, atmospheric motion vectors, land surface temperature, smoke, dust, sea surface temperature, volcanic ash, upper-level SO₂, etc. A majority of the products are led by scientists from CIMSS/ASPB.

Preparation for GOES-R has been advancing for more than a decade; we are getting close(r) to the 2015 launch. Instrument prototypes are undergoing testing, operational algorithms and documentation are being finalized, and the ground system processing system development is well underway. As the



*Image of GOES-R satellite
courtesy of Lockheed Martin.*

current GOES and POES programs have demonstrated, work to improve operational GOES-R algorithms and products must continue well after launch, as well as developing new approaches and concepts to more fully utilize these advanced measurements.

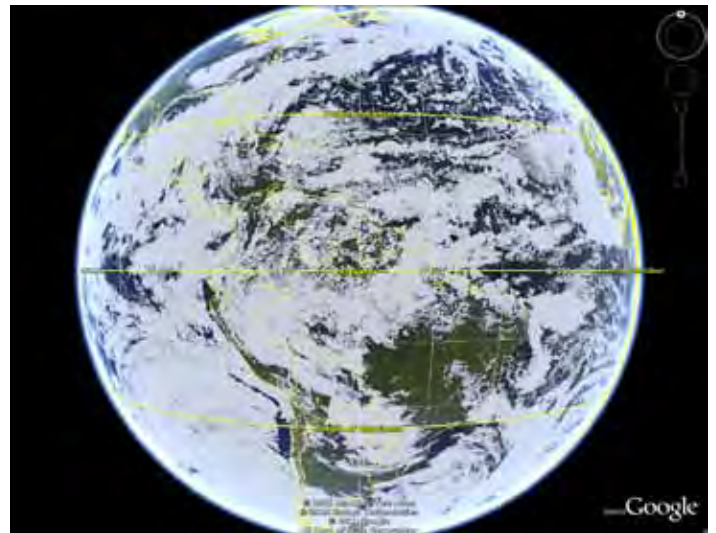
This future development work will involve closer collaborations with other research centers and working more directly with prediction centers and other users. Another key focus will be in the “fusion” of multiple observing systems with assimilation systems and forecast models to take advantage of the information content from several systems and provide improved products and services to customers in need of this information. Finally, the CIMSS satellite blog has many GOES-R related links, to showcase future improvements: <http://cimss.ssec.wisc.edu/goes/blog/archives/category/goes-r>.

On the following pages are descriptions of a few of the products that CIMSS scientists are creating for the GOES-R AWG program.

Leanne Avila
Tim Schmit
Tom Achtor

continued on page 4

GOES-R Product: Cloud Mask



The ABI Cloud Mask (ACM) provides information on the presence of cloud within each field-of-view for each pixel element of the GOES-R ABI. As a first guess cloud mask that is useful to all ABI algorithms, the ACM is not designed to be perfect for each application but to perform well enough to reduce the need of every application to detect clouds on its own, thereby increasing the overall computational efficiency of the ABI processing and reducing the effective latency of information. However, the ACM allows applications to ignore any test they choose and to simply recompute a cloud mask that is optimal for that particular application.

In addition to its main application of serving as input to other ABI algorithms, the ACM product is useful for forecasters who need to know high-resolution cloud cover. The ACM is also used to determine the large-scale cloud coverage, an important climate parameter and a useful diagnostic for verifying NWP cloud forecasts.

Example application of the ACM to current GOES Imager data. This example was taken from the 17:45 UTC scan of GOES-12 (60W) on 28 June 2011. The image on the left shows a false color image based on the 0.65 and 11 micron observations. The image on the right shows the cloud mask overlaid on the false color image. The light colored areas are determined to be clouds. The cloud mask results were generated using all tests. The images were taken from a Google Earth display of the NOAA AWG Cloud algorithm results.

Because the ABI product suite includes masks for the presence of volcanic ash, dust and fog, the ACM does no special processing to detect these phenomena.

The product generates a binary (yes/no) decision on the presence of cloud. In addition to this binary decision, a 4-level (clear, probably-clear, probably-cloudy and cloudy) mask is also generated, just like for the official cloud mask products for the NOAA/NESDIS AVHRR, GOES, MODIS, and JPSS/VIIRS. The ACM also generates an additional 4 bytes of output per pixel which contain the (yes/no) decisions for each cloud mask test and flags that determined the processing path (i.e., was a pixel considered to be oceanic glint).

The ACM uses 12 tests taken largely from the tests run currently by NOAA and NASA, plus two additional tests based on approaches used by EUMETSAT on the MSG/SEVIRI mask. The passing of any one test is sufficient for the classification of a pixel as cloudy.

In general, the ACM relies most heavily on infrared observations and relies on the clear-sky computations for generating many of the infrared thresholds. Spatial tests including the use of warmest pixels over 21x21 arrays and the covariance of infrared and water vapor channels are in the ACM.

**Andrew Heidinger
William Straka III**

GOES-R Product: Hurricane Intensity Estimate (HIE)



The mean annual damage to the mainland US from tropical storms/hurricanes is \$4.9 billion, and the US has at least a 1 in 6 chance of experiencing losses related to hurricanes of at least \$10 billion. Hurricane Katrina in 2005 was a powerful example of a devastating disaster that could have been much worse if not for the accurate and timely track forecasts and warnings issued by the National Hurricane Center (NHC).

While hurricane track forecasts have generally improved over the past decade or two, less progress has been made with intensity forecasts. The slow rate of improvement in intensity analysis and forecast accuracy, and the particularly large errors that can occur in dangerous episodes of rapid intensification, have prompted NHC to elevate this issue to its top priority for the tropical meteorology research community.

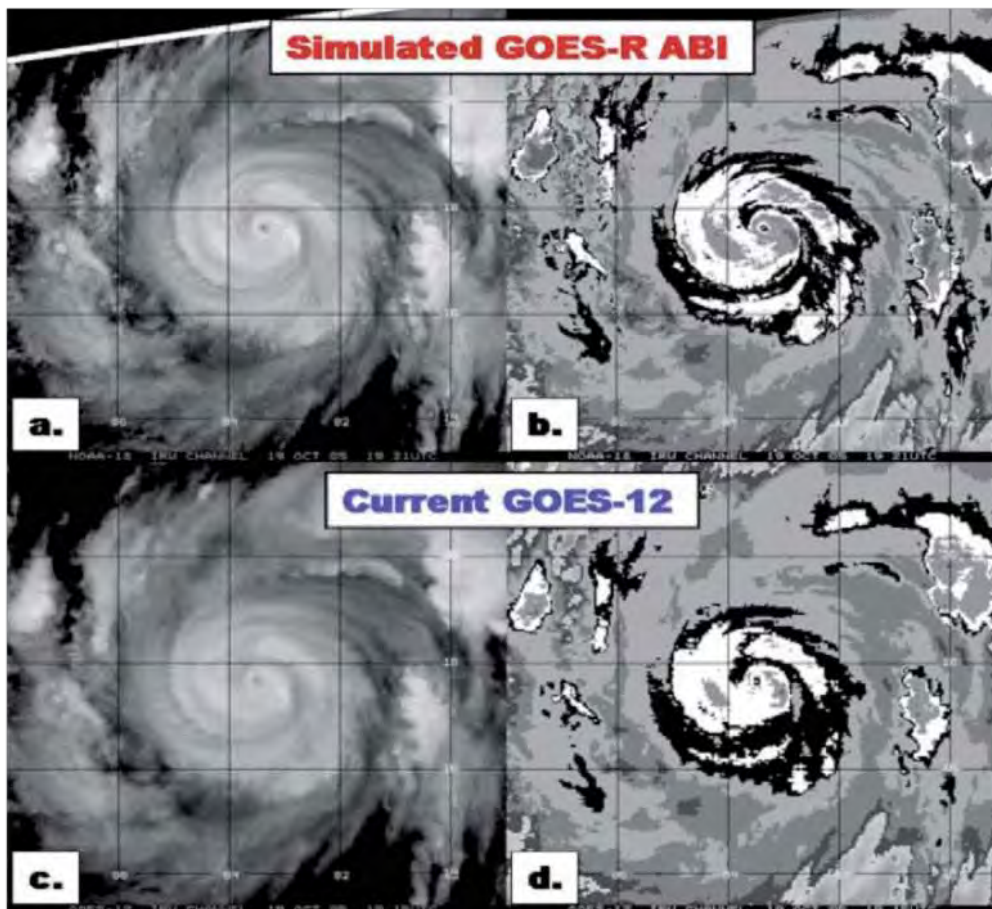
The HIE algorithm is derived from the Advanced Dvorak Technique (ADT), an objective and fully automated algorithm developed at CIMSS that operates on current GOES data and is now used operationally by NHC. The HIE will generate real-time hurricane intensity estimates of hurricane central pressure and maximum sustained winds using 10.35 μ m infrared window channel imagery.

The improved performance and higher spatial resolution of the ABI will provide a greater ability to detect smaller cloud features, allowing for better characterization of small hurricane eye structures.

The primary products that will be generated by the HIE include an intensity estimate analysis from the most current satellite image being interrogated, as well as additional information about the intensity trend of the analyzed storm. Graphical illustrations and textual listings of the hurricane intensity estimates will be viewable and distributed to the user community in real time.

The HIE will be used by hurricane analysts and forecasters from NHC, the CPHC (Central Pacific Hurricane Center), and the JTWC (Joint Typhoon Warning Center). The HIE products will help these analysts/forecasters assess real-time hurricane intensity trends.

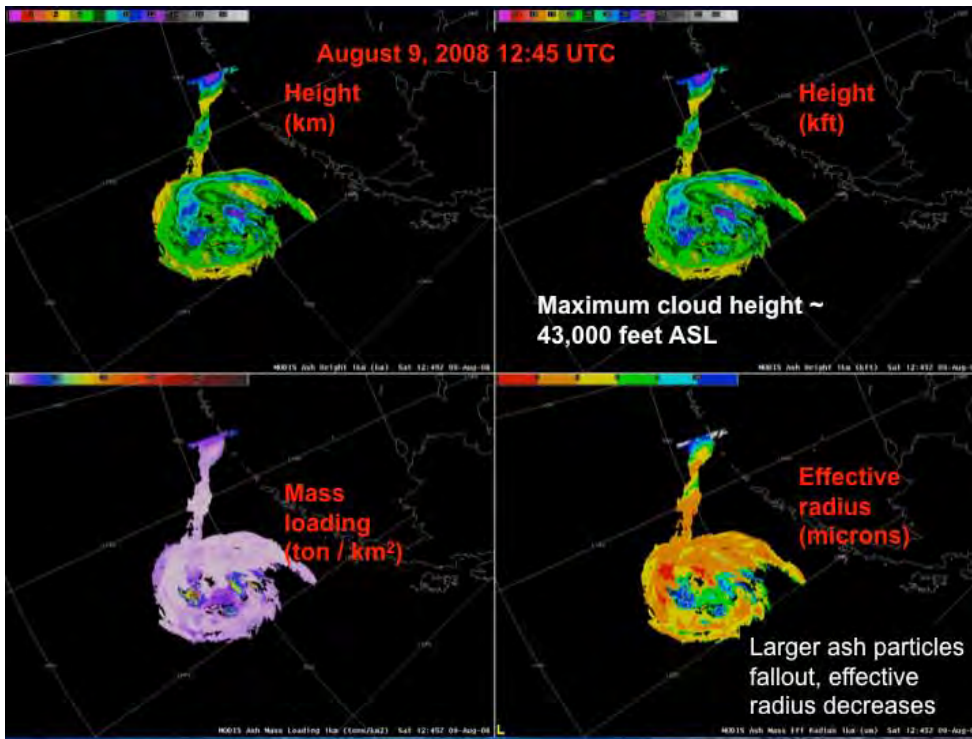
Chris Velden
Tim Olander



Simulated GOES-R ABI infrared imagery with black/white contrast stretch (a) and "Hurricane" enhancement (b) compared to current GOES-12 imagery (c and d) for Hurricane Wilma on 19 October 2005. The contrast stretch/enhancements show the improved capability to capture small eye features with the ABI, which will lead to improved hurricane intensity estimates from the HIE.

continued on page 6

GOES-R Product: Volcanic Ash Detection and Height



The GOES-R volcanic ash products are shown in an Advanced Weather Interactive Processing System (AWIPS) 4-panel display. The ash cloud was produced by the 08 August 2008 eruption of Kasatochi, located in the Aleutian Islands of Alaska. The ash cloud height, in km above mean sea level, is shown in the top left panel. The ash cloud height, in thousands of feet above mean sea level, is shown in the top right panel. The ash cloud mass loading (ton/km²) is shown in the bottom left panel. Finally, the ash cloud effective particle radius (μm) is shown in the bottom right panel.

Airborne volcanic ash is a major aviation, health, and infrastructure hazard. When ingested into aircraft engines, volcanic ash causes engine damage or failure.

In December 1989, a 747 jetliner carrying 231 passengers encountered an ash cloud during an eruption of the Mount Redoubt volcano, located southwest of Anchorage, AK. Within 60 seconds of encountering the heavy ash cloud, all four engines of the aircraft had stalled. Fortunately, the

pilot was able to restart the engines, narrowly avoiding a crash.

Not only is volcanic ash extremely abrasive, but even small concentrations can cause severe damage to the exterior of aircraft. In addition, ash falls pose significant health and infrastructure threats to those on the ground.

The GOES-R AWG volcanic ash products are being used to improve volcanic ash cloud warnings and

forecasts. More specifically, these products provide objective estimates of ash cloud coverage, height, mass, and particle size, which are necessary to issue Significant Meteorological Information (SIGMET) advisories for aircraft and to improve dispersion model forecasts (e.g., ash cloud height is a critical input parameter required by dispersion models).

Volcanic ash clouds can often be differentiated from other types of clouds by using measurements from the infrared portion of the electromagnetic spectrum. The amount of radiation absorbed by volcanic ash generally decreases as the wavelength of the radiation increases while the opposite is true for regular weather clouds.

Infrared measurements can also be used to determine the properties (e.g., height, mass loading, and effective particle radius) of ash clouds using an optimal estimation based inversion procedure. In recent years, the methods used to detect volcanic ash clouds and quantify their properties have improved greatly and continue to evolve.

The Anchorage Volcanic Ash Advisory Center (VAAC), which is responsible for issuing volcanic cloud related advisories for the North Pacific and Alaska, is currently evaluating the GOES-R volcanic ash products in operations.

Mike Pavlonis
Justin Sieglaff

GOES-R Product: Ice Cover, Concentration, Age/Thickness



The cryosphere collectively describes elements of the earth system containing water in its frozen state and includes sea ice, lake and river ice, snow cover, solid precipitation, glaciers, ice caps, ice sheets, permafrost, and seasonally frozen ground. The cryosphere exists at all latitudes.

The presence of frozen water affects energy, moisture, gas and particle fluxes, clouds, precipitation, hydrological conditions, and atmospheric and oceanic circulation. Snow and ice data therefore are essential for numerical weather forecasting and climate reanalysis. Elements of the cryosphere also contain important records of past climate, providing benchmarks for interpreting modern climate change.

For GOES-R, a variety of snow and ice products are being developed: snow cover, snow depth in the Great Plains, sea and lake ice cover, concentration, age, and motion. Of these, snow cover (created by colleagues at JPL and the NOAA/NWS National Operational Hydrologic Remote Sensing Center) and ice concentration are the products that are most readily assimilated by current numerical weather prediction models, though there is an increasing interest in sea ice thickness.

The Ice Cover product gives the areal extent of sea ice and lake ice. For GOES-R, the Great Lakes are perhaps of greatest interest, though ABI will also view the southerly portion of Arctic sea ice. The procedure is

simpler than that used for snow cover, primarily because there are only two surface types to consider (unfrozen water and ice) in contrast to the many types found on land (snow, grassland, forest, and rock).

Only a few ABI channels are used to distinguish ice from open water. The Ice Concentration product gives the subpixel coverage of ice, analogous to the fractional snow cover product. Determining ice concentration requires a more complex procedure than simply identifying ice, so a dynamic threshold method is used to determine the spectral characteristics of ice in a small region and then in each image pixel.

Estimating ice age and thickness from space is one of the grand challenges of remote sensing. Passive microwave data have been used to determine the type of sea ice – first-year or multi-

year – for decades. However, this only gives a rough estimate of thickness, a property that is far more important in determining the surface energy budget than age. Satellite lidar and radar altimeters are also being used to estimate thickness with some success.

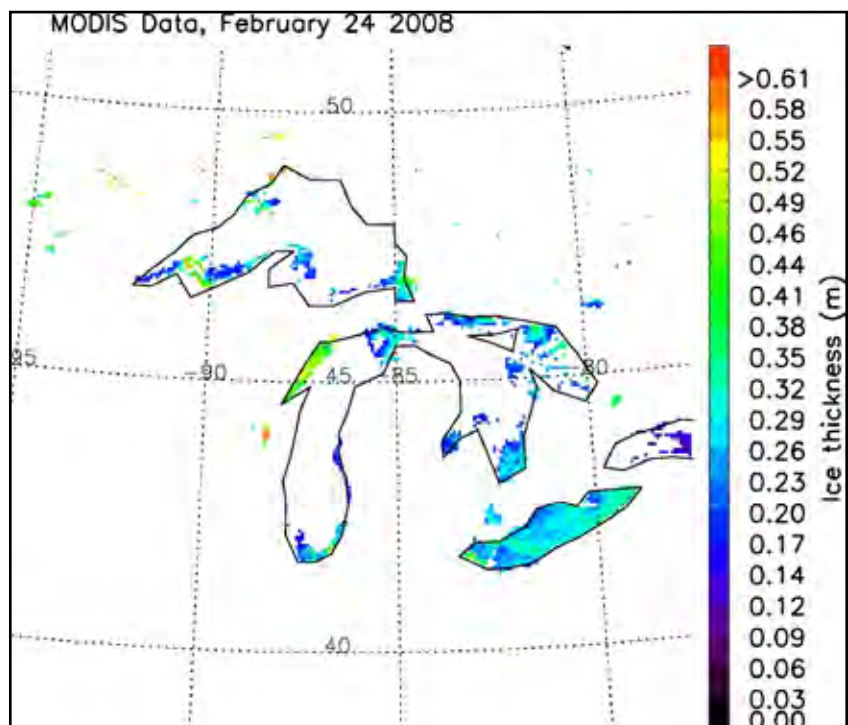
The GOES-R ABI approach is very different: calculate the ice thickness that balances the energy budget. This calculation requires accurate information on surface temperature, radiative fluxes, and the surface wind speed.

Some of these inputs are GOES-R products, some are parameterized as part of the energy budget model, and others come from global model forecasts.

Jeff Key
Xuanji Wang
Yinghui Liu

continued on page 8

Ice thickness from MODIS Aqua data on 24 February 2008 for the clear sky portion by using the One-dimensional Thermodynamic Ice Model (OTIM) developed at CIMSS.



GOES-R Product: Turbulence



Atmospheric turbulence is a major aviation hazard; prompt detection is essential for airspace safety. The advanced spatial resolution of the GOES-R ABI will provide identification of more turbulence-causing events (such as overshooting convective cloud tops and tropopause folding), while the improved temporal resolution will offer earlier detection of turbulence and timelier updates. This information will allow flight planners to provide warning or reroute aircraft that may be affected by turbulence.

An overshooting convective cloud top (OT) is a domelike bulge atop an anvil cloud representing a severe updraft within the convective system. Despite their relatively small size and short duration, storms with OTs often produce hazardous weather conditions such as aviation turbulence, frequent lightning, heavy rainfall, large hail, damaging wind, and tornadoes. Research shows that turbulence occurs over 40% of the time when aircraft fly within 10 km of an OT.

OTs appear in GOES-R ABI imagery as a small cluster of very cold brightness temperatures (BTs) in the 11 μm (longwave) infrared region. OTs continue to cool as they ascend into the lower stratosphere,

making them significantly colder than the surrounding anvil cloud, which normally has temperatures at or near that of the tropopause level. The algorithm detects the cold pixel clusters of the OT, utilizing the longwave IR brightness temperature difference between the OT and the surrounding anvil.

The Tropopause Folding Turbulence Prediction (TFTP) product focuses on

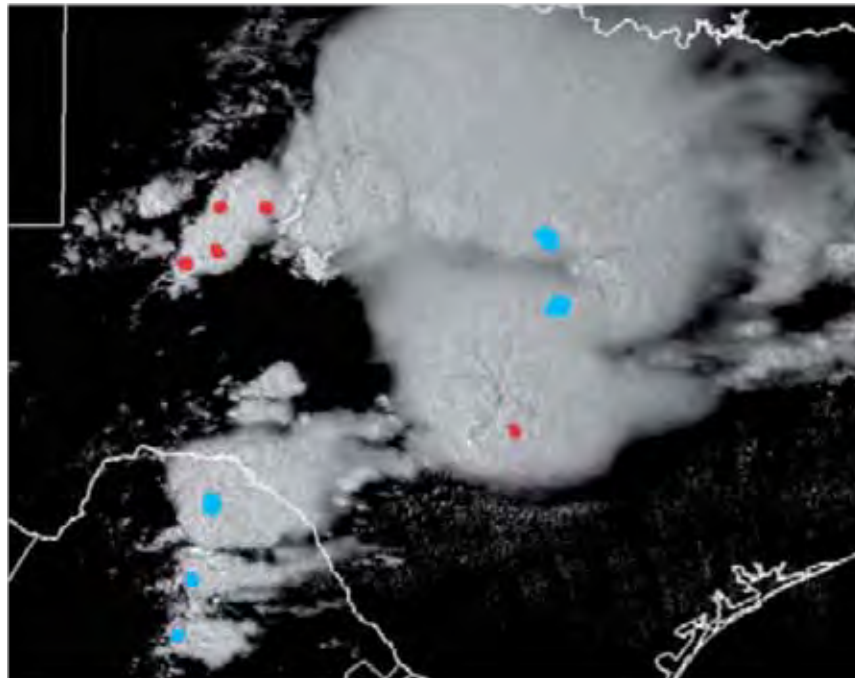
Tropopause folding occurs when a layer of stratospheric air is drawn into the lower atmosphere under the path of the jet stream or an area of robust convection. The vertical stability of this air, combined with the effects of the high wind speed, causes strong turbulent eddies to develop. The location of these eddies is often associated with observations of significant in-flight turbulence. The TFTP product does not detect these

turbulent episodes directly, but rather detects the boundaries in the atmosphere where clear-air turbulence is likely to occur.

The upper-tropospheric water vapor channel of the GOES-R Advanced Baseline Imager (channel 8) is the source for resolving gradients that reveal the horizontal distribution of tropopause folds. The tropopause fold features are then reconstructed by the TFTP algorithm as objects that project out from the major gradients in the ABI image. Information from an ancillary

numerical weather model is used to constrain these objects vertically in the atmosphere.

Anthony Wimmers
Jason Brunner
Wayne Feltz



Overshooting top detections overlaid upon a 0.25-km resolution Moderate Resolution Imaging Spectroradiometer (MODIS) image for part of Texas on 13 July 2003; the blue dots indicate overshooting tops detected using both a current 4-km GOES-12 image and the synthetic ABI image, and the red dots indicate additional overshooting tops detected only with the high resolution 2-km synthetic ABI imagery.

a particular type of clear-air turbulence that is generally undetectable from the aircraft cockpit or from radar, yet can cause in-flight injuries aboard commercial aircraft and even more serious hazards for smaller aircraft.

Highlights of Recent Publications

Nowcasting convective storm initiation using satellite-based box-averaged cloud-top cooling and cloud-type trends.

Journal of Applied Meteorology and Climatology, v.50, no.1, 2011.

Sieglauff, J. M., L. Cronic, W. Feltz, K. Bedka, M. Pavolonis, and A. Heidinger

Geostationary Operational Environmental Satellite (GOES) imager cloud typing methodology and cloud top cooling rates using the 10.7 micron infrared channel are used to determine which maturing cumulus clouds were likely to grow into significant convection. The technique was shown to have a probability of detection of 55% and a false alarm rate of 25%.

Estimation of liquid cloud properties that conserve total-scene reflectance using satellite measurements.

Journal of Applied Meteorology and Climatology, v.50, no.1, 2011.

Foster, M. J., R. Bennartz, and A. Heidinger

A new method of deriving statistical moments related to the distribution of liquid water path over partially cloudy scenes is tested using a satellite cloud climatology. The method improves the ability to reconstruct total-scene visible reflectance when compared with an approach that relies on valid liquid water path retrievals, and thus it maintains physical consistency with the primary satellite observations when deriving cloud climatologies.

Pollution from China increases cloud droplet number, suppresses rain over the East China Sea.

Geophysical Research Letters, v.38, 2011.

Bennartz, R., J. Fan, J. Rausch, L.R. Leung, and A. Heidinger.

Rapid economic growth over the last 30 years in China has led to a significant increase in aerosol loading, which is mainly due to the increased emissions of its precursors such as SO₂ and NO_x. These changes significantly affect wintertime clouds and precipitation over the East China Sea downwind of major emission sources.

Investigating cloud radar sensitivity of optically thin cirrus using collocated Raman lidar observations.

Geophysical Research Letters, v.38, 2011.

Borg, L.A. R.E. Holz, and D.D. Turner.

The sensitivity of the millimeter cloud radar (MMCR) to optically thin single-layer cirrus at the Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site is investigated using collocated Raman lidar observations. The sensitivity is characterized in terms of cloud optical depth (OD) and infrared (IR) radiative flux using over three years of coincident Raman lidar and MMCR observations. For cases when the Raman lidar is not fully attenuated (OD < 2.0) the MMCR detects approximately 70% of the total cloud OD with the majority of missed

cloud OD occurring near cloud top. This result highlights the importance of combining Raman lidar, or other sensitive cloud lidars that are able to measure cloud extinction directly, with the MMCR in order to accurately characterize the cloud radiative forcing for thin cirrus cases.

Development of a GPU-based high-performance radiative transfer model for the Infrared Atmospheric Sounding Interferometer (IASI).

Journal of Computational Physics, v.230, no.6, 2011.

Huang, B., J. Mielikainen, H. Oh, and H-L A. Huang.

To take the full advantage of high-resolution infrared observations, a computationally efficient radiative transfer model is needed to facilitate satellite data assimilation. In recent years the programmable commodity graphics processing unit (GPU) has evolved into a highly parallel, multi-threaded, many-core processor with tremendous computational speed and very high memory bandwidth. The radiative transfer model is very suitable for the GPU implementation to take advantage of the hardware's efficiency and parallelism where radiances of many channels can be calculated in parallel in GPUs. In this paper, we develop a GPU-based high-performance radiative transfer model for the Infrared Atmospheric Sounding Interferometer (IASI) launched in 2006 onboard the first European meteorological polar-orbiting satellites, METOP-A.

Honors and Awards

Andrew Heidinger

Received 2010 NOAA Bronze Medal.

Selected January 2011 NOAA Employee of the Month.

Michael Pavolonis

Received 2010 NOAA Bronze Medal.

Fred Best

Named Distinguished Instrumentation Innovator-Research

Margaret Mooney

Participated in White House Roundtable on Communicating Climate Change Adaptation.

Jordan Gerth

Received 2011 Wisconsin Space Grant Consortium Graduate Fellowship Award.

New Supercomputer to Improve Weather Forecasting

The largest, most powerful computer on the University of Wisconsin-Madison campus began systems testing in June of 2011. Housed at SSEC, the new system contains 3,072 CPU cores, 8 terabytes of RAM, over 450 terabytes of disk space, and a 40 gigabit infiniband network. The system is more than half again as large as any previous campus high performance computer cluster.

Funded by the National Oceanic and Atmospheric Administration (NOAA), the system will be used by NOAA and UW researchers to run data assimilation experiments with the goal of improving the NOAA operational weather models used to generate weather forecasts for the United States.

The NOAA National Environmental Satellite, Data and Information Service (NESDIS), Center for Satellite Applications and Research (STAR)



*Endre Doeringsfeld and Paul Czerniak install a component.
Photo credit: Mark Hobson*

approached Principal Investigator Liam Gumley and his team with a proposal to provide a million dollar grant for SSEC to design a large, extremely capable system and, upon approval of the design, purchase the hardware. The system had to be able to run NOAA's operational data assimilation and numerical weather prediction models and will serve as a test bed to develop and improve the use of satellite measurements in numerical weather prediction.

SSEC Technical Computing staff, including Jesse Stroik, John Lalande, and Technical Lead Scott Nolin, created the design proposal using NOAA's parameters and critical guidance from NOAA scientist Brad Pierce and other SSEC scientists. When the design

was approved by NOAA, the team procured the equipment.

The system was installed in the first week of May and has been undergoing set-up and testing since that time.

Gumley said, "The design our Technical Computing crew put together was based on our ten-year experience with building Linux clusters. Previous builds topped out at 250 CPU cores. The amount of memory in a system is vital as it directly maps to the resolution of the model you can run. Every grid point in a model has to be represented in memory. And for every grid point there are perhaps 40 or 50 parameters to track."

The SSEC Data Center provides the working environment and ongoing maintenance and system administration services for the system, while STAR provides guidance on system resource allocation and selection of users.

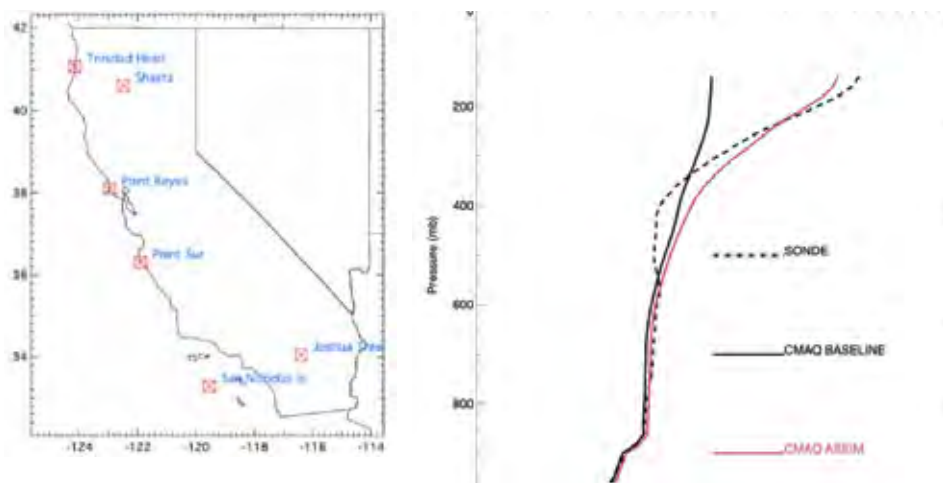


Photo credit: Mark Hobson

90% of the system's capacity will be used by NOAA's STAR researchers. The other 10% is assigned to SSEC. Some of those STAR researchers are members of the Advanced Satellite Product Branch (ASPB) which is part of the STAR Cooperative Research Programs Division and is collocated with CIMSS within SSEC.

The supercomputer system will be used to enhance the accuracy of weather prediction systems through improved use of satellite data within the US operational data assimilation and forecast systems, at global and regional scales. Applications include studying the impact of future observing systems, such as the Advanced Baseline Imager on future GOES satellites, on the forecast skills of US Numerical Weather Prediction models.

For example, Brad Pierce leads an effort to assess the impact of assimilation of GOES total column ozone within the Community Multi-scale Air Quality (CMAQ)



Comparison between observed (dashed), CMAQ baseline (black) no assimilation, and CMAQ GOES Total Column Ozone retrieval assimilation (red) ozone (right panel) for ozonesonde measurements in California (left panel) during the CalNex field mission.

forecast model. CMAQ is used by NOAA to help predict surface ozone concentrations needed for National air quality forecast guidance. The figure above illustrates results of recent CMAQ ozone assimilation studies. These experiments show that assimilation of GOES total column ozone results in improved agreement with ozonesonde measurements

collected during the NOAA CalNex field mission.

Other projects will look at the impacts of assimilating satellite data into the full suite of operational forecast models within the National Centers for Environmental Prediction (NCEP) National Environmental Modeling System (NEMS).

“We will be running to NOAA’s specifications,” Gumley said. “NOAA wants this system to improve their Operational assimilation and prediction models. NOAA has at least two other systems similar to this. One is at a NOAA facility and one at NASA; both of them out east at federal sites. The NASA system is a similar size to this one, but the NOAA system is heavily over-used. It is tough for researchers to get enough cycles.”

NOAA’s desire was for a top-flight system that was also accessible and easy to use. SSEC and the University of Wisconsin stepped up to meet those goals.

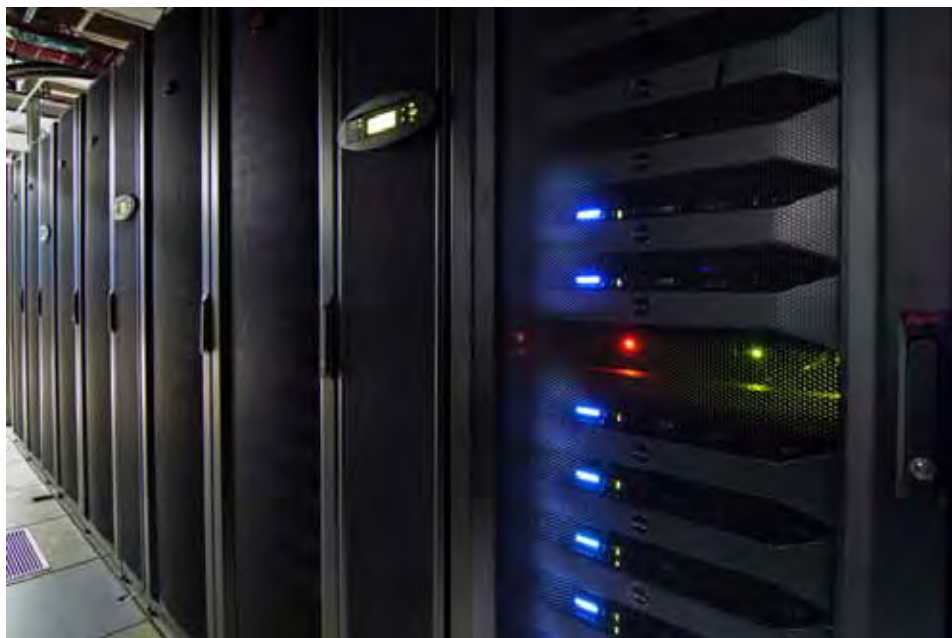


Photo credit: Bill Bellon

Mark Hobson

Ground-based Atmospheric Monitoring Instru

SSEC and CIMSS have developed the Ground-based Atmospheric Monitoring Instrument Suite (GAMIS). GAMIS collects, archives, and displays near-realtime data from various instruments situated on SSEC's rooftop and a buoy located in nearby Lake Mendota. These instruments provide valuable near-realtime validation and quality control of GOES- and POES-derived meteorological parameters.

GAMIS provides atmospheric monitoring of temperature/moisture profiles, integrated water vapor, atmospheric stability, liquid water path, aerosol optical depth, total cloud fraction, cloud phase, and cloud extinction profiles useful for ongoing GOES and POES satellite product validation efforts. Both the fixed rooftop site and the mobile laboratory (also known as the Aeribago) are excellent observation and validation facilities that greatly benefit NOAA programs.

The Lake Mendota buoy project is a collaboration among SSEC, the UW-Madison Center for Limnology, and the Department of Civil and Environmental Engineering. The buoy measurements provide researchers valuable information to better understand the biological processes governing the health of the lake and the impact of human activity on water quality.

The buoy is located approximately 1.5 km Northeast of Picnic Point and measures both atmospheric and lake properties including:

- Wind direction and speed,
- Air temperature,
- Dew point/relative humidity,
- Vertical profile of water temperature,
- Dissolved oxygen,
- Chlorophyll, and
- Phycocyanin.

The measurements are updated every two minutes providing near real-time observations of the lake conditions.

SSEC, in collaboration with the Department of Atmospheric Science, also maintains several high-resolution cameras atop of Atmospheric, Oceanic and Space Sciences Building on the UW-Madison campus. These cameras take pictures every 10 seconds. A website (<http://metobs.ssec.wisc.edu/aoss/cameras/>) dedicated to these images is automatically updated about every two minutes with fresh photos. These are also available via an auto-updating smartphone-friendly format. This information is key when selecting certain validation criteria days for satellite and ground-based product cross-reference.

Via an NSF grant, SSEC/CIMSS recently acquired a 14-channel microwave profiler (22-60 GHz) and a high frequency 90/150 GHz microwave radiometer, greatly expanding remote sensing capabilities to measure temperature, water vapor, and cloud properties from both the rooftop instruments and the mobile weather laboratory. This new acquisition complements the Atmospheric Emitted Radiance Interferometer (AERI) that routinely measures the downwelling infrared radiance at high spectral resolution, providing accurate temperature and moisture retrievals of the lower troposphere every 10 minutes (or higher temporal resolution).



Roof top cameras: North View



Northw



Lake Mendota buoy positions.

Instrument Suite (GAMIS) Provides Data Validation



East View

West View

With support from Department of Energy, NSF, and NOAA funding, SSEC is currently building a High Spectral Resolution Lidar (HSRL) that will provide continuous retrievals of cloud and aerosol properties. Not only are these four remote sensing instrument systems housed in an SSEC rooftop laboratory, but they are also available for deployment in the field.

Other existing SSEC/CIMSS rooftop instrumentation includes a Vaisala RS-92 GPS capable rawinsonde launch and receiver system, a Multi-Filter Rotating Shadowband Radiometer (MFRSR) providing solar derived aerosol optical depth, a Total Sky Imager (TSI) providing cloud fraction and daytime sky imagery, a Vaisala ceilometer for cloud base height measurements, a standard surface meteorological tower, GPS total precipitable water receiver, and longwave broadband flux instrumentation.

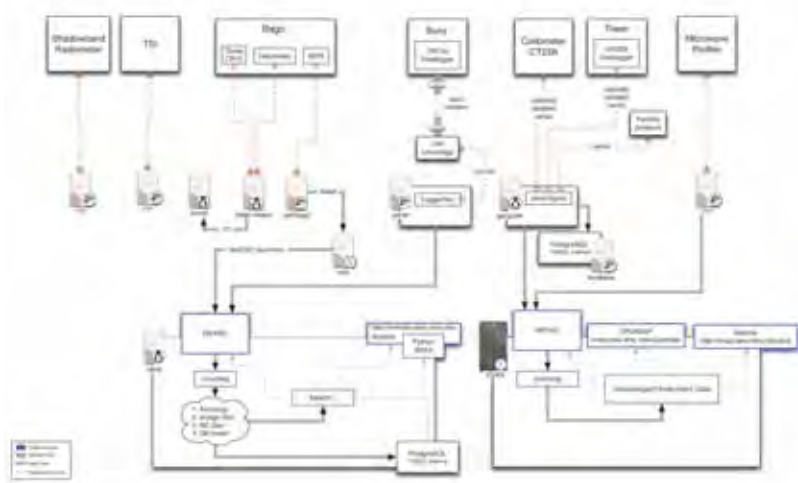
An archival system also allows acquisition of specific historical data sets which will be accessible to the research community via a web interface. After the datasets are collected in a central location, all data files are converted to NetCDF and then reformatted to achieve Climate and Forecast (CF) netCDF compliance. Vaisala Ceilometer, lake buoy, AERI, and microwave data are included in the archive, and new datastreams are pending.

Research goals for this wide array of ground-based instrumentation focuses on streamlining archival and data access portals for data. New visualization software such as McIDAS-V will be integrated into the data portal to allow immediate scientific access and interrogation of the rooftop database.

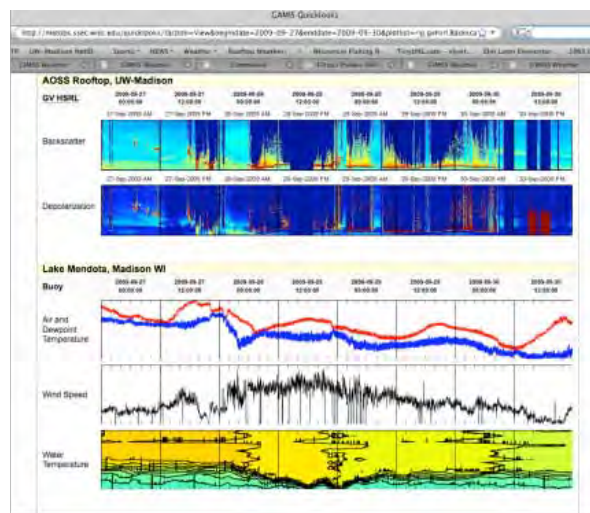
With support from the NOAA Ground System program, SSEC and CIMSS will continue to develop integrated hardware and software systems to acquire, archive, and distribute the measurements in dimensions and formats convenient to the user community. This database supports NOAA science projects such as GIMPAP, PSDI, and GOES-R by providing validation for atmospheric retrieval products on a routine basis.

A near real-time quicklook interface for rooftop data and the Lake Mendota buoy system is available at <http://metobs.ssec.wisc.edu/quicklooks/>.

Wayne Feltz



A diagram indicating GAMIS flow of data from instruments to computer servers, archival system, and final display.



Example of quicklook interface to AOSS rooftop data showing High Spectral Resolution Lidar (HSRL) and Lake Mendota Buoy measurements.

DISC Drill Breaks Antarctic Record

On 28 January 2011 the Deep Ice Sheet Coring (DISC) drill passed the previous record depth for US ice drilling. Designed and built by engineers of the SSEC Ice Drilling and Design Operations (IDDO) group, the drill reached a depth of 3331.5 meters (10,928 feet), breaking the previous record of 3053 meters set in 1993 in Greenland.

The DISC drill is a tethered mechanical drill system, essentially a rotating hollow tube with four razor-sharp blades at its cutting end. The drill is designed to retrieve cores of ice from depths of up to 4,000 meters, the limit of its suspending cable.

“Think of these cores as a giant library of ancient weather reports,” said Principal Investigator and Professor Emeritus Charles Bentley. “The scientific community decided what they needed for a new drill. They wanted lots of new capabilities. Their requests drove our design team and the result was the DISC drill.”

The sonde consists of six distinct and separable sections raised and lowered in the fluid-filled borehole with a cable approximately 15 mm in diameter:

- the cutter head assembly that actually cuts the ice,
- the core barrel in which up to 3.5 meters of core is collected,
- the screen section in which chips of ice resulting from the cutting operation are separated from the drilling fluid and stored,
- the motor/pump section that houses a pump to circulate the drilling fluid and motors to drive the pump and rotate the lower portions of the drill that cut the ice,
- the instrumentation section that contains controls for the pump and cutting motors as well as numerous sensors to monitor the drilling operation, and
- the upper section that provides for the termination of the cable and “anti-torques” that center the drill and provide a torque reaction point to prevent the entire sonde from rotating.



*Nicolai Mortenson tilting the DISC Drill tower.
Photo credit: Jay Johnson*



DISC Drill cutter head with ice core. Photo credit: Krissy Dahnert

The cutter head, core barrel and screen section rotate while the sections above are restrained.

The cable used at WAIS Divide is 4000 meters long and provides the support for lowering and raising the sonde. In addition, it contains the power supply for the motors and instruments in the sonde and optical fibers for data transmission. The cable winch is electrically driven and is designed to have the smallest “footprint” possible.

“The DISC drill is revolutionary technology,” said Alexander Shturmakov, director of engineering and research for IDDO. “Its electronic brain makes this drill more complex than any comparable device.”

The ice cores produced by the DISC drill are 12.2 cm (4.8 inches) in diameter and up to 3.5m long. Suspended in the ice cores winched up from below are millions of tiny bubbles – ancient air that was trapped when the snow fell millennia ago. At the 3,300-meter mark, the ice (and the air trapped within it) is approximately 55,000 years old.

The most significant and unique characteristic of the WAIS Divide project will be the development of climate records with an absolute, annual-layer-counted chronology for the most recent ~40,000 years.

The WAIS Divide ice core will provide the first Southern Hemisphere climate and greenhouse gas records of



*Core handlers and drillers. Last core of 2010-2011.
Photo credit: Jay Johnson*

comparable time resolution and duration to Greenland ice cores, thus enabling comparison of environmental conditions between the northern and southern hemispheres. Greenhouse gas concentrations in the paleo-atmosphere will be studied with a greater level of detail than previously possible.

The WAIS Divide ice core will also be used to test models of WAIS history and stability, and to investigate the biological signals contained in deep Antarctic ice cores.

Basal and subglacial studies at the WAIS Divide ice coring site will address several of the top-level scientific goals identified previously by the WAIS Divide science community: (1) determining how the West Antarctic Ice Sheet (WAIS) responded to climate changes in the past, (2) improving models of WAIS contribution to near-future global sea level changes, and (3) understanding microbial life in deep ice.

Mark Hobson



*Dr. Charles Bentley, IDDO P.I., with ice core at WAIS Divide camp, Antarctica.
Photo credit: Krissy Dahnert*

On-Orbit Absolute Radiance Standard for Future IR Remote Sensing Instruments

Future NASA infrared remote sensing missions, including the CLimate Absolute Radiance and REfractivity Observatory (CLARREO) mission, will require better absolute measurement accuracy than is now available, and will most certainly rely on the emerging capability to fly International Standard traceable values to provide irrefutable absolute measurement accuracy.

accuracy validation for infrared remote sensing instruments.

Figure 1 illustrates the key features of the OARS in a section view. The blackbody design is based on the on-board calibration system developed for the NASA Geosynchronous Imaging Fourier Transform Spectrometer (GIFTS). A temperature controlled light-trapping blackbody cavity

(with a 30 mm aperture) contains thermistor temperature sensors and miniature phase change cells that provide on-orbit temperature calibration.

Three or more phase change cells with different reference materials can be used, thus providing multiple calibration

the cavity view to the halo are known. Laboratory measurements of an OARS type blackbody, with a spectral emissivity greater than 0.999, have been made with uncertainties less than 0.0004 ($k=3$).

A temperature calibration point is obtained by measuring the transient cavity temperature response to a small increase in power. The sequence of events during a typical melt of gallium is illustrated in Figure 2.

After initial stabilization in the constant temperature mode, a constant power is used to transition through the melt plateau, where the phase change signature is observed. Note that these signatures are clearly discernable even though there is less than one gram of melt material. Other melt materials have been demonstrated, including H_2O , Hg, and a Ga-Sn eutectic.

The effective temperature is determined by a weighting of the different thermistors imbedded at key locations within the cavity. The weighting has been determined from analysis that uses a Monte-Carlo ray trace model of the cavity with a temperature distribution calculated from a thermal model.

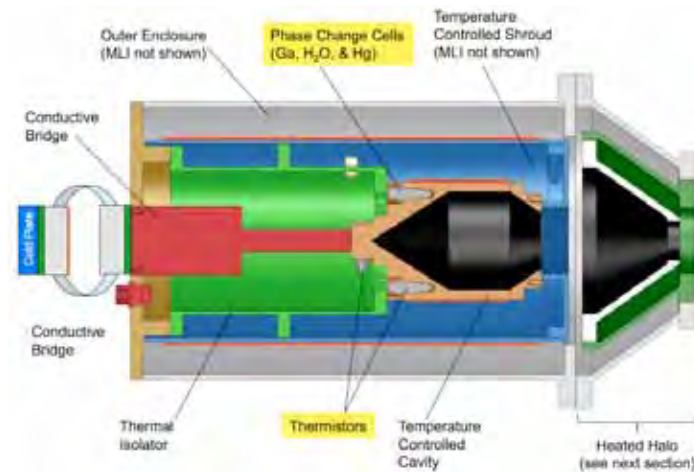


Figure 1: Key features of the OARS

As an example, instrumentation designed to measure spectrally resolved infrared radiances with an absolute brightness temperature error of better than 0.1 K will require high-emissivity (>0.999) calibration blackbodies with emissivity uncertainty of better than 0.06% ($k=3$), and absolute temperature uncertainties of 0.045K ($k=3$). Key elements of an On-Orbit Absolute Radiance Standard (OARS) meeting these stringent requirements have been demonstrated in the laboratory at SSEC and are undergoing further refinement under the NASA Instrument Incubator Program (IIP).

This work will culminate in an integrated subsystem that can provide on-orbit end-to-end radiometric

temperatures. The heatable conical frustum (heated halo) in front of the cavity provides the broadband source for periodic measurement of emissivity. These measurements are made by the spectroradiometer that normally views the cavity for calibration verification, but in this case measures the reflected signal of the heated halo.

Cavity emissivity can be calculated when the heated halo and effective background temperatures and the solid angle view factor of

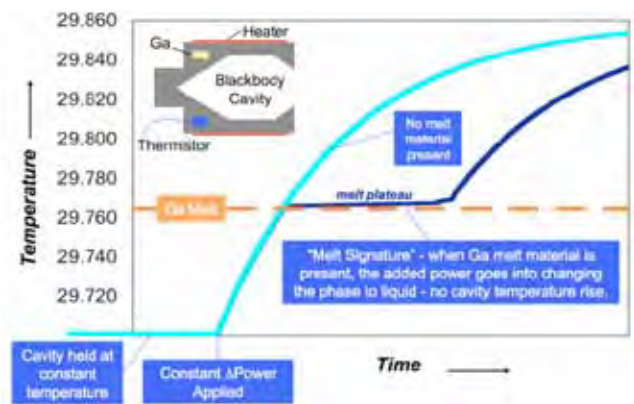


Figure 2: Key elements of a transient melt signature, in this case for Gallium. The melt plateau is approximately 4,000 seconds in duration.

Experimental Results

A. Phase Change Cells

The melt materials are individually confined into miniature welded phase change cells. After defining the detailed containment configuration, the phase change cells were subjected to a full accelerated life test that was designed to simulate the expected mission temperature soak and cycling environmental exposure. Tests were devised to show that the phase change materials had not been unacceptably contaminated via dissolution, and that the containment materials were not mechanically compromised via mechanisms such as liquid metal embrittlement.

Mechanical integrity was also investigated by comparing the housing morphology both before and

after the accelerated life testing. In addition, significant testing has been conducted to explore the melt plateau repeatability, and to characterize the relationship between the time taken to go through the melt and the melt plateau (mid-melt) temperature.

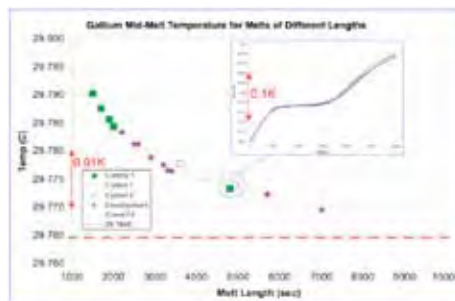


Figure 3: The inset plot at upper right shows the three melt signatures associated with the circled data points. Data included in the plot is from three different phase change cells taken before and after a full duration hot soak and deep temperature cycling.

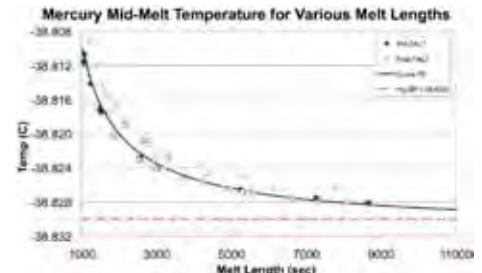
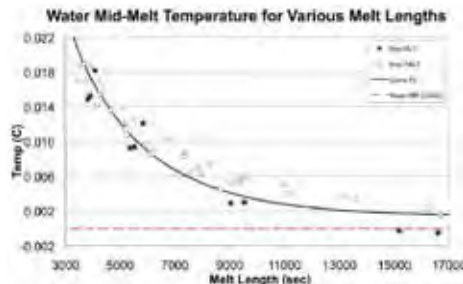
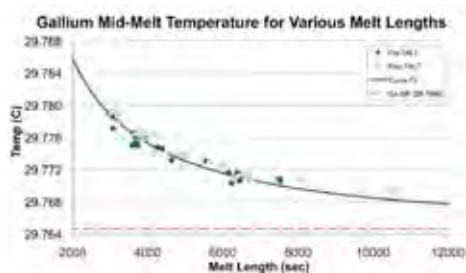


Figure 4: Plots of the characteristic curves for the gallium, water, and mercury melt housing samples.

B. Heated Halo

The dominant source of uncertainty in a well-designed blackbody arises from the measurement of the cavity temperature and the effect of the non-unity emissivity of a practical blackbody with a macroscopic aperture.

The Heated Halo is a broadband thermal radiation source designed to

fill a large fraction of the solid angle of a given blackbody's field of view, while being physically outside of the field of view of the detector observing the blackbody. The Heated Halo used in this experiment is a hollow aluminum cylinder, painted black and heated to 95°C (Figure 5).

For this experiment, we measured the emissivity of the Atmospheric Emitted

Figure 3 illustrates that as melt time is increased, the mid-melt temperature asymptotically approaches the known (in this case) gallium melt temperature. This characteristic asymptotic behavior has shown to be constant for a given physical configuration. This is the case for all three melt materials.

The definitive test of the melt cell performance is the melt signature. All three melt materials, gallium, water, and mercury, have undergone extensive examination of the melt signature behavior in several different configurations as well as before and after a full accelerated life test, with excellent agreement. As seen in Figure 4, the signatures for all three melt materials fall within about $\pm 2\text{mk}$ of the characteristic mid-melt temperature versus melt length curve, regardless of orientation, pre- or post-life test, or housing-to-housing variation.

Radiance Interferometer (AERI) blackbody. The blackbody employs a light-trapping cavity geometry which is painted with diffuse black paint (Aeroglaze Z306). Its temperature is measured by embedded thermistors to within a combined uncertainty of 0.05 K ($k=3$). The blackbody is operated at ambient room temperature (about 23°C).

continued on page 18

Two different spectrometer systems were used to observe the AERI blackbody: (1) the Scanning High-

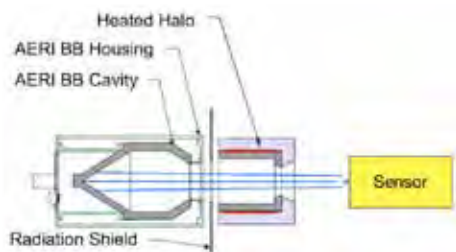


Figure 5: Schematic cross-sectional representation of the first generation Heated Halo. A radiation shield reduces radiative heating of the blackbody by the Heated Halo.

resolution Interferometer Sounder (S-HIS), a Fourier transform spectrometer (FTS) designed for autonomous operation on board research aircraft; and (2) the Absolute Radiance Interferometer (ARI), a laboratory-based FTS using a pyroelectric detector.

The emissivity spectrum of the AERI blackbody, measured by both the S-HIS and the ARI using the Heated Halo method, and compared to a model result from a Monte Carlo simulation, is shown in Figure 6. The overall shape of the observed emissivity curve, notably the step in emissivity around 1200 cm^{-1} , is consistent with the properties of the Aeroglaze Z306 paint.

Using the S-HIS and ARI spectrometers, the spectral emissivity of the AERI blackbody was measured in the $200\text{--}2800\text{ cm}^{-1}$ spectral range with the Heated Halo method. The measurements are in agreement with each other, as well as with a Monte Carlo model, within their uncertainties. The low level of systematic (type B) experimental uncertainty across most of the infrared spectrum (4×10^{-4} , $k=3$) is encouraging, suggesting that the Heated Halo can be deployed on space-based instruments to monitor calibration blackbody

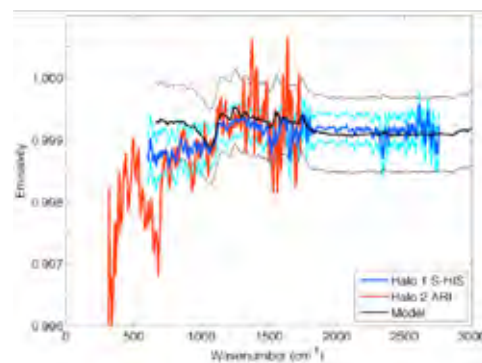


Figure 6: Comparison between two versions of Heated Halo measurements, S-HIS (blue) and ARI (red), as well as the modelled emissivity of the AERI blackbody. The dashed curves represent the systematic (type B) uncertainty ($k=3$) for the S-HIS and the model result.

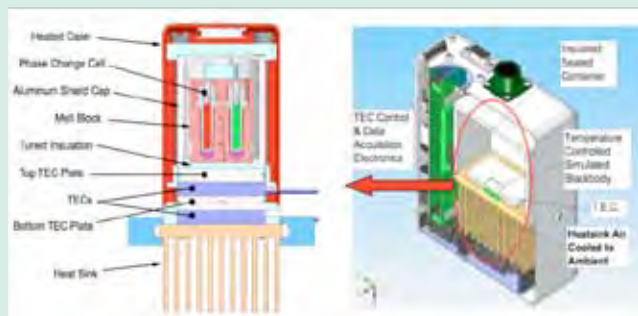
emissivity, on-orbit, throughout the lifetime of satellite missions.

The OARS is expected to be completed soon and ready for testing with the ARI spectrometer.

Fred Best

Microgravity Demonstration on the ISS

NASA has provided a separate grant to demonstrate the performance of the UW melt cell concept on the International Space Station, sometime within the next year.



The configuration for microgravity demonstration of the phase change includes three different melt materials and makes use of the Experiment Support Package developed by Utah State Space Dynamics Laboratory.

The phase change cells are contained in the aluminum melt block, along with the temperature sensor to be calibrated. The aluminum shield cap is thermally coupled to the top Thermo Electric Cooler (TEC) plate. Two TECs are sandwiched between the melt block and a heat sink, which the TECs use to draw/reject heat in order to heat and cool the melt block. The bottom TEC provides a level of isolation from ambient temperature fluctuations, which allows the top TEC to maintain greater stability. The outer case is held at constant temperature using a heater to provide a stable environment.

The temperature control and data collection for this demonstration are provided by the Experiment Support Package developed by Utah State Space Dynamics Laboratory. Because the Experiment Support Package does not have the capability to get to the freezing point of mercury, we plan to use a binary eutectic of gallium as our third material along with gallium and water.

Art Meets Science for a Spectacular View of Wisconsin

Over fifty years ago the idea of studying the Earth from space was successfully launched at the University of Wisconsin-Madison by Professors Vernor Suomi and Robert Parent. Their experiment aboard the Explorer 7 satellite in 1959 ushered in a new era of orbiting platforms gazing down at their home world, gathering and transmitting data day and night.



From 4 February to 9 September 2011, SSEC, CIMSS, and University-affiliated Tandem Press are proud to present the history, the science, and the beauty of this ongoing mission to study our planet with a spectacular and dynamic display entitled “Satellites See Wisconsin” at the Dane County Regional Airport.

The practical value of these satellite images can be seen every day in their effects on climate studies and

Satellites See Wisconsin SSEC

severe weather prediction, but exhibit organizer Steve Ackerman, Director of CIMSS, wanted to go beyond simply celebrating the data.

“The goals of this exhibit,” said Ackerman, “are not only to inform folks of the current and historic role that the UW-Madison plays in satellite remote sensing and to show how satellites are used to study the environment, but also to reveal visually stunning and rarely seen images of our world as seen by satellite.”

Ackerman presented the idea to Paula Panczenko, executive director of Tandem Press, and, with a team of 15 people from SSEC and CIMSS, the show was envisioned and created.

Images from SSEC, CIMSS, and the UW-Madison Department of Forest Ecology were selected, cropped, enlarged, printed, mounted, captioned, and finally arranged to their best advantage in five large glass cases at the airport. In addition to the stunning satellite images of Wisconsin in all seasons and several different bands of EM radiation, a magnificent enclosure of towering tapestries presents SSEC’s 3D-animated interactive “Science on a Sphere.”

A beautiful historical timeline of half a century of satellite study can be found teamed with the Online Weather Looper (OWL), a display of current world-wide images and data gathered from satellite feeds.

In a central position of honor a full-scale model of the Explorer 7 satellite anchors the exhibit.

Landsat images, 3D images of Wisconsin terrain (with free glasses to see the full effect), and explanations of satellite data acquisition add up to an in-depth and moving experience.

If you happen to be passing through the Dane County Regional Airport, you can’t miss the sprawling display. Just make sure you give yourself enough extra time to take it all in.

Mark Hobson



Photos by: Mark Hobson



McIDAS-V Adds Support for NPP Weather Satellite Data

As the launch of the NPOESS Preparatory Project (NPP) approaches, SSEC/CIMSS programmers are focusing their efforts on ensuring that SSEC's premier visualization tool, McIDAS-V, will be ready for the onslaught of new data. Currently scheduled to launch 25 October 2011 from Vandenberg Air Force base in California, NPP will supply crucial weather and climate data to meteorologists and other scientists. While visualization and analysis capability have been added for three of the five sensors onboard NPP, programmers are pushing ahead to ensure the remaining components will be ready before launch.

To date, visualization and analysis capabilities have been successfully added to McIDAS-V for the Visible/Infrared Imager Radiometer Suite (VIIRS), the Advanced Technology Microwave Sounder (ATMS), and the Cross-track Infrared Sounder (CrIS). Work remains on the Ozone Mapping and Profiler Suite (OMPS) and the Clouds and the Earth's Radiant Energy System (CERES).

To develop support for this new satellite, SSEC utilized pre-launch test data, which are being generated and made available to approved organizations from the NOAA Satellite Operations Facility in Suitland, Maryland. A computing center called the Government Resource for Algorithm Verification, Independent Testing, and Evaluation (GRAVITE) is the source of the simulated data, which is generated from similar, predecessor instruments.

The NPP data format is complex, and has been challenging to adapt to analysis tools.

The data is delivered as HDF5 granules, and in the most typical case

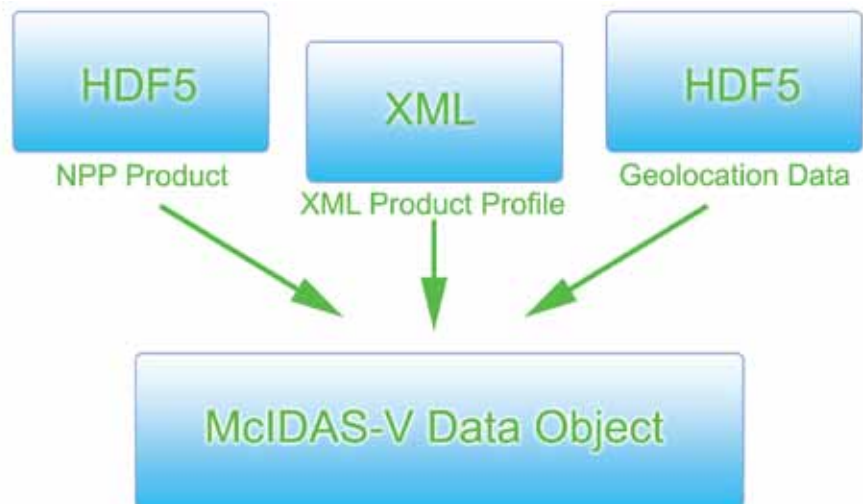


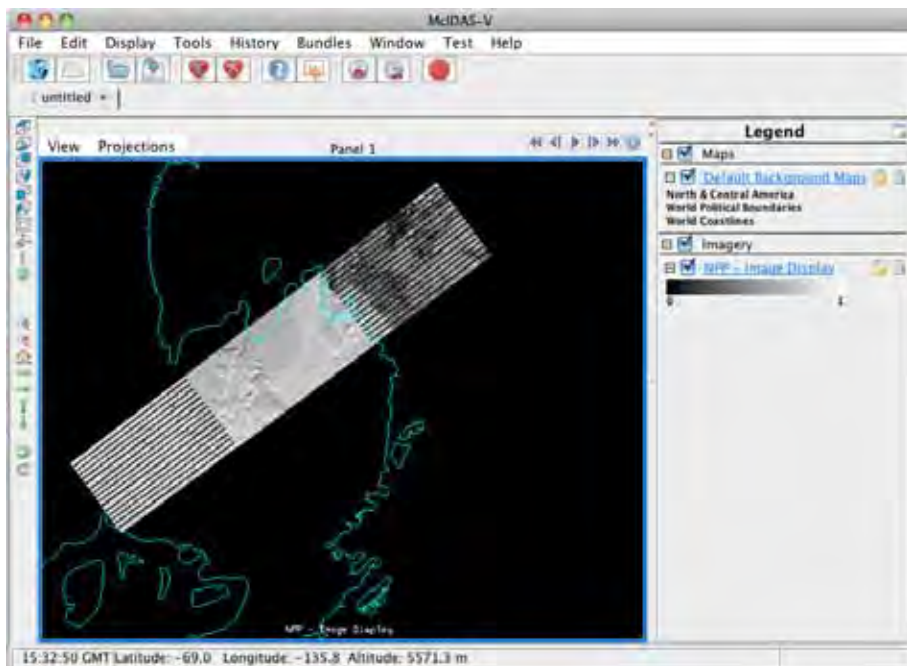
data must be gathered from three separate files to visualize a single granule. The three files are:

1. an HDF5 file containing data products,
2. an HDF5 file containing geolocation information, and
3. an XML file containing necessary metadata such as scale/offset values and fill values.

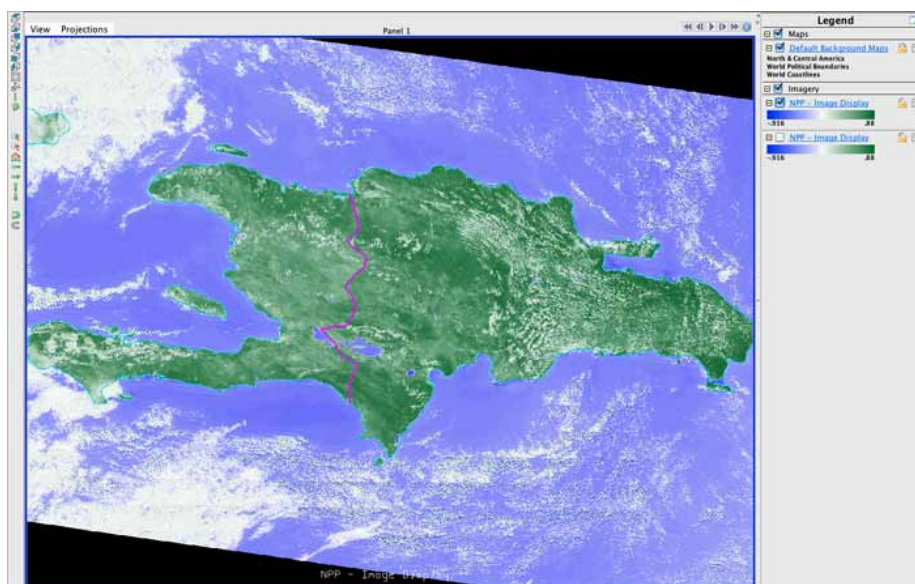
For McIDAS-V, code had to be written which combines the necessary parts of all three file types into a single displayable DataSource object, depicted visually below.

Fortunately, this development effort was able to leverage the work previously done to integrate HYDRA into McIDAS-V. The HYDRA functions allow scientists to interrogate multi- and hyperspectral satellite data in very novel, very useful ways. Additionally, a granule aggregator was written to allow users to select and display an arbitrary set of contiguous granules. Once loaded, the full McIDAS-V capabilities are available, including subsetting, reprojecting, applying formulas, etc. The following images provide some visual examples of working with NPP data in McIDAS-V.





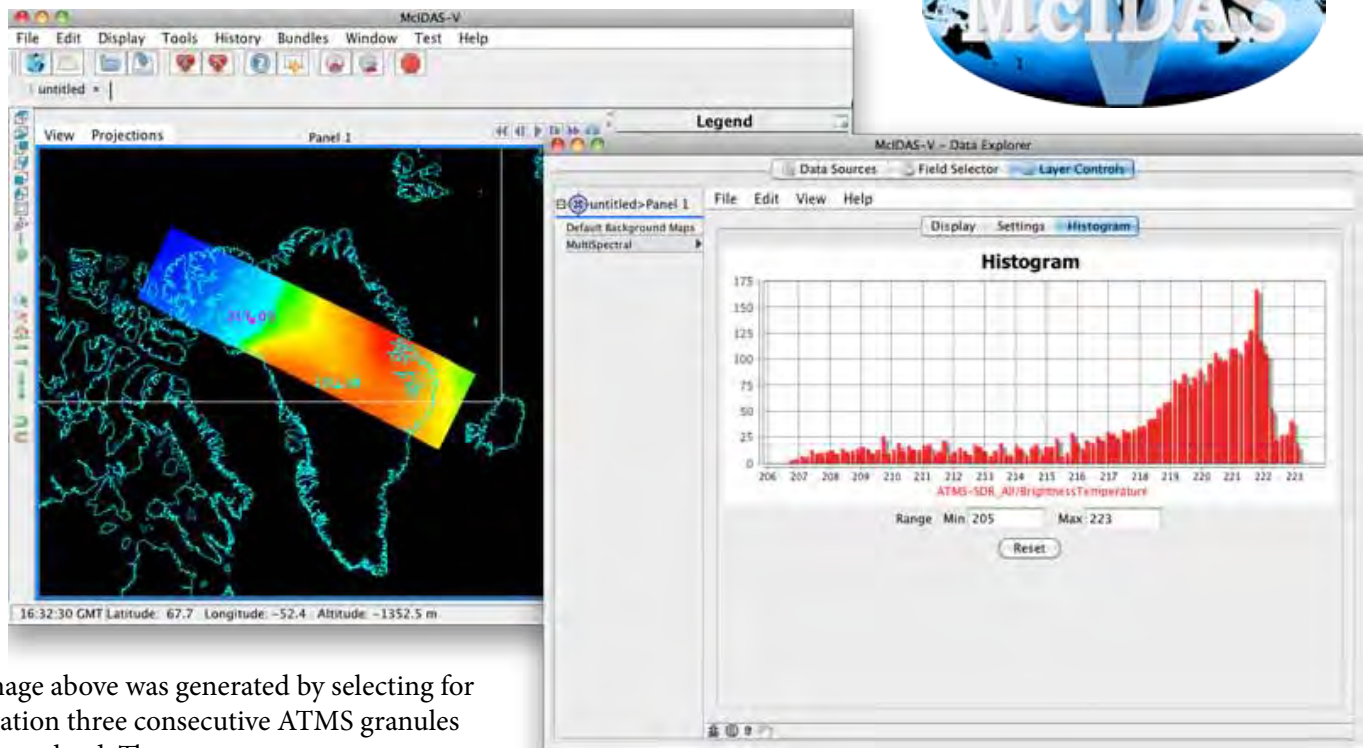
This image shows the reflectance data for a full granule of VIIRS Band 1 data over Antarctica. VIIRS has a 3,000 km swath width, about 30% greater than MODIS, and maintains a more consistent pixel size across the swath. The appearance of missing data is due to “bow-tie” deletion in the simulated data. This mechanism reduces spatially redundant data at the edge of successive scans, and thus reduces the overall data rate. The appearance of gaps is currently an artifact of how McIDAS-V samples and geolocates the granules by default. An upcoming revision of McIDAS-V will have the option to regrid VIIRS data for display to eliminate this visual effect.



This image shows a simple formula and color enhancement applied to VIIRS granules to produce a Normalized Difference Vegetation Index (NDVI) over the Caribbean island of Hispaniola. The formula is $(I_2 - I_1) / (I_2 + I_1)$, where I_1 is Imager Channel 1 and I_2 is Imager Channel 2. This NDVI illustrates the deforestation crisis in Haiti, visible right up to the political boundary with the Dominican Republic. The VIIRS granules were re-gridded to a Lambert Equal Area 380m resolution grid to account for bow-tie deleted instrument FOVs. The display was created via the Python-based, user defined computation component of McIDAS-V.

McIDAS-V - free, open source software for 3D geophysical data analysis and visualization.
For more information and to download: <http://www.ssec.wisc.edu/mcidas/software/v/download.html>

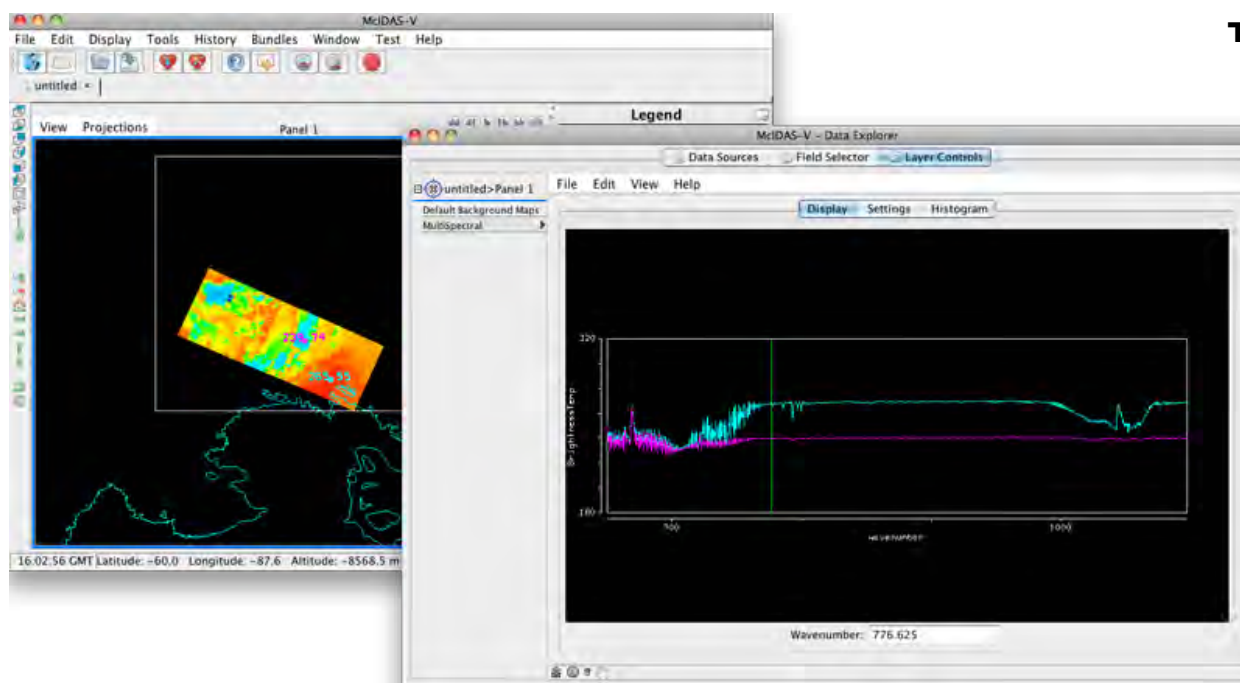
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The image above was generated by selecting for aggregation three consecutive ATMS granules over Greenland. There are numerous ways to analyze multispectral data in McIDAS-V. For this ATMS aggregation, we see a color enhancement, dual data probes, and a histogram.

McIDAS-V provides a novel way to visualize and interrogate hyperspectral data. Below, all 717 longwave CrIS channels can be manipulated bi-directionally (from both display windows).

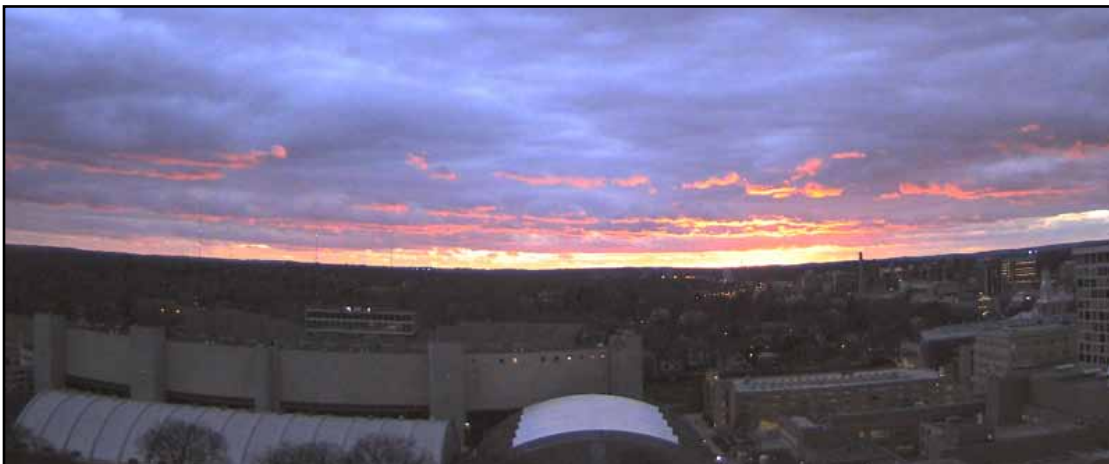
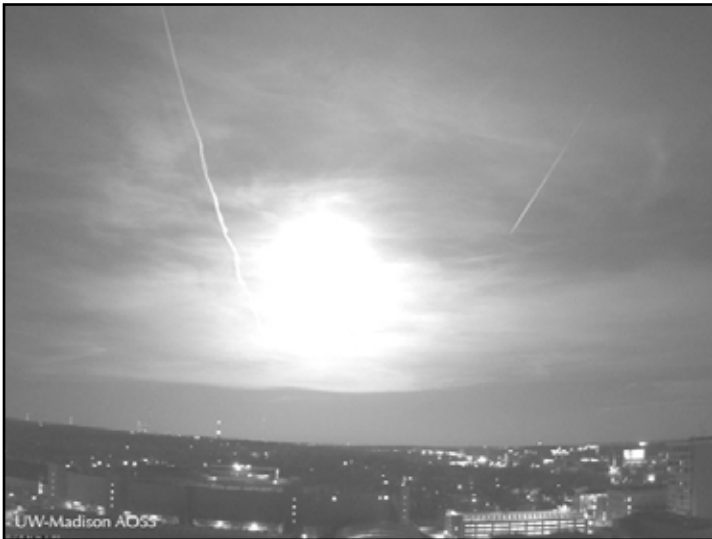
In the remaining months before NPP's launch, SSEC/CIMSS programmers plan to ensure that McIDAS-V is ready for this new generation of data. NPP data users will have another powerful, and freely available, visualization tool at their fingertips.



Tommy Jasmin

Roof Cam's Greatest Hits

SSEC, in collaboration with the Department of Atmospheric and Oceanic Sciences, maintains several high-resolution cameras atop of Atmospheric, Oceanic and Space Sciences Building on the UW-Madison campus. These cameras take pictures every 10 seconds. A website (<http://metobs.ssec.wisc.edu/aoss/cameras/>) dedicated to these images is automatically updated about every two minutes with fresh photos. (See article on Page 12).



Several images captured by the SSEC/AOSS Roof Cam, including the 14 April 2010 meteor burst over Wisconsin (center left image).

If you would like to be added to our mailing list for *Through the Atmosphere*, please contact Maria Vasys at maria.vasys@ssec.wisc.edu.

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