CIRA
Connecting Models and Observations

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College of Engineering

Celebrating 10 Years of CloudSat: Revealing the Inner Secrets of Clouds

Colorado State University

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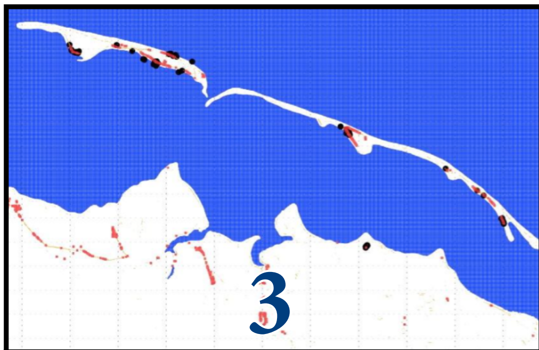

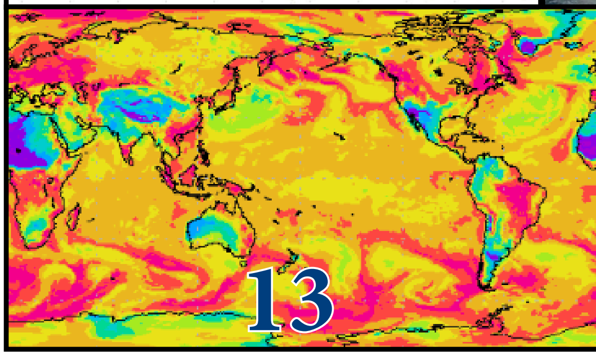

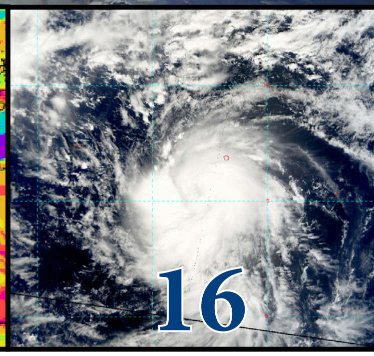

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Editor and Designer: Ivy Jones
Cover Photo: Graeme L. Stephens. *CloudSat: The Useful Pursuit of Shadows.* Oil on Canvas. Department of Atmospheric Science, Colorado State University (photographic reproduction)

From the Director's Desk

I want to start by emphasizing our vision of improving the connection between models and observations. Here at CIRA, we work to achieve this through several approaches: data assimilation, data fusion, and hybrid approaches. We have seen greater activity not only in data assimilation here in Fort Collins, but also in closer collaborations with NOAA's Global Systems Division to work on satellite assimilation of precipitation into the HRRR model. Using the LAPS model developed by GSD, we are also beginning to work with KMA on a small project to help bring data into the forecast model for the 2018 Winter Olympics in Pyeongchang. This fits well with CIRA's activities at the Aviation Weather Testbed, which is quite naturally focused on providing the best possible product irrespective of source. From this perspective, I feel good that as we progress, we will not only make inroads within our own groups, but hopefully be in a position to share and learn from each other to find new methods to continue merging models and observations.

With the launch of the GOES-R satellite now only a few months away, I think it is an understatement to say that we are simply excited about what the new data will show. With five-minute full disk images and spatial resolutions of 1km in the visible and 2km in the infrared, we will be able to track cloud development like we have never done before. The daily images that the RAMMB members are generating from Himawari-8 as a way to prepare for GOES-R are quite amazing, and we look forward to sharing these images on the CIRA web site soon. It is quite clear from watching those images, however, that a vastly improved capability of tracking changes in clouds– something difficult to do with one hour or 30 minute imagery- will represent a paradigm shift in cloud research going forward. In addition, thanks to the GOES-R project, CIRA has recently received a grant to assimilate five-minute GOES-R data into a regional model. We plan to use the High Resolution Rapid Refresh (HRRR) model running on a very limited domain to see how far we can get in terms of predicting thunderstorm outflows and quantitative precipitation forecasts and analyses.

Also in this issue is an update on our CloudSat processing system. CloudSat has had an amazing 10-year run, with more than enough science results to fill a hundred CIRA magazines. The data system is still unique in its focus on science rather than just data products. Its success speaks for itself. In fact, the CloudSat Data Center (DPC) will be spearheading our GOES-R data archive, which we intend to focus on severe storms and tropical cyclones. Not only will we archive the appropriate satellite sectors for the storm's duration, but we also plan to use the DPC infrastructure to add the HRRR model, ground-based radar, and any other available data to build up a library of storms for use by the broader research community. Look for the first data sets early next year once GOES-R data is released on a routine basis.

Let me conclude by congratulating a few individuals who deserve our special recognition. The NESDIS/STAR Ocean Color Team of Lide Jiang, SeungHyun Son, and Xiaoming Liu won this year's CIRA Research Initiative Award for successfully completing the VIIRS mission-long ocean color data re-processing project far ahead of all other JPSS teams. The team made significant contributions in the development of NOAA's infrastructure and capability to acquire, process, monitor, evaluate, and archive VIIRS ocean color products. Equally impressive were the efforts of Missy Petty who won this year's Service Initiative Award for her exceptional contributions, including team leadership/mentorship capability and the implementation of innovative and creative technology. Also, Phil Partain, Shawn McClure, and the team of Jennifer Raab and Holli Knutson won CIRA's Exceptional Service Award. Congratulations to all of you, as well as our CIRA data assimilation interns. After a year learning data assimilation, both Biljana Orescanin and James Taylor find themselves with full-time jobs doing data assimilation on behalf of NOAA.

Christian Kummerow,
CIRA Director

Chris Kummerow

Modeling Snow Drifts to Identify Polar Bear Den Locations

Glen Liston and Matt Rogers

As winter approaches over the Arctic coast, pregnant polar bear females seek out deep snow banks. The bears burrow into the snow, creating a comfortable, if confined, den in which they will spend the long, cold Arctic winter to give birth to a litter of baby polar bears. The first weeks, or even months, of the lives of these cubs are spent entirely within the den, where the mother polar bear lives off of stored fat reserves while nursing her infants. By March or April, the young bears are old enough to survive in the outside world, and the new family exits their den to make the trek to the sea ice.

The shelter provided by the den during the winter ensures the survival of the Arctic's top predator species; locating suitable den locations is therefore a high priority, not just for polar bear mothers, but for other, more recent, Arctic residents. As resource extraction and transportation activities along the Arctic coast continue to grow, the potential for negative interactions between polar bear and human populations increase. Eager to identify potential polar bear den sites to better coordinate activities to give the bears needed space, governmental agencies such as the U.S. Fish and Wildlife Service are turning to researchers to tackle this issue; CIRA researchers have answered the call.

Long-time readers of CIRA Magazine are familiar with the polar journeys of researcher Glen Liston (more on Glen can be found in the Fall 2012 issue). One of Dr. Liston's primary projects is snowdrift modeling – two tools developed here at CIRA of particular interest are the MicroMet and SnowModel systems. MicroMet takes observations and gridded output products from large-scale numerical weather prediction (NWP) models and creates a high-resolution gridded product used to drive snow drift prediction models. SnowModel is a sophisticated snow analysis model that accounts for snow accumulation, sublimation, drifting, density, evolution, and changes in snow qualities as snowpack ages and/or melts. Several major studies using these tools have been applied to polar research, allowing researchers to glean important information about the nature of the high-latitude snowpack and giving insight into the changes the polar regions are undergoing as part of a changing climate.

The ability of SnowModel to characterize snow drifts at fine scales opened up the possibility of searching out den site locations. Highlighting the smallest of drifts that were deep enough to serve as bear den locations offered a particular challenge for the model and would require the best possible NWP predictions, snow observations, and a high-resolution digital elevation model (DEM) of the region of interest for the proof of concept project to succeed. Several regions covering the Beaufort Sea coast of Arctic Alaska were selected as test locations; these sites were of interest to coastal communities and, notably, had historic den sites already located, giving the model a ground truth against which verify model results.

Historical snowfall observations from the Natural Resource Conservation Service SNOpack Telemetry (SNOTEL) dataset were employed along with model reanalysis data from the NCEP North American Regional Reanalysis (NARR) project for a time period spanning from 1995 through 2012 and were prepared for ingest into MicroMet. An ultra-high-resolution (2.5 m) LIDAR-derived elevation dataset for coastal Alaska was used to give the best possible topographic information for the model simulations. The system then simulated the winter snowdrift accumulations for each year of the 18-year study for the regions of interest. During the simulation, the model developed realistic coastal snowdrifts, and analysis of the model output allowed for identification of potential den sites which could then be compared against historical den sites.

The results of the project show a great deal of promise. Figure 1, depicting Pingok Island off the Beaufort Sea coast of Coastal Alaska, shows potential denning sites identified by the model analysis (snow drifts deeper than 1 meter) marked with red dots, while historical den sites are marked with black dots. A good deal of agreement exists between the modeled potential site locations and where bears actually build their dens. Further analysis of the coastal topography, specifically looking at the depth of the so-called "cut banks" as the coast recedes into the ocean, identifies some critical elements for creating sufficiently deep snow drifts to serve as den sites; if the cut banks are too low, snow drift depth will be insufficient to create a safe den for a bear. (Figure 2) This information could prove valuable for the human population of the northern coast as they seek to avoid contact with their ursine neighbors.

The challenges of a changing climate have already impacted polar bear populations throughout the Arctic – changing conditions in sea ice amounts and temperatures change the manner in which bears hunt for food, while changes in the timing of the Arctic seasons interfere with the migratory properties of bear populations. Ensuring that this vulnerable species has as few challenges as possible to their continued survival in one of the most harsh, austere environments on Earth is a responsibility that denizens of the Arctic take seriously. Research from CIRA is helping to ensure the future of these majestic predators, one den at a time.

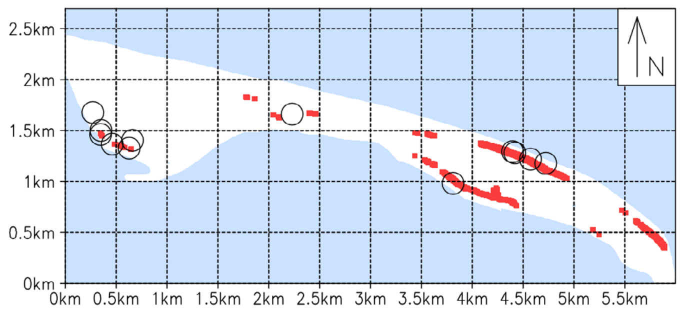


Figure 1
Modeled potential den sites (red dots) compared to historical polar bear den sites (black dots) along the coast of Northern Alaska.

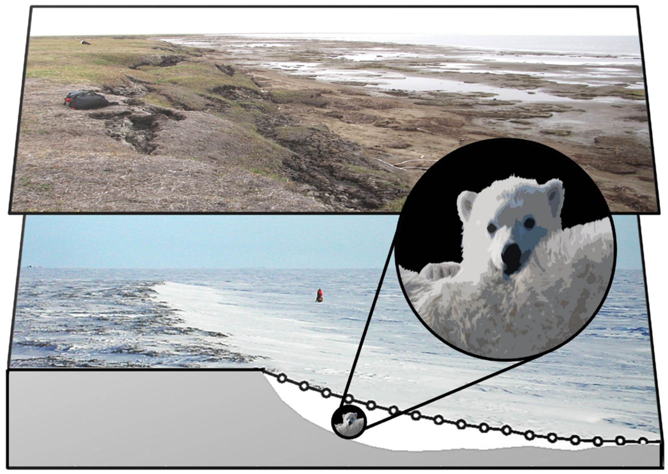


Figure 2
Summer and winter views of a coastal cut bank along the Beaufort Sea in Northern Alaska, showing the characteristics of snow drifts along the cut bank. Image credit: Glen Liston, Craig Perham, Dick Shideler, and Jon Aars.

Figure 3
The field team with whom Glen Liston worked.

Figure 4
Gracie and Kavik helped locate bear dens.

CloudSat: A Decade Spent Revealing the Inner Secrets of Clouds

Matt Rogers

April 28, 2006-- The CloudSat satellite launch.

Looking back in time to April 2006, Twitter was a one-month-old idea that would not officially launch for several more months. The original iPhone launch was a year away, and Blu-Ray discs were a just-announced technology. In cinema the previous month, Crash had won Best Picture at the Academy Awards, surprising film buffs who were certain of a victory for Ang Lee's Brokeback Mountain. In sports, the victors of Super Bowl XL, the Pittsburgh Steelers, were planning their trip to meet with President George W. Bush in Washington, and Barry Bonds of the San Francisco Giants was experiencing a temporary slump in his controversial march to claiming the major league home run title.

For a group of scientists at NASA's Jet Propulsion Lab (JPL) and at Colorado State University, led by former CIRA Director and University Distinguished Professor Graeme Stephens, the bulk of April 2006 was spent playing a nearly interminable waiting game. At Vandenberg Air Force Base near Lompoc, California, a first of its kind satellite, named CloudSat, sat in a launch facility atop a Delta II rocket. Built in Boulder, Colorado by Ball Aerospace and carrying a novel 94 GHz cloud-profiling radar using a klystron built by the Canadian Space Agency, CloudSat was slated to be the first spaceborne radar designed to detect the properties of clouds through measurement of the minute droplets and ice crystals composing these ethereal and permeating components of the Earth's atmosphere.

Previously-launched spaceborne radars (such as the Tropical Rainfall Measuring Mission, or TRMM) had focused on measuring precipitation composed of particles that are much larger than cloud particles. Detecting the latter, with diameters sometimes measured in thousandths of millimeters, was a task for a different kind of instrument – one that the project scientists involved with the CloudSat mission were hoping would make orbit soon. Nestled along with CloudSat atop the Delta II rocket sat another groundbreaking mission – the Cloud-Aerosol LIDAR and Infrared Pathfinder Satellite Observation (CALIPSO) spacecraft, a joint mission between NASA and the French space agency CNES. It was another first of its kind instrument designed to profile aerosols and the most ephemeral of cloud-ice particles. Coordinating the logistics of launching the dual payload to low-Earth orbit presented a challenging task.

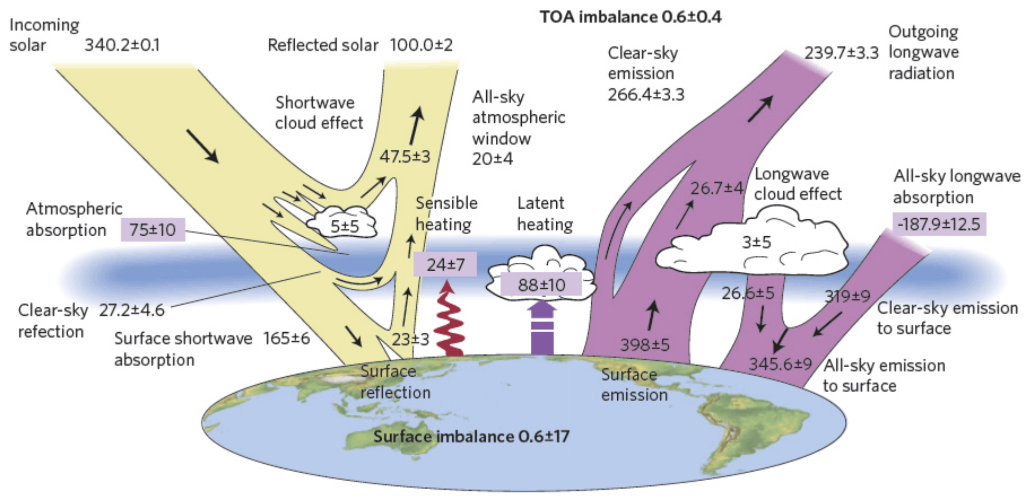
By April 19th, 2006, flight engineers had completed their launch readiness review and began fueling the Delta II rocket in anticipation for a launch early on the morning of Friday, the 21st. As the countdown towards launch progressed towards T-48 seconds, the primary and backup communications between Vandenberg AFB and CNES were lost, causing the first of what would be many launch scrubs. Later that week, mishaps with refueling of launch-tracking aircraft, temperature sensors aboard the Delta II launch vehicle, and perhaps ironically, too much cloud cover, would delay the launch of CloudSat and its sister satellite. It wasn't until early morning on the 28th of April that conditions were finally right, and at 3:02 AM Pacific Daylight Time, CloudSat took flight, reaching orbit approximately an hour after launch.

In the 10 years since the launch of CloudSat, advances in social media, the rise of smartphones, and other revolutions in the aspects of our daily lives have changed how we look at the world. So too have the observations made by CloudSat similarly revolutionized our understanding of Earth's water cycle and energy budget.

The Useful Pursuit of Shadows – Why Clouds Matter

Every day, the heating of the Earth's surface by the sun contributes to the evaporation of water from the Earth's oceans and lakes, releasing water vapor into the atmosphere. Elsewhere around the planet, rain- and snowfall bring that water back to the surface of the Earth, either ending or beginning the journey of water through the terrestrial components of the water cycle, depending on one's point of view. In between, the distribution of water in the form of water vapor, and in clouds and the precipitation created by these clouds, is a subject of intense importance. Condensed to a liquid volume, nearly 13,000 cubic kilometers of water takes residence in the atmosphere of the Earth at any given moment, but tracking the amount and distribution of that quantity as it manifests in nature offers a significant challenge.

Besides linking the arms of the water cycle, water (especially in the form of clouds) represents a significant portion of the Earth's energy balance. Clouds can trap the infrared energy of the Earth, warming the planet while also reflecting incoming sunlight, shielding the Earth from its primary source of energy and thereby cooling the planet. Clouds of different composition accomplish these two processes differently. In general, high clouds, or tall, thick clouds tend to warm the planet on balance, whereas clouds lower to the surface of the Earth tend on balance to cool the planet. In the context of potentially changing climate, understanding the distribution of these high and low clouds is a primary concern. Would a warming climate create more high clouds, creating a positive feedback loop leading to more warming still, or would an increasing abundance of low clouds provide a natural braking action, slowing down or even reversing the initial change?



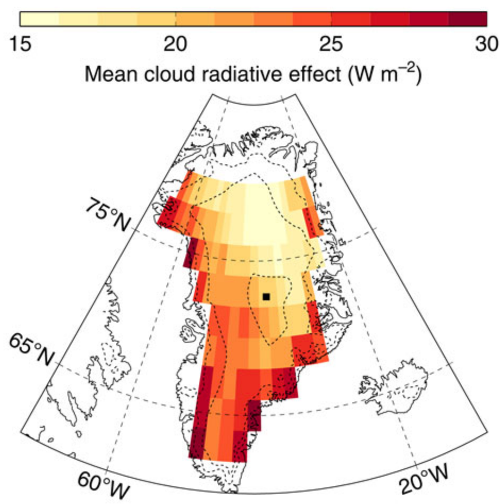
Shortwave and longwave energy budget for the Earth as determined by CloudSat observations. Improvements in estimations of global precipitation and infrared processes through CloudSat has given us a more accurate picture of the energy budget of the planet.

The evaporation of water into airborne vapor, accomplished through the heating of the Earth's surface, provides another important but difficult-to-measure energy source. The transport of this energy (referred to as the energy of latent heating) through the atmosphere, locked to the water molecules thus liberated, provides the source for many of the Earth's most powerful weather systems – thunderstorms, tornadoes, and hurricanes all gain their power through the release of this latent heat energy when water vapor returns to its liquid phase, condensing as cloud droplets in the atmosphere. A standard thunderstorm, found commonly throughout the Great Plains during the summer, can release up to three and a half million megajoules of this energy, each. Completing our understanding of the Earth's water and energy budgets would clearly require a comprehensive accounting of the Earth's cloud population.

Looking Nadir, Taking Data – The Ways and Means of Spaceborne Cloud Radar Observations

From its vantage point 700 kilometers up, CloudSat makes a complete orbit of the Earth approximately once every 90 minutes, traversing the planet on a trajectory that begins near the South Pole and moves toward the North Pole on the daylight side of the planet, and continuing from north back to south on the nighttime side. As CloudSat orbits, the Earth continues to turn on its axis below, meaning every ascending orbit CloudSat begins is over a new track, to the west of the track from its previous orbit. It takes roughly two weeks for the spacecraft to return to any arbitrary starting point, giving the satellite a global count of the Earth's cloud populations in the intervening weeks. Flying along with CloudSat are a number of different satellites; along with CloudSat's sister mission, CALIPSO, there are an additional four spacecraft all making the same orbit, passing over the same area of the Earth within minutes of each other with each taking unique observations of some component of the Earth's atmospheric and environmental systems. The constellation of satellites (as such a grouping is known) makes their daylight-side equator crossing around 1pm in the afternoon, giving rise to the term "the afternoon constellation", or as its more properly known, the "A-Train".

While in orbit, the cloud-profiling radar mounted at the base of the spacecraft sends out pulses of microwave energy. Designed to interact specifically with the size and composition of cloud particles, the reflection of these energetic pulses back towards the spacecraft reveals the location and amount of cloud as the spacecraft passes above. Lower clouds have longer periods of travel for the pulses compared to higher clouds (although at the speed of light, not much longer), and clouds with more water, in the form of larger particles, higher concentrations, or both, reflect proportionally more of these pulses back to the spacecraft than more tenuous clouds. By studying these reflections of energy, scientists can compute properties of the underlying cloud layer: the number and size of cloud particles, the amount of water represented by those particles, energetic properties relating to visible and infrared radiation, and more. These results then inform critical scientific research aimed at answering the questions posed earlier. With 10 years of results, much progress has been made towards this end.



Impact of clouds on the radiation budget over Greenland. Improved observations from CloudSat and CALIPSON demonstrate that perhaps up to 1/3 of the runoff from the melting Greenland ice sheet may be due to cloud effect.

CloudSat data has been used to estimate arctic cloud cover amounts, filling in gaps in the observational dataset and leading to a quantitative understanding of how the interaction between clouds and the surface can lead to enhancement of the melting and runoff of Greenland's ice sheet. At the other end of the Earth, CloudSat observations have been used to compute the changing mass of the East Antarctic ice sheet, critical to understanding climate interaction with that remote region of the planet. Subtle and difficult to measure interactions between aerosols and cloud droplets and the role that changes in cloud droplet size and concentration based on this interaction plays in changing the radiative structure of the atmosphere have been informed by CloudSat observations.

Finally, the global energy cycle has benefitted most directly from the ability of CloudSat to place clouds, with their many means of interacting with the Earth's forms of energy, accurately over the less-observed oceanic regions of the planet. Bringing these observations together, researchers have discovered that our best guess of how much precipitation falls on the planet prior to CloudSat missed the mark – it rains more than we thought it did. We also didn't have a complete understanding of how much of the Earth's infrared radiation was being trapped by the atmosphere, and that this error was essentially evenly matched by the complex processes of energy transfer caused by the extra precipitation we were missing out on. In other words, prior to CloudSat, our energy budget for the Earth balanced, but did so with incomplete information. Being right for the wrong reasons has always been one potential starting place of scientific advancement, but completing the picture accurately and fully accounting for all variables is where that advancement must ultimately lead. Through a decade of CloudSat observations, we are able to fully flesh out the Earth's energy budget accurately, leading to a better understanding of the physical processes that govern how the Earth works and better models that will tell us how the Earth's climate will continue to evolve over time.

Data Processing Center and CIRA Ties

None of these revolutionary advances would be possible without the free and ready flow of data, of course, and nestled in the basement of the Atmospheric Science and CIRA Research Center (ACRC) building at the CIRA Foothills Campus, the CloudSat Data Processing

Center (DPC) quietly and quickly collects, computes, and distributes the complete set of observations and computed products from CloudSat. Over 10 years of operation has yielded approximately 43 million data files, consuming nearly 1.5 petabytes of disk space.

Ten years ago, the capability to store, process, and distribute such an astronomic volume of data would have fallen squarely into the realm of a massive data center, populated by supercomputers and staffed by dozens. But another quiet revolution in the world of scientific computing was put into motion 10 years ago, when the CloudSat DPC team, then led by Don Reinke, turned a basement room full of off-the-shelf computing components into a massively powerful but not prohibitively complex cluster of workstations into one of the most effective and elegant satellite data processing centers in existence.

A decade later, the award-winning DPC, led now by CIRA researcher Phil Partain, continues to blaze paths into the future of scientific data processing (for more details, read our article on data fusion in the Spring 2014 issue of CIRA Magazine) bringing together cutting-edge software development and implementation of theory to commercially available hardware platforms, allowing for a small and adept team to accomplish incredibly challenging tasks, providing one of CIRA's most promising opportunities for future growth. And the processing of CloudSat data, which has been distributed to many thousands of researchers in 64 different countries at the time of this writing, was the impetus of it all.

The Future of CloudSat and Cloud Observations

Ten years into the planned two-year mission, CloudSat had started to show signs of aging. In April 2011, some of the aging batteries aboard the spacecraft began failing, enough to place the spacecraft into a safe mode. Previous battery anomalies aboard the spacecraft (all of which occurred after the three-year design life of the spacecraft) had caused some changes in how the CloudSat radar could be operated; but the anomaly of April 2011 caused an outage in operations until October 2011, during which CloudSat was maneuvered out of the A-Train satellite constellation it had been part of since launch. By changing the manner in which CloudSat took operations (namely, by no longer running the radar on the nighttime side of the planet), the science and operations team were able to resume operations and rejoin the A-Train, allowing for scientific observations from CloudSat to continue despite the increasing wear and aging of CloudSat systems.

There will inevitably come a day, however, when even the robust systems of CloudSat can no longer make reliable observations. When that day comes, after much deliberation and planning, CloudSat will fire its thrusters one last time and de-orbit not just from its spot on the A-Train but from its decade-plus vantage point in space to harmlessly burn up in the Earth's upper atmosphere. Unfortunately at this time, there are no immediate plans for CloudSat 2, but other missions incorporating 94-GHz cloud-profiling radars have been kicked around, including options to place instruments aboard the International Space Station. Notably an ESA-led mission called EarthCARE, planned to launch in 2018, will fly a cloud-profiling radar (in concert with several other instruments) to continue observations of clouds from orbit. Whether EarthCARE will join CloudSat in its role observing clouds or succeed it remains to be seen, but the value of continuing spaceborne observations of clouds demonstrated by CloudSat has clearly been demonstrated.

The model of CloudSat as one for groundbreaking and compelling research will serve as a valuable legacy to emulate as well as to appreciate.

Much has changed in the 10 years since CloudSat launched. The advances of mobile computing has made accessibility to information a nearly worldwide resource, making the world a bigger place; at the same time, the connection and sharing of that information has brought more disparate communities together, making the world paradoxically a smaller place as well. The role that CloudSat observations has played during those ten years has likewise been to revolutionize our understanding of the Earth's structures, broadening our knowledge of how the Earth works while improving and reforming our models of how to accurately represent the Earth as a whole. As scientists imagine and develop the missions of tomorrow, the model of CloudSat as one for groundbreaking and compelling research will serve as a valuable legacy to emulate as well as to appreciate.

CloudSat Education and Outreach

Bringing Science to the Masses

Matt Rogers

"Revealing the Inner Secrets of Clouds" is the motto that sits proudly on the CloudSat mission patch; 10 years into the mission, it's clear that CloudSat has revealed many of these secrets to the enormous benefit of the scientific community. Another side to CloudSat, perhaps less visible to the research community, was the CloudSat education and public outreach (E/PO) program. Composed of a global network of schools engaged in cloud observations in concert with CloudSat researchers at CSU and CIRA, along with a professional development network to improve the scientific capabilities of K-12 teachers nationwide, the CloudSat E/PO program plays a compelling role in bringing the science of the CloudSat mission to the public.

The goal of the CloudSat E/PO program is to promote a better public understanding of the significant effects of clouds on Earth's energy balance, climate, and weather. Because weather affects people's daily lives and clouds are familiar objects, CloudSat E/PO can use these starting points to develop a better understanding of the much more complex concepts that are topical but not widely understood. From there, the program seeks to promote interest in science, technology, engineering, and mathematics (STEM) careers and in NASA's Earth science missions.

To accomplish this goal, CloudSat's E/PO program provides quality hands-on, inquiry-focused experiences for students and the public. Initially, the centerpiece of these efforts was a network of over a hundred schools from around the world actively engaged in collecting cloud and precipitation data, coincident with CloudSat overpasses of their school. This student data was made available to CloudSat scientists conducting research using CloudSat data products as well as to other student researchers conducting earth-science related research. Called the CloudSat Education Network (CEN), this component of the CloudSat E/PO program was a partner with the NASA-funded Global Learning and Observation to Benefit the Environment (GLOBE) program. As an early partner with GLOBE, CloudSat researchers helped develop a set of standardized observations (called protocols) for viewing the atmosphere and clouds.

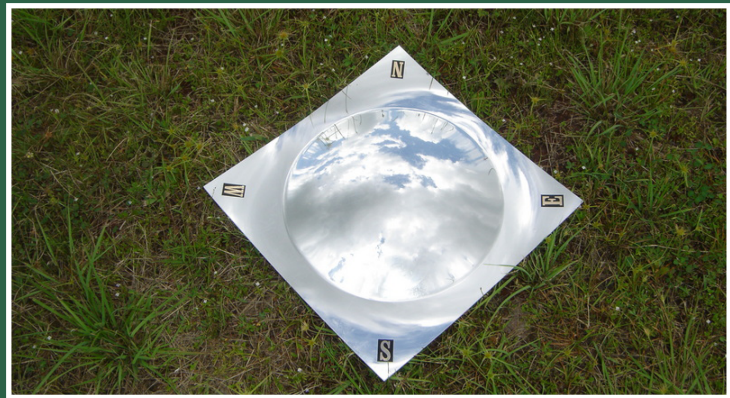
By 2007, the CEN was online and growing, receiving hundreds of student observations per year. Hosted at CSU, the CEN website offered unique logins for each school in the CEN, and students would go to the website to find the next time that CloudSat would be directly over their school. When that time came, the students would go outside and write down the types of clouds they saw, what direction those clouds were relative to their school, and collected other basic meteorological observations such as temperature, 24-hour rainfall, etc. As part of the CEN, each school was issued a small digital camera, tripod and curved mirror that could capture the entire sky. As part of their observations, students would take photos of the clouds they saw, one each for the cardinal directions and one of the curved mirror oriented to point north. Students would then go back to the website and upload their data and photos, where it was archived at CSU.

Students could then see direct comparisons between what they saw through their photos and what the satellite saw through CloudSat quicklook products. Students could also work with other schools within the CEN for collaborative projects, leading to interesting and international comparisons of different kinds of weather. Critically, CloudSat researchers had access to the data, and with sufficient training these surface observations became a valuable source of ground-truthing for the satellite. Figure 1 shows an overpass of CloudSat over a CEN school located on the north island of New Zealand. In the CloudSat retrieval of cloud type shown in the figure, the satellite had determined that at the time of the overpass the clouds underneath consisted of altocumulus and stratus. The students also observed altocumulus and stratus – but critically, they also observed cumulus clouds and had the photographic evidence to back it up (Figures 2 and 3). CloudSat researcher, CEN lead and now CIRA researcher Matt Rogers was able to take this ground truth observation and find a bug in the retrieval code that allowed for altocumulus clouds to exist below 4 km (by definition, altocumulus only exists above 4km). Student observations of the CEN were more than a feel-good educational product; in other words, the students of the CEN were actively helping make the science mission of CloudSat better.

Of course, the primary role of the CEN was to improve the science literacy of students and help with advancement in their academic careers. Any help the students could give CloudSat was a bonus. And the CEN offered many new options for participants. A girls' school in Punjab noticed an increase in enrollment for 10th- through 12th-grade students after a few years of CEN participation. When contacted by partner staff in the region, CEN staff learned that because the school offered a high-grade science program in part because of the CEN, female students who attended the school were much more likely to receive scholarships for university studies. In this rural part of northwest India, many girls leave school shortly after the 8th or 9th grade, as the social custom is to marry young; more education beyond this level wasn't seen as being needed. Becoming a college graduate in a technical or scientific field improves both the educational and financial status of families in this region, and girls who previously would have dropped out were now attending university on scholarships, all based on work they performed as part of the CEN.

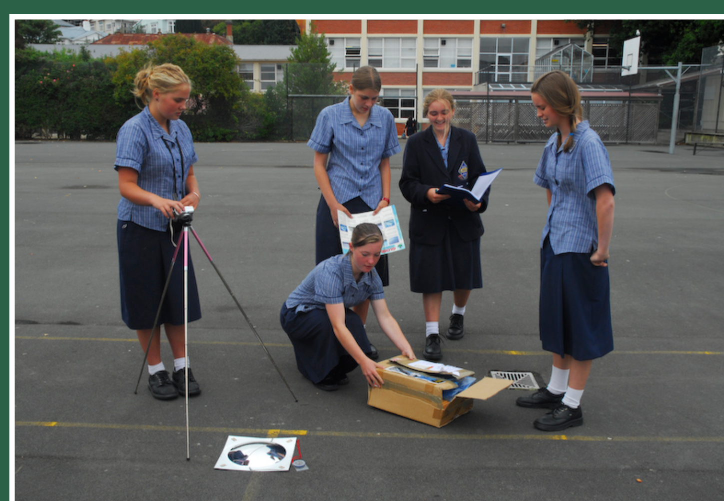
Other students used CEN observations from different parts of their countries to improve crop planting and harvesting, as one program from CEN schools in Thailand demonstrated. French, German, and Estonian CEN schools regularly hosted student conferences, contributing to the social and scientific growth of these European schools. In Cameroon,

How CloudSat Helps the Students



A curved mirror is used to estimate total cloud cover by students of the CloudSat Education Network. Image credit: Matt Rogers, CIRA/CSU

Teachers and students of the CloudSat Education Network refresh cloud observation skills on the roof of the Police DAV School in Jaladhar, India.



CEN student participation in Punjab, India. Image credit: Nandini McClurg, CSU

How the Students Help CloudSat

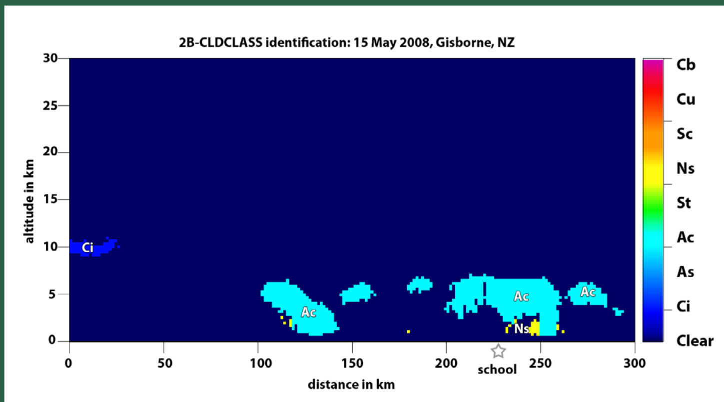


Figure 1: A CloudSat retrieval over a CEN School in New Zealand. It shows no cumulus clouds.

Figure 2: A Photograph taken by students on the ground that shows the presence of cumulus clouds missed by CloudSat.

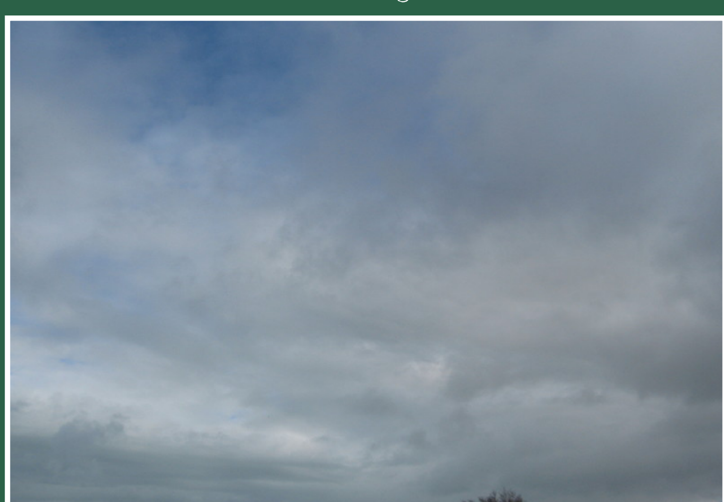


Figure 3: Another photograph that shows the presence of cumulus clouds missed by CloudSat.

students would take overpass observations and then pedal upwards of seven miles to the nearest internet café to upload their observations until the CEN program worked with the State Department to provide internet access to the schools, offering internet connectivity to these communities for the first time.

As the United States moved toward a test-based education system in the middle 2000s, educating teachers on the increasingly strict and comprehensive science standards became a high priority. While maintaining support for CEN activities, Cloudsat E/PO staff began a nationwide effort to conduct standards-based teacher professional development workshops. Led by CloudSat researcher turned education professional Todd Ellis, dozens of workshops across the country used CEN protocols and other inquiry-based learning activities to improve the science literacy of teachers everywhere. External evaluations of the program showed massive success in increasing the science content knowledge of CloudSat-affiliated teachers. Reaching individual classes of students allowed the CEN to impact 30 students or more at a time. By training 30 teachers at a time, the CloudSat E/PO project had the potential to reach hundreds of students every year, improving their understanding of clouds and the role they play in the Earth's water and energy cycle.

As the mission passes its 10-year anniversary, changes in how NASA performs education and outreach activities is ushering a new era for CloudSat education. Certainly these changes will build on the great successes of a decade of successful outreach activities and will hopefully take the valuable lessons learned and apply them to other Earth science missions. Finally, as CloudSat alumni complete their higher education and begin their scientific careers, you could say that the real impact of the CloudSat E/PO program has really just begun!

Archiving FIM Subseasonal Run Datasets with

Ning Wang, James Rosinski, Haiqin Li, Shan Sun, and Sher Schranz

A subseasonal simulation with the FIM global atmospheric forecast model produces a large amount of data that presents a challenge for storage and transmission. One solution to this problem is to move the datasets to a remote mass storage facility (HPSS). However, the transmission and archiving delay can be so great that this solution becomes unfeasible.

A typical FIM subseasonal simulation running in coupled mode with the IHYCOM ocean model produces a data set of 128 forecasts (32 x 4) of approximately 30 atmospheric and oceanic variables. Discretized on an icosahedral grid at subdivision level 8 and 64 vertical levels, each atmospheric variable has a size of 167,772,672 bytes (655,362 x 64 x 4), and each ocean variable has a size of 83,886,336 bytes (655,362 x 32 x 4). The typical size of the dataset produced by each model run is over half a terabyte.

To conduct a subseasonal forecast experiment, the model will run thousands of times over a simulation period that lasts a decade or longer. After each run, the dataset needs to be saved for later analyses. It could take hours to upload and download the datasets to and from the mass storage system, and often the system times out before completion.

A compression technique could pose a valid solution, combining a high fidelity wavelet lossy compression and a lossless compression to significantly reduce the volume of the datasets. After applying the compression, the compressed dataset (which is significantly smaller) would be uploaded to HPSS. When a dataset is needed for analyses and evaluations, it can be downloaded from HPSS and decompressed.

The key to the proposed approach is to achieve significant compression while maintaining adequate fidelity of the compressed dataset. The computational efficiency of the compression and decompression also needs to be considered.

High Fidelity Data Compression Technique

The compression technique used for each sub-seasonal forecast dataset is a combination of a high fidelity wavelet data compression technique and a lossless

Figure 1

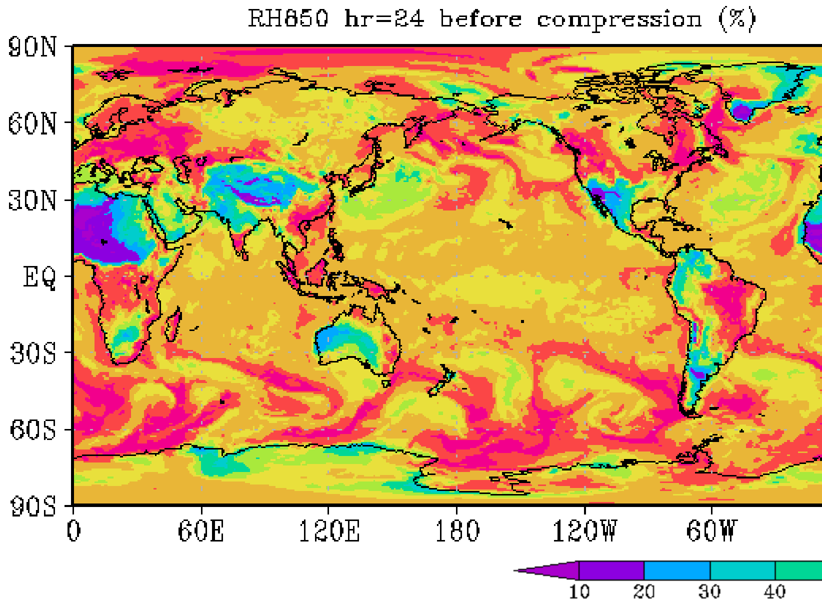
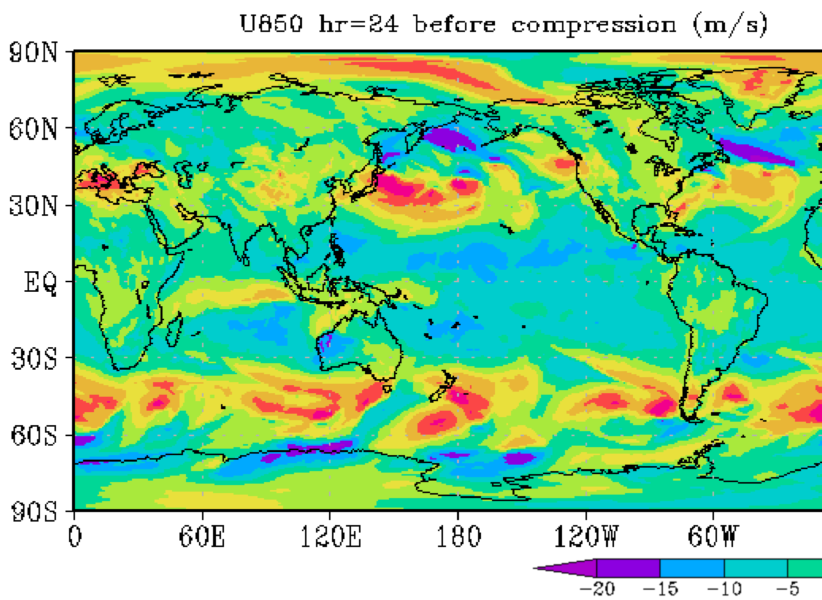
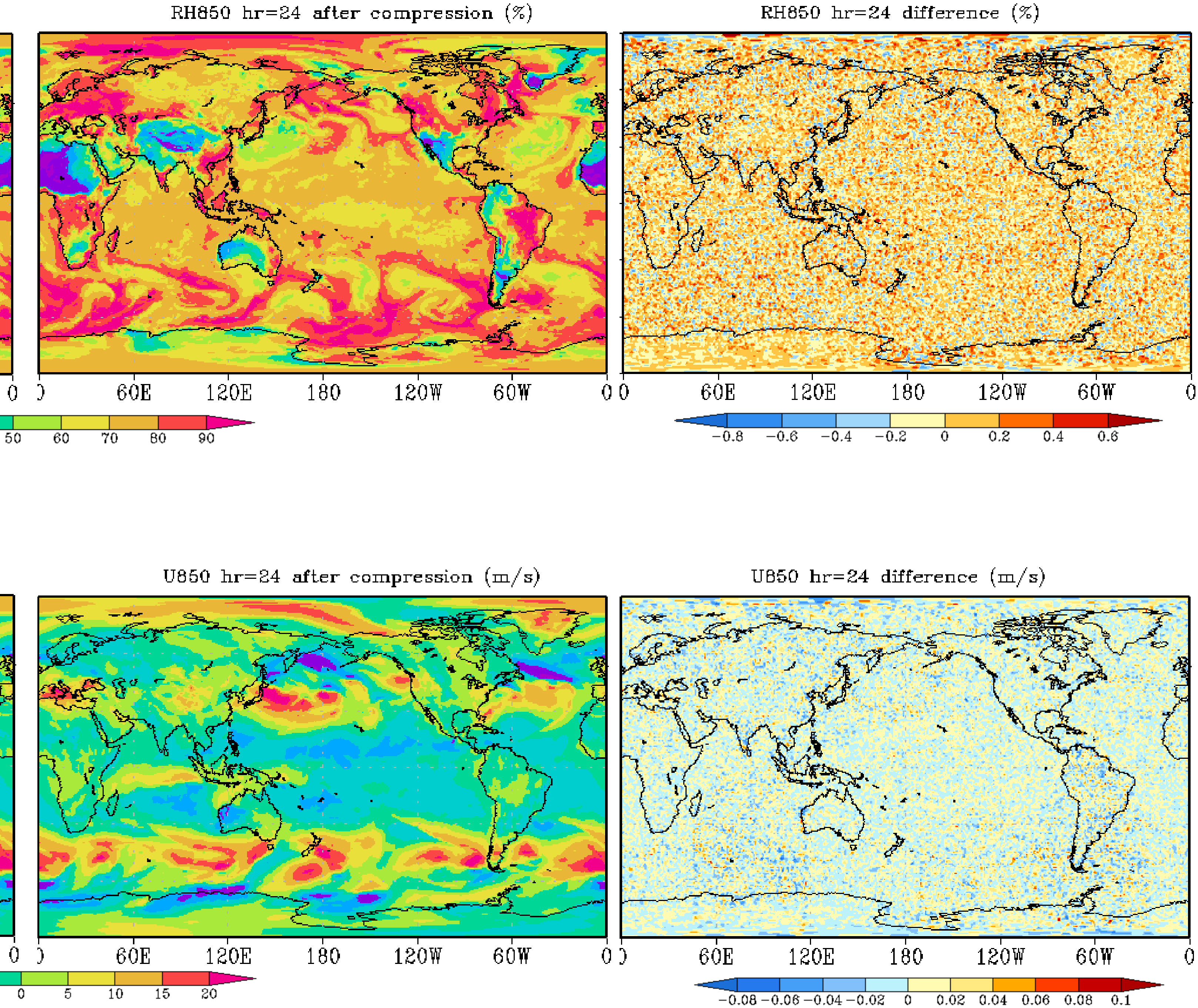


Figure 2



a High Fidelity Data Compression Technique



compression technique. The wavelet compression technique encodes the data set on the native icosahedral grid to avoid interpolation error and unnecessary expansion of the data set to a Cartesian grid. To maintain the high fidelity of the data set, the wavelet compression technique is implemented to guarantee both average error (L^2 norm error) and maximum absolute error ($L\infty$ norm error) for the compressed data set. The details of the compression technique are described in a paper recently published in the Journal of Atmospheric and Oceanic Technology.

Computational Time and Coarse Grain Parallelism

For such a large dataset, compression could take a significant amount of CPU time, especially for a high fidelity wavelet compression. When running in serial mode, it could take three to four minutes to compress one forecast time and several hours to compress an entire dataset. To reduce the data compression time, an available high performance computing environment can be used, where model output data are generated. We compress the datasets in parallel on the high performance computing system.

The compression job runs on the NOAA high performance computing system theia, on a single node, which has 24 CPU cores. We tested two coarse-grain parallel schemes for a dataset of a 32-day model run, with forecast output every six simulated hours. The first scheme is just to queue 32 background tasks from a Linux shell. The second is to use the so-called "hungry puppy" approach, where processors are fed new tasks as they complete earlier ones. The overall compression time for both schemes are not significantly different, with both being around 20 minutes.

Compression Experiment

First, permitted average error (RMSE, or L^2 error) and maximum absolute error (MAE, or L^∞ error) need to be specified for each compressed data field. The specification is listed in Tables 1 and 2.

With this precision specification, the compressed data set maintains a similar or higher numerical accuracy when compared to the GRIB files specified by most numerical weather prediction centers for forecast products; visually, as shown in Figures 1 and 2, one cannot observe any differences.

The overall compression and upload takes about 30 minutes on theia and the HPSS system with an exclusively allocated node. The overall decompression and download takes slightly less time compared to compression and upload time.

The experiment shows that the compression technique is effective and efficient in reducing the size of the sub-seasonal output data set produced by the coupled model. The compression maintains high fidelity of the dataset and ensures that it has adequate precision for numerical analysis and diagnosis. The significant reduction of the dataset size helps to store and transmit large volume datasets and makes it possible to archive decadal runs of sub-seasonal forecasts.

Table 1

Field	Unit	Average Error	Maximum Absolute Error
Temp.	degree	0.05	0.1
th3D	degree	0.05	0.1
td3D	degree	0.05	0.1
us3D	m/s	0.05	0.1
vs3D	m/s	0.05	0.1
up3P	m/s	0.05	0.1
vp3P	m/s	0.05	0.1
hgtP	m	0.04	0.1
ph3D	gpm	0.4	0.8
rh3D	%	0.4	0.8
rp3D	%	0.4	0.8
pr3D	Pa	0.2	0.5
2D vars	various	0.0	0.0

Table 2

Field	Unit	Average Error	Maximum Absolute Error
Temp.	degree	0.005	0.01
dens	kg/m^3	0.01	0.03
dpav	m	0.01	0.05
mont	m^2/s^2	0.01	0.03
rave	kg/m^3	0.01	0.03
saln	psu	0.005	0.01
save	psu	0.01	0.03
tave	deg.	0.01	0.03
thik	m	0.01	0.03
tr01	none	0.01	0.03
uave	m/s	0.01	0.03
vave	m/s	0.01	0.03
uvel	m/s	0.01	0.03
vvel	m/s	0.01	0.03

Previewing GOES-R

What We Can Expect From the Next Generation of Earth Observing Geostationary Satellites

Matt Rogers

By the next issue of CIRA Magazine, we will hopefully be putting together articles about the successful launch of GOES-R. Slated for October 2016, the most advanced geostationary observation platform for Earth observation ever launched by the United States promises several new ways for researchers and forecasters alike to see and predict our planet. CIRA has spent several months working with NASA and NOAA to chronicle several of these new features, which we can share here as a preview of what's to come with GOES-R.

Fall Foliage from True-Color Observations

The changing colors of fall foliage signify more than just a beautiful display of nature's adaptability to seasonal changes; they allow scientists to study and understand several important processes related to the biosphere. Trees account for a significant portion of absorbed carbon dioxide, and understanding the annual cycle of tree growth helps scientists understand more about the carbon cycle. In the west, significant drought on forests can be seen in the decreased chlorophyll content in trees, which can be seen from space. Extreme drought that kills large sections of forest is another item that can be seen from space, giving forest managers more information about the fuel sources for upcoming wildfire seasons. And finally, monitoring the health of forests in the face of human development, especially in regions like the Amazon, is another instance where seeing the color of forests from space is an important tool for scientists to use.

Until very recently, our only ability to see color from space was limited to polar-orbiting satellites, which make more infrequent passes over regions of interest to scientists. With the forthcoming launch of the Advanced Baseline Imager (ABI) aboard GOES-R, scientists will be able to see the color of forests with great resolution and over any time period. The ABI instrument will see the atmosphere in several colors, including blue and red exactly as the human eye would see those colors. And by incorporating information from other colors that the ABI will be able to see, including colors related to water vapor and chlorophyll emissions, researchers are creating a hybrid green color channel as well, giving us the ability to create true and natural color imagery products using red, blue, and green channels.

With this information, scientists will have valuable insight into forest health, carbon cycle information, wildfire forecasting, and other scientific interests. We all will also get to share in a spaceborne view of another of the Earth's beautiful phenomena – the changing of color in the fall.

Fire Detection with the ABI Instrument

Monitoring wildfires is a difficult task. Prior to the space age, extensive networks of tall towers, staffed around the clock by fire observers were used to monitor many (but not all) of the nation's forests. With the ability to see the entire country from space with satellites, the opportunity to detect wildfire became more practical, but several technological hurdles had to be overcome.

All objects in the universe emit some kind of light energy, and the kind of light energy emitted depends on the temperature of each object. For instance, the Sun emits primarily visible light, while humans emit infrared light. Wildfires, which are significantly hotter than humans but cooler than the Sun, emit a different form of infrared than humans do – one that's more similar to the visible light emitted by the Sun. By comparing the amount of light at these different wavelengths, scientists can tease out what might be creating the different kinds of light, including any potential fires.

Our main weather satellites, the current GOES series, are designed to measure visible light and a few different kinds of infrared light that correspond to different atmospheric features (for example, the kinds of light emitted by water vapor, or clouds) and which can also be used to see wildfire only if it's big enough. The current GOES series instruments see the Earth with pixels that are four km wide and four km tall – good enough for a fire once it's started but not necessarily useful for finding small fires. Furthermore, only one of the other five channels is useful for detecting fire, and clouds can screen the fire from the view of the sensor.

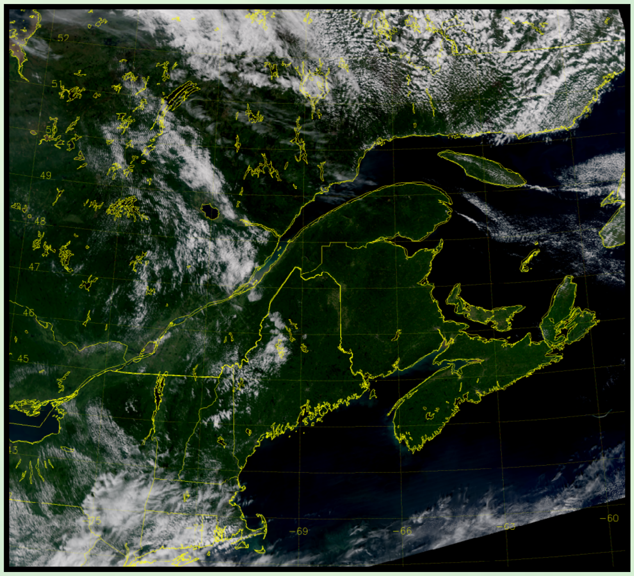
The sensors of the GOES-R ABI are designed to work with each other to see fires more easily. By comparing the view from a camera designed to see at 3.9 microns against the view from other sensors, the ABI will be able to better detect the presence of fire. By using the other channels (sixteen in all) to better mask out clouds, detect background differences, and account for other confusing elements (such as reflected sunlight spots), scientists using the ABI will be able to better determine where fire hotspots are occurring due to finer resolution. This helps to catch fires in their earlier phases when they are easier to fight.

Tropical Storms and Hurricanes from Space with the ABI

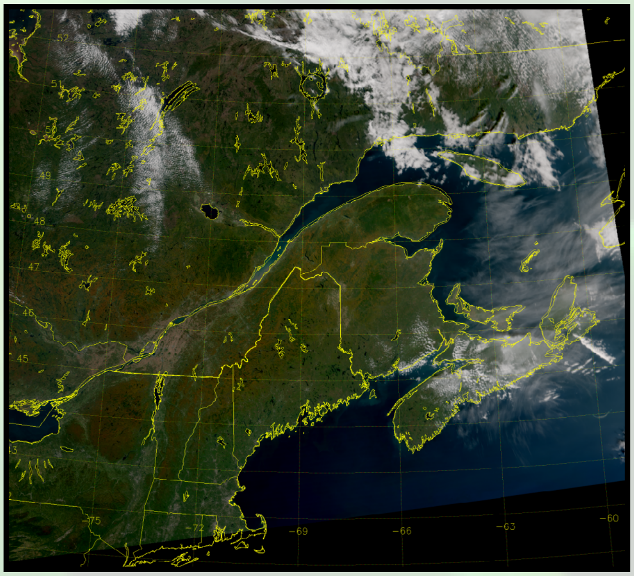
Prior to the Space Age, forecasting hurricanes and tropical storms was a troublesome affair. Forming well out to sea with only sporadic weather observations from oceangoing vessels (most of whom sailed far away from severe weather), the first indication that a tropical storm was approaching was often when it hit an outlying island. Even then, knowing a storm existed did little to help forecast its intended direction; with sparse observations of upper-level winds, getting the forecast track and intensity were notoriously difficult tasks. With the advent of Earth-orbiting satellites, all this began to change.

With the forthcoming GOES-R satellite, scheduled to make its trip to geostationary orbit in October 2016, even better ways of detecting and tracking hurricanes will be possible. Currently, the satellites we have refresh their view every 15 minutes and can see down to 1km x 1km in resolution for some channels (and only to 4km x 4km for other channels). With better resolution and faster refresh rates, scientists could get better information on how these storms work or get a better view of the conditions in which these storms form. The ABI on GOES-R will have the ability to resolve images at 250m x 250m. That's four times the resolution of our current satellites, which will give us details on how the eyewalls of hurricanes (containing the strongest thunderstorms of the whole system) work. Furthermore, the entire image on GOES-R will refresh every five minutes instead of 15 – and we'll be able to select parts of the image to refresh every 30 seconds if needed, giving us a wealth of information on how strong the storm is becoming, how fast the storm is rotating, and helping us to find areas over the ocean that may be spinning up to become the next big storm.

Having an eye in the sky to watch over tropical storms and hurricanes helps us understand these beauties of nature while giving us the lead time to evacuate the regions most affected by these storms when they come ashore. With GOES-R, our ability to do both of these things can only get better.



True color image from VIIRS of foliage in New England prior to fall leaf change. Image credit: Curtis Seaman, CIRA/CSU.



True color image from VIIRS of leaf color change during New England autumn. Image credit: Curtis Seaman, CIRA/CSU.

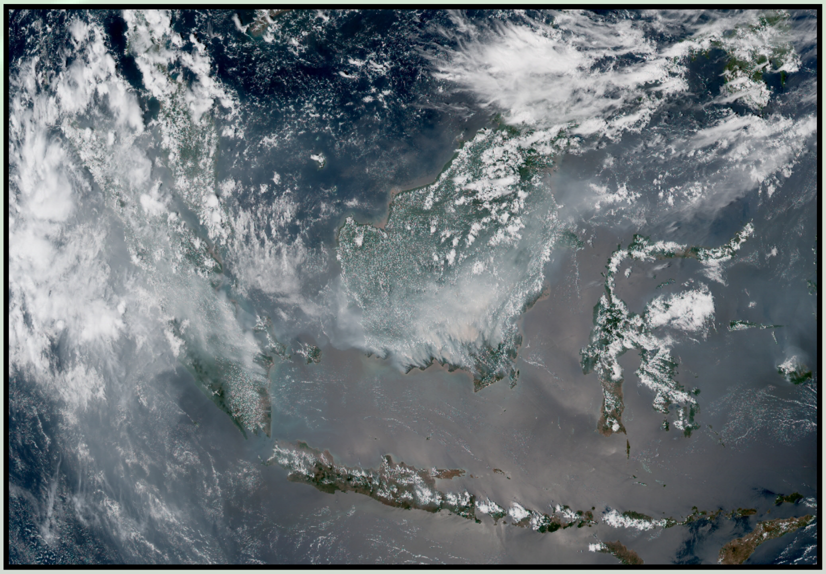
Severe Weather and Flooding

Severe thunderstorms are common to nearly every part of the United States and typically have their greatest impact in the late spring, summer, and early autumn months as cold fronts bearing subarctic air masses interact with warm, moist air drawn from the Gulf of Mexico. The most severe storms form most commonly over the Great Plains and the American South and cause destruction from tornadoes, hail, wind, and flooding.

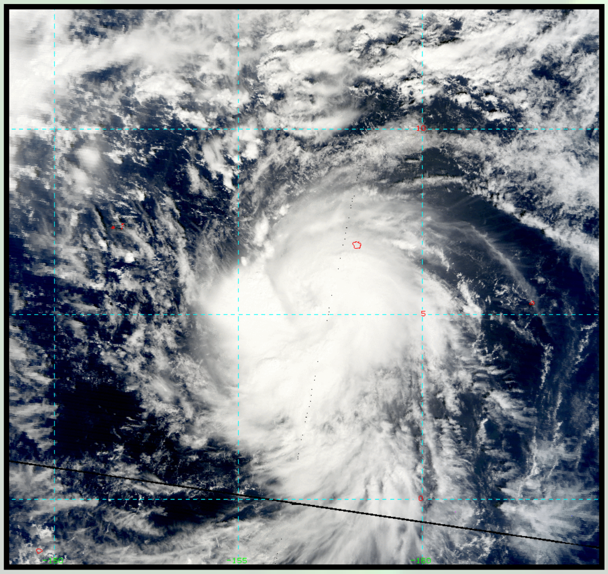
Severe thunderstorms can form in less than an hour. Extremely powerful storms can go from an innocent field of cumulus clouds to a well-organized and long-lived supercell thunderstorm in the span of an afternoon. To monitor these powerful forces of nature, a network of sophisticated weather radars placed strategically around the nation scan for potentially hazardous storms every 15 minutes during pleasant weather, and every five minutes during stormy weather. These radars can see very fine detail in the storms, but are expensive and have limited coverage in range. In some places of the country, there exist gaps in the radar coverage where the distance between radars is large enough that potentially dangerous storms can occur with little observation.

Satellite observations of storms are useful, of course, and the current GOES series of satellites offer valuable information about the location of potentially severe storms, especially in regions where radar coverage is sparse. These observations are limited somewhat, however, in how far they can go to detect the severity of a storm – for some of the satellite's observations, the horizontal resolution is too coarse (measured at four km by four km) to get needed detail about storm structure. The scanning resolution in time is also an issue - between 15 and 30 minutes could elapse between scans of a storm – plenty of time for a developing, potentially dangerous storm to become a real threat. Other characteristics of severe storms, such as lightning, are not readily detectable by the current observation platforms available.

The instruments aboard GOES-R will make major efforts toward helping forecasters understand storms. The ABI instrument of GOES-R will scan storms with a 5-minute refresh rate, and for areas of special interest, potentially as few as 30 seconds between images to help see the development of the storm over time. The horizontal resolution of the ABI images will be fine enough to resolve critical features in the storm, such as areas of high water content and deep penetration into the atmosphere, which could signal heavy hail amounts or potential for flooding. The Geostationary Lightning Mapper (GLM) instrument will detect lightning strikes from orbit – good for knowing where lightning danger is occurring as well as providing forecasters information on where the strongest updrafts of a developing storm are located. Finally, using the rapid scanning capability of the ABI, scientists are beginning to develop techniques to attempt to detect rotation in the most severe of thunderstorms, providing additional warning against the formation of deadly tornadoes.



Smoke from forest fires in southern Borneo as seen in true color imagery from the AHI sensor aboard Himawari-8. Image credit: Steve Miller, CIRA/CSU.



True color image of Typhoon In-FA as seen from the MODIS instrument about Terra. Image credit: RAMMB/CIRA/CSU.

Communiqué

Welcome to New CIRA Members

Stephanie Guedj

Dr. Stephanie Guedj is a Research Associate III who joined CIRA in College Park, Maryland in February 2016. As a member of the Joint Center for Satellite Data Assimilation (JCSDA), she participates in the development of the new JCSDA observation system assessment standing capability (JOSASC), a new infrastructure to perform comprehensive observing system assessment based on the NCEP Gridpoint Statistical Interpolation and the Global Forecast System. Dr. Guedj's previous employment was as a EUMETSAT Research Fellow at Météo-France preparing the utilization of future sounding data from Meteosat Third Generation (MTG) for Numerical Weather Prediction.

Suryakanti Dutta

Dr. Suryakanti Dutta is a Research Associate IV who joined CIRA in College Park, Maryland in March 2016. As another member of the JCSDA, he also participates in development of JOSASC. Through his work with JOSASC, observing system experiments (OSEs) will be conducted to assess the impacts of existing satellite instruments on NOAA global and regional numerical weather prediction. Dr. Dutta joins CIRA from a Visiting Postdoc Fellowship at the Canadian Meteorological Center in Dorval, Canada.

Donald Reinke

Don Reinke is a Senior Research Associate who returned to work part-time at CIRA on the CloudSat project in June 2016 to assist with DPC operations and to help with special projects. He worked at CIRA for 30 years as a Research Associate and served as the CloudSat Data Processing Center (DPC) Manager until his retirement in 2015. His supervisor is Phil Partain.

Jason Burks

Jason Burks is a Research Associate IV (Programmer/ Analyst) who joined the CIRA team at NWS/MDL in Silver Spring, Maryland in May 2016. He works with Ken Sperow and the VLab team on developing tools for the AWIPS II system. Jason comes to us from a previous position at NASA SPoRT in Huntsville, Alabama, where he also worked on AWIPS II tool development, specifically in the area of visualization tools for GOES-R satellite data. Jason's supervisor is Ken Sperow.

Xin Xi

Dr. Xin Xi is a Postdoctoral Fellow who joined CIRA in College Park, Maryland in June 2016. As a member of the Sea Surface Temperature Team within the Satellite Oceanography and Climatology Division (SOCD) of the Center for Satellite Applications and Research (STAR) in College Park, he is responsible for the development of improved SST and cloud mask algorithms for VIIRS, AHI, ABI, AVHRR, MODIS and SEVIRI, including the processing of global SST data in near-real time; radiative transfer modeling using Community Radiative Transfer Model (CRTM); optimization of cloud screening, constraining cloud mask and SST algorithms based on NWP upper air fields; use of global NCEP and ECMWF data analysis and forecast and their use in conjunction with CRTM; and improving sensor calibration techniques and quality control of satellite radiances. Prior to coming to CIRA, Dr. Xi served as a Postdoctoral Fellow with the NASA Ames Research Center at Moffet Field, CA . His supervisor is Cliff Matsumoto.

NOAA STAR
Center for Satellite Applications and Research
Award Winners

Technology

Team: Sea Surface Temperature (SST), The Algorithm Scientific Software Integration and Transition (ASSIST) Teams
Alexander Ignatov (FED/STAR/SOCD/OSB)
Walter Wolf (FED/STAR/SMCD/OPDB),
Maxim Kramar (CONT/GST)
Boris Petrenko (CONT/GST)
Prasanjit Dash (CONT/STAR/SOCD/CIRA)*
Xingming Liang (CONT/STAR/SOCD/CIRA)*
Yury Kihai (CONT/GST)
Shanna Sampson (CONT/IMSG)
Aiwu Li (CONT/IMSG)
Meizhu Fan (CONT/IMSG)

***Indicates CIRA member at time of award**

Best Paper

Team: **John A. Knaff (FED/STAR/CRPD/RAMMB)***
Scott P. Longmore (CONT/STAR/CoRP/RAMMB)*
Debra A. Molenar (FED/STAR/CRPD/RAMMB)*

As of November/December 2015, this paper received enough citations (25) to place it in the top 1% of the academic field of Geosciences based on a highly cited threshold and publication year, according to The Web of Science.

CIRA Vision and Mission

The Cooperative Institute for Research in the Atmosphere (CIRA) is a research institute of Colorado State University.

Our Vision:

To conduct interdisciplinary research in the atmospheric sciences by entraining skills beyond the meteorological disciplines, exploiting advances in engineering and computer science, facilitating transitional activity between pure and applied research, leveraging both national and international resources and partnerships, and assisting NOAA, Colorado State University, the State of Colorado, and the Nation through the application of our research in areas of social benefit.

Our Mission:

To serve as a nexus for multi-disciplinary cooperation among CI and NOAA research scientists, university faculty, staff and students in the context of NOAA-specified research theme areas in satellite applications for weather/climate forecasting. Important bridging elements of the CI include the communication of research findings to the international scientific community, transition of applications and capabilities to NOAA operational users, education and training programs for operational user proficiency, outreach programs to K-12 education and the general public for environmental literacy, and understanding and quantifying the societal impacts of NOAA research.

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