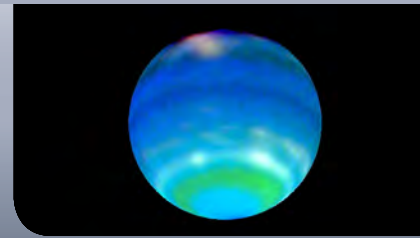
Space Science and Engineering Center | Cooperative Institute for Meteorological Satellite Studies | University of Wisconsin-Madison

TtA 2017
Winter / Spring

SSEC



# through the atmosphere

## Hurricane research: New connection between activity and intensity

TtA Winter / Spring 2017

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Paul Menzel

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*Through the Atmosphere* is a semiannual magazine featuring atmospheric, space science, and engineering research and education accomplishments of the University of Wisconsin-Madison's Space Science and Engineering Center (SSEC) and its Cooperative Institute for Meteorological Satellite Studies (CIMSS).

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Cover image, Terra MODIS image of Hurricane Matthew from 7 October 2016. Credit: SSEC

Other images: Pgs. 6-7, Earth limb. Credit: NASA. JPSS rendering. Credit: NOAA. Pgs. 12-13, Solar panel graphic. Credit: NOAA, Pgs. 16-17 Mammatus clouds on 24 July 2009 taken from the rooftop of the Space Science and Engineering Center, University of Wisconsin-Madison. Credit: Hank Revercomb. Pg. 18 Artist drawing of ATS-I. Credit: NASA

# Director's Note

This issue of Through the Atmosphere (TtA) addresses several research activities within the Space Science and Engineering Center (SSEC) and the Cooperative Institute for Meteorological Satellite Studies (CIMSS) that are now realizing new results.

▶ Scientists and educators at SSEC and CIMSS, along with our NOAA colleagues, have long anticipated GOES-16, the newest geostationary weather satellite in the United States. It was launched in November 2016. Our successful participation in this program also includes education training for K-12 teachers from across the nation. As part of this "From orbit to classroom" activity, 15 teachers attended the launch and are preparing to use this national resource in their teaching.

▶ As we await data from GOES-16, scientists are now preparing for the 2017 launch of the Joint Polar Satellite System-1, or JPSS-1. On board that satellite are two instruments with which scientists at SSEC and CIMSS have become very familiar: VIIRS and CrIS. Two similar instruments have flown on the Suomi-NPP satellite, and many folks have developed algorithms and used those data to study our planet. But, before these new observations can be used, the instruments must be characterized pre- and post-launch as discussed in the article "On deck."

▶ Using data from geostationary and polar-orbiting satellites such as GOES-16 and Suomi-NPP, SSEC and CIMSS scientists have a long history of studying hurricanes. In fact, a recent study published in the journal Nature continues this heritage by explaining connections between hurricane activity and intensification.

▶ Finally, Hank Revercomb was recently recognized with the honorific title of Fellow of the American Meteorological Society. We highlight Hank's impressive scientific achievements along with a recap of other award winners since the last issue of TtA.

*Steve Ackerman*

Steve Ackerman
Interim Director, SSEC

# Hurricanes approaching U.S. coast more likely to weaken during active hurricane periods

Active Atlantic hurricane periods, like the one we are in now, are not necessarily a harbinger of more, rapidly intensifying hurricanes along the United States coast.

New research published on January 4 in Nature by NOAA National Centers for Environmental Information scientist James Kossin, based at the NOAA Cooperative Institute at the University of Wisconsin–Madison, indicates that hurricanes that approach the U.S. coast are more likely to intensify during less active Atlantic periods. During active hurricane periods, those that approach the coast are more likely to weaken.

The relationship between the number of hurricanes that develop in the Atlantic basin and the number of major hurricanes that make landfall is a poor one, says Kossin, and one that has not yet been well explained. The new study explains at least part of that relationship.

Historically, notes Kossin, researchers (including himself) have focused primarily on the tropical Atlantic, the main hurricane development region, without distinguishing how hurricane-producing conditions may vary outside of it.

They knew a combination of warm ocean temperatures in the tropics and low vertical wind shear results in favorable conditions for hurricane formation, while cooler than average sea surface temperatures work in tandem with higher than average wind shears to produce quieter hurricane seasons. Scientists also knew that environmental conditions, primarily ocean temperatures and wind shear (changes in wind speed relative to altitude), determine whether Atlantic hurricanes intensify or weaken as their natural track pushes them northwesterly toward the U.S. coast.

But Kossin wondered "what other patterns there might be." His study took a step back and looked for related patterns over the entire basin.

*"The two parameters – ocean temperatures and wind shear – generally act in concert to either increase activity or reduce activity."*

Kossin analyzed two datasets gathered over three 23-year periods spanning 1947 to 2015. The first dataset, from the historical record of hurricane observations maintained by the U.S. National Hurricane Center, supplied six-hourly observations and included information on location, maximum winds and central pressure.

The second, an environmental dataset from the National Centers for Environmental Prediction and the National Center for Atmospheric Research, provided a benchmark for sea surface temperatures and wind shear for the period of interest.

Overall, when the tropics generate many hurricanes – during periods of low wind shear and high ocean temperatures in the tropical Atlantic – they also create a situation where those hurricanes lose energy if they approach the coast, as they encounter a harsh environment of higher wind shear and cooler ocean temperatures.

"They have to track through a gauntlet of high shear to reach the coast and many of them stop intensifying," Kossin says. "It is a natural mechanism for killing off hurricanes that threaten the U.S. coast."

What are the implications for U.S. coastal regions? According to Kossin, "it is good news. Greater activity produces more threats, but at the same time, we increase our protective barrier. It's pretty amazing that it happens to work that way."

The data seem to suggest that we may be moving into another quieter period in the basin, however, where less activity works hand-in-hand with lower wind shears along the coast, eradicating the protective barrier. As a result, says Kossin, while there may be fewer hurricanes approaching the coast, those that do may be much stronger, in the range of category 3 to category 5.

The threat of rapid strengthening is highly relevant to society, and in particular, to those who live along densely populated coastlines where the warning times for evacuation may already be short.

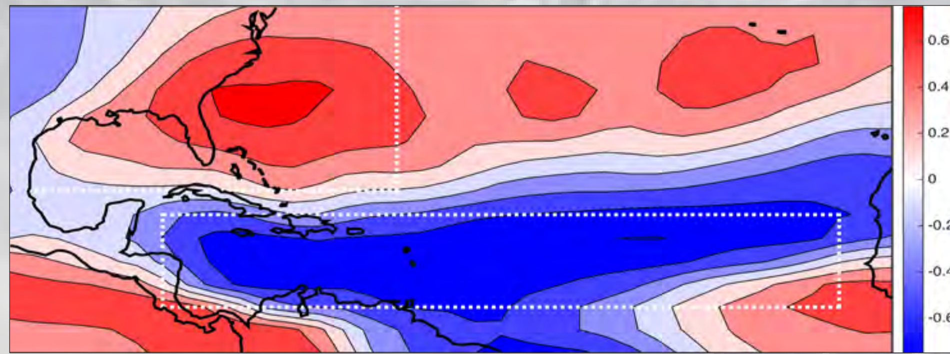
"Knowing the relationship between tropical activity and coastal conditions that either protect the coast or make it more vulnerable may help us better prepare for future landfalls," Kossin says.

Like any research study, the results raise more questions. For instance, how might climate change affect this relationship? Other studies, explains Kossin, have documented a rise in sea surface temperatures, a shift attributed to anthropogenic climate change. But the sea surface trend does not seem to be having a large effect on hurricane activity in the coastal region, at least over the past 70 years or so.

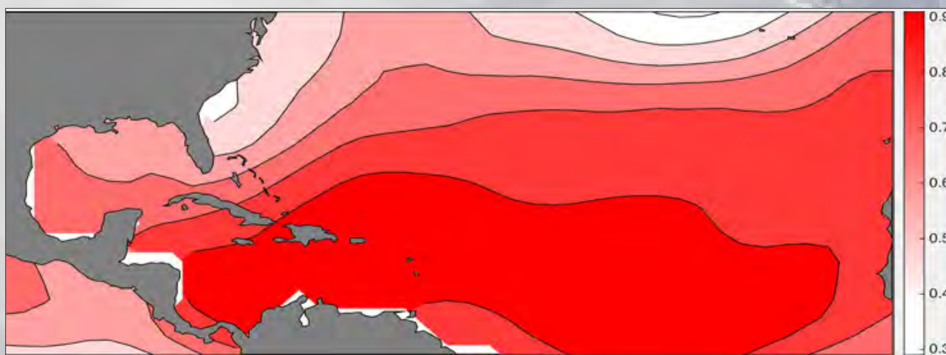
Kossin says this could fall under the heading of a "climate surprise" if the environmental conditions responsible for the protective barrier during active periods are compromised by climate change.

"There is no reason to think that this is a stationary mechanism," notes Kossin. "It's entirely possible that changes in climate could affect the natural barrier and thus significantly increase coastal hazard and risk."

**| Jean Phillips**




Pattern showing how vertical wind shear (VWS) varies in the Atlantic. When shear is abnormally low in the tropics, it is abnormally high along the U.S. coast. The lower dashed box shows the tropical Atlantic and the upper dashed box is where hurricanes must pass before striking the U.S. coast. Credit: James Kossin.




Pattern showing how sea surface temperature (SST) varies in the Atlantic. When SST is abnormally warm in the tropics, it is much less so along the U.S. coast. Credit: James Kossin.

# On deck

## SSEC scientists' calibration and validation efforts prepare JPSS-1 for 2017 launch

While scientists at the Space Science and Engineering Center (SSEC) and the Cooperative Institute for Meteorological Satellite Studies (CIMSS) are still celebrating the launch of GOES-R (now renamed GOES-16), they are also anxiously awaiting and preparing for the launch of another meteorological satellite. It, too, will be the first in a new series – the next generation of polar-orbiting weather satellites.

A collaborative effort between NASA and the National Oceanic and Atmospheric Administration, the Joint Polar Satellite System (JPSS) is scheduled to launch its first satellite, JPSS-1, in 2017 – currently planned for sometime after 1 July. And as with GOES-16, SSEC and CIMSS scientists are working to make sure the instruments on board JPSS-1, as well as the measurements to follow, are properly calibrated and validated. Those assessments are vital in order for scientists to use the data to improve weather forecast models and climate studies.

As noted on the JPSS website (jpss.noaa.gov/news.html), "polar and geostationary satellites are important and complementary components for weather forecasting, monitoring environmental conditions and mitigating the risks of severe weather, such as hurricanes, floods, fires and tornadoes… Together the sets of data are used to improve forecasting and the accuracy of weather prediction models across the US."

SSEC and CIMSS scientists are focused on two JPSS instruments: the Cross-track Infrared Sounder (CrIS) and the Visible Infrared Imaging Radiometer Suite (VIIRS).

"We've been involved with the new instruments since the beginning for both CrIS and VIIRS," says Dave Tobin, SSEC senior scientist.

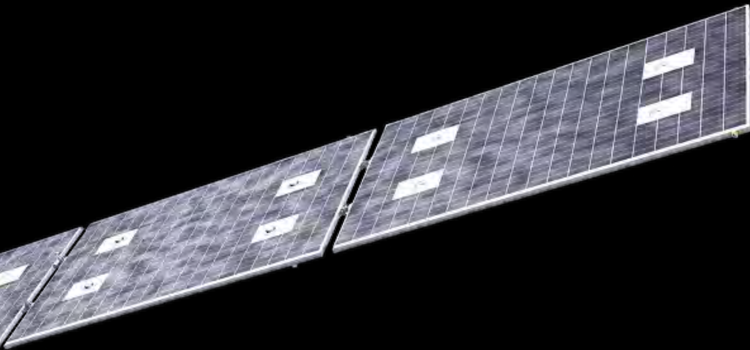
In fact, there is a strong connection between SSEC and CrIS, owing to a long heritage of not just sounding research, but specifically hyperspectral sounding research. The instrument will continue the record of high altitude observations of cloud motions from polar orbit, a concept that began at SSEC nearly 50 years ago with the plan to measure winds to improve forecasts.

### CrIS

JPSS-1 has one unique advantage that GOES-16 did not: essentially duplicate versions of the JPSS instruments are currently orbiting the Earth on the Suomi National Polar-orbiting Partnership (NPP) satellite. While that arrangement reduces much of the risk and the number of unknowns, the effort to calibrate and validate the instruments and data remains critical.

*"We've been involved with the new instruments since the beginning for both CrIS and VIIRS."*

The CrIS instrument to fly on JPSS-1, however, is not exactly the same as that on Suomi NPP. The spectral resolution is higher and the radiometric calibration has been improved, which should lead to more accurate data. Tobin noted that SSEC scientists have been very involved in the instrument development process, from the pre-launch design and testing to post-launch plans to assess the quality of the CrIS data.



Approximately a month or so after launch, the instruments will be cleared to be placed into operational mode, at which point they will begin taking measurements for “first light images” – those eagerly anticipated earliest publicly available images. At the same time, SSEC scientists will be assessing the data and products as they go from one level of maturity to the next: from beta to provisional to validated.

“At each level there is more and more scrutiny put on the data and little tweaks to change the calibration a little bit,” says Tobin.

And the sooner the data are validated and can be used, the better.

JPSS-1 will have the same orbit as Suomi NPP, but they will be separated by 50 minutes – making them 180° out of phase, or on exact opposite sides of the Earth.

“The observations are separated from each other as much as possible so that they’re independent and add more information,” says Tobin.

That configuration adds a layer of complexity when assessing the quality of the JPSS data as the two CrIS instruments are not viewing the same scene at the same time and cannot be directly compared. Instead, scientists bring in data from another polar-orbiting satellite instrument, the Infrared Atmospheric Sounding Interferometer (IASI) on the European MetOp satellite series, and use the Simultaneous Nadir Overpasses (SNOs) that occur near the poles when IASI and one CrIS or the other are crossing near the pole at the same time.

“So we’ll compare JPSS CrIS to IASI. And then separately we’ll compare Suomi NPP CrIS to IASI. You take the difference between those two, and the IASI drops out. So it’s just the difference between the two CrIS [instruments], statistically,” says Tobin.

SSEC scientists have extensive experience with this method as it was used when they compared data from two IASI instruments on separate MetOp satellites with data from the Suomi NPP CrIS.

The Cross-track Infrared Sounder (CrIS). SSEC scientists have been very involved in the instrument development process for the Cross-track Infrared Sounder (CrIS), from the pre-launch design and testing to post-launch plans to assess the quality of its data. Credit: NOAA.

Scientists also need to address the issue of detector non-linearity, as the detectors initially do not always capture temperature changes as they should.

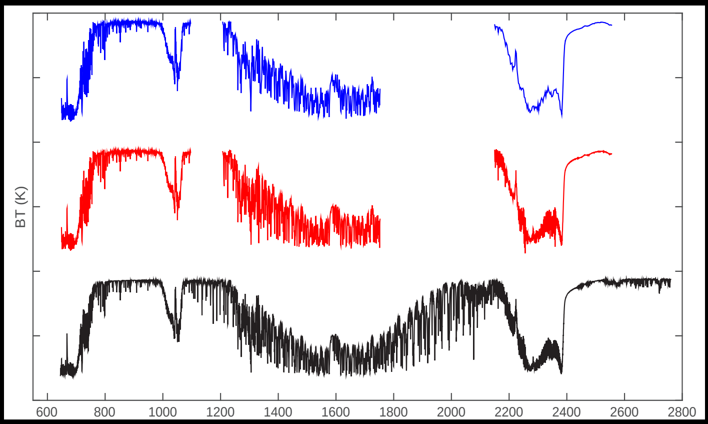
Tobin explains, “If you’d look at an increasingly hot scene, you would want the output of the detector to be linear. That would be ideal because then it’s a very straightforward relationship between the counts that are coming out of the detector and what you are looking at. But it’s not linear; it’s slightly non-linear. So you have to characterize that.”

While scientists characterized the non-linearity during thermal vacuum testing which simulates the space environment, it may change as the instrument is exposed to temperature swings, particularly those at launch, notes Lori Borg, a researcher at SSEC. A post-launch assessment will re-examine the non-linearity issue and determine whether additional corrections are necessary.

In addition, SSEC will be involved in a field campaign using its aircraft instrument, the Scanning HIS, to underfly JPSS– as well as GOES–16 to observe and take measurements of the same scenes. SSEC scientists will analyze those data to see how well they compare in order to determine how well the new satellite-based instruments are operating.

All these efforts aim to improve the accuracy of weather forecasts as the main use of CrIS data is in numerical weather prediction (NWP) models. Tobin explains that CrIS data from Suomi NPP are finally starting to have a large

continued ▸▸



Example clear sky brightness temperature spectra for CrIS at Normal Spectral Resolution (blue), CrIS at Full Spectral Resolution (red) and IASI (black). Credit: Dave Tobin, SSEC.

impact on those models, which in turn produce forecasts. He attributes that success to a noise covariance matrix recently introduced into NWP models.

"CrIS has significantly lower noise than other sensors like it, such as AIRS and IASI. If you have data that's noisy, there's a lot of wiggle room. With CrIS the noise is much lower and so all these other little sources of error [such as in the radiative transfer or in the model itself] had to be characterized much better," says Tobin.

And the improvements due to the noise covariance matrix are notable. Tobin states that the European Center for Medium range Weather Forecasting (ECMWF) has already remarked on the positive impact CrIS data has had on their forecast model.

SSEC scientists are also looking ahead to additional advances that might be possible with changes to the CrIS instrument for JPSS-2 and later. Specifically, they are advocating for filling in existing spectral gaps and smaller footprints. Agnes Lim, a CIMSS researcher, is examining the impact of a smaller footprint on the forecast model. A smaller footprint would also correct the current mismatch between footprint size and model grid size.

"As NWP models go with smaller and smaller grid sizes, this [change] would complement that," says Borg.

## VIIRS

While the VIIRS instrument designs are virtually the same, as with CrIS, the JPSS-1 version will benefit from technical upgrades based on the experience with the version on Suomi NPP, with those upgrades designed to improve performance.

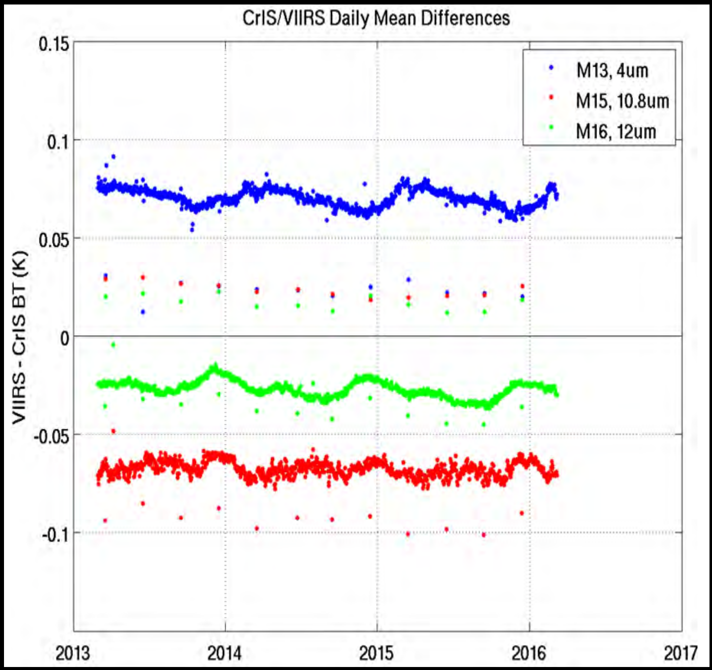
"The JPSS-1 VIIRS spectral filters for the VisNIR [Visible Near Infrared] bands were redesigned to reduce scattered light, improving the spectral purity of the filters. The mirror coating process in the fore optics was also reviewed to eliminate on-orbit degradation of mirror reflectance due to solar UV light illumination," writes SSEC scientist Chris Moeller in an interview over email.

Moeller's involvement with the VIIRS instrument began long before launch. Once construction of VIIRS was completed, its radiometric, spectral, and spatial performance were characterized during a series of tests. Moeller participated in the spectral testing at a Raytheon Space and Airborne Systems facility in El Segundo, California; Raytheon built the VIIRS for both Suomi NPP and JPSS-1.

The test allowed Moeller and others to observe the instrument's spectral performance and note any issues that Raytheon should address before launch.

"Importantly, the pre-launch test program is the only opportunity to directly characterize the spectral performance of VIIRS so we really want to make sure we've captured the spectral performance with comprehensive high quality measurements," noted Moeller.

Following the test, Moeller added that the spectral data are further analyzed to build the VIIRS spectral response functions "for application in VIIRS readiness testing and ultimately to support the operational radiance and science products after launch."



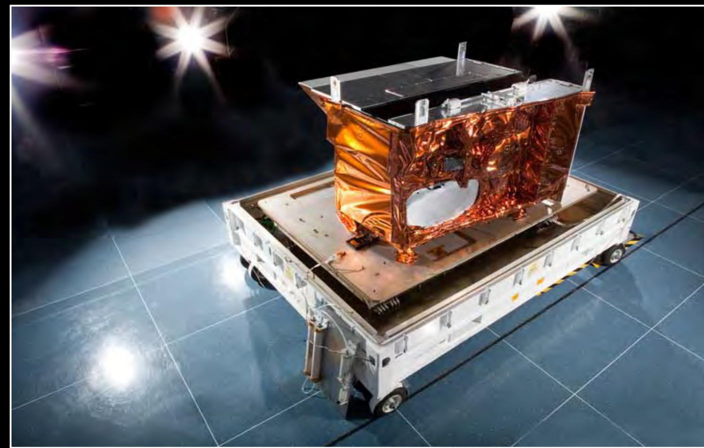
SNPP VIIRS Sensor Data Record (SDR) comparisons to CrIS SDR demonstrating the close agreement and excellent stability of both sensors over the mission. Periodic (quarterly) departures from that behavior are due to special VIIRS instrument warmup-cooldown exercises that support on-orbit calibration verification. Credit: Chris Moeller, SSEC.

Once JPSS-1 reaches its designated orbit, a new round of tests will commence to verify if VIIRS is performing as expected. SSEC scientists will compare data from VIIRS to other instruments on JPSS-1 (such as CrIS), as well as to instruments on other satellite platforms (such as IASI on MetOp-A/B), to look for biases that may affect the measurements. That information will inform whether or not scientists need to alter the VIIRS radiance algorithm to ensure accurate data records.

"This evaluation of biases between VIIRS and other on-orbit sensors is a critical element of preserving climate quality measurements over the decades of multi-sensor observations that will be needed to support climate change research," wrote Moeller.

Moeller went on to add that for the past four-plus years they have been conducting similar research using the VIIRS on Suomi NPP, which has been proven to be remarkably stable.

Moeller anticipates that first light images for the VisNIR bands will arrive within 30 days of launch, with the first light for the thermal bands to arrive sometime within 30 days after the VisNIR. Once all the bands have come online and are collecting data and the instruments have undergone an initial checkout period, scientists will then rigorously examine the data quality as it moves from beta to provisional to validated – with the goal of reaching validated within 20 months after launch.

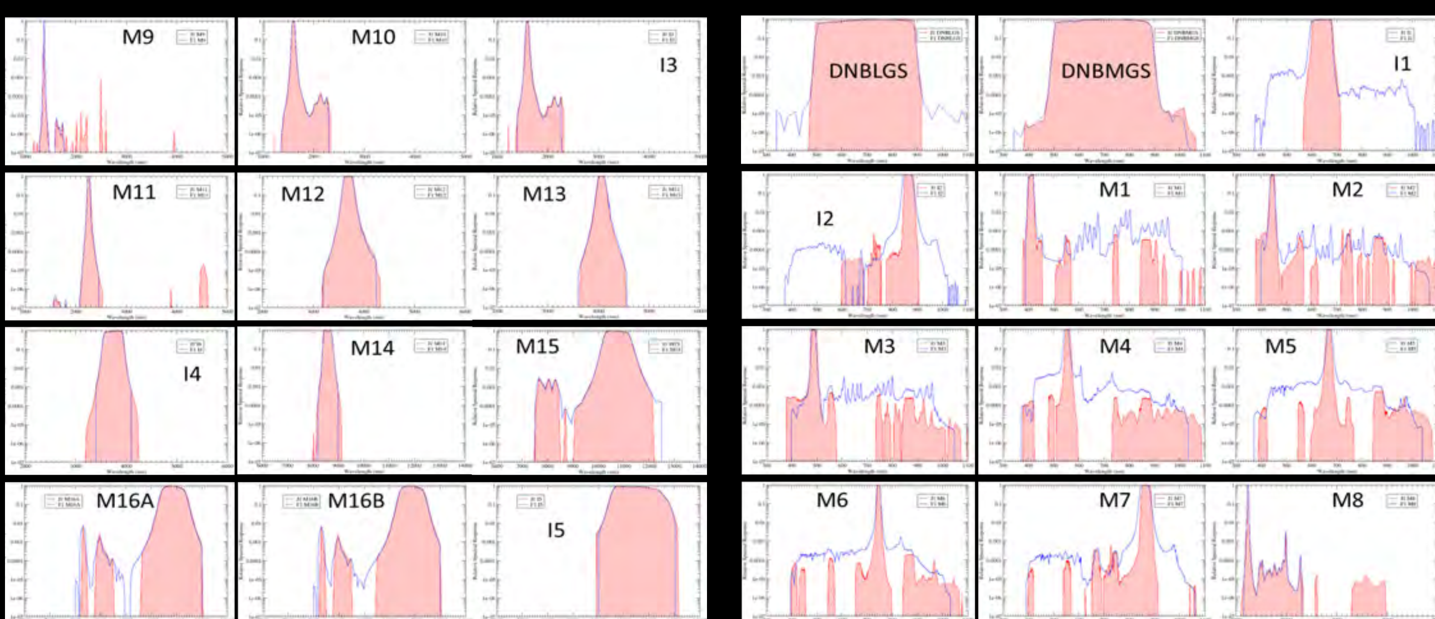


The Visible Infrared Imaging Radiometer Suite (VIIRS). Credit: NOAA.

That goal is finally coming closer to reality as all the instruments have been integrated into the JPSS-1 spacecraft at Ball Aerospace in Colorado, and spacecraft-level testing of the instruments has been successfully completed. As the countdown to launch continues, SSEC scientists are ready to carry out their calibration and validation plans because despite everything "surprises can happen," notes Tobin, adding "that's why we do it."

*Look for more stories about SSEC's JPSS-related research later in 2017 as the launch date approaches!*

**| Leanne Avila**




VIIRS relative spectral response characterization for all bands of JPSS-1 (shaded pink) and SNPP (blue profile). Response includes the specified high response zone of the in-band region plus any out-of-band response caused by filter leaks and/or crosstalk. Much of the out-of-band response in the VisNIR bands (I1, I2, M1-M7) of SNPP was eliminated by redesigning the filters for JPSS-1 VIIRS.
X-axis: Wavelength (nm) Y-axis: Relative Spectral Response. Credit: Chris Moeller, SSEC.

# Highlights of recent publications


▶ Arvani, B, R. B. Pierce, A. I. Lyapustin, Y. Wang, G. Ghermandi, and S. Teggi. 2016: **Seasonal monitoring and estimation of regional aerosol distribution over Po valley, northern Italy, using a high-resolution MAIAC product.** Atmos. Environ., 141, 106-121.

▶ Brunner, J., R. B. Pierce, and A. Lenzen, 2016: **Development and validation of satellite-based estimates of surface visibility.** Atmos. Meas. Tech., 9, 409-422.

▶ Cintineo, R. M., J. A. Otkin, T. A. Jones, S. Koch, and D. J. Stensrud, 2016: **Assimilation of synthetic GOES-R ABI infrared brightness temperatures and WSR-88D radar observations in a high-resolution OSSE.** Mon. Wea. Rev., 44, 3159-3180.

▶ Foster, M. H., S. A. Ackerman, K. Bedka, R. A. Frey, L. Di Girolamo, A. K. Heidinger, S. Sun-Mack, B. C. Maddux, W. P. Menzel, P. Minnis, M. Stegel, and G. Zhao, 2016: **State of the climate in 2015: Cloudiness.** Bull. Amer. Meteor. Soc., 97, S28-S29.

▶ Foster, M. J., A. Heidinger, M. Hiley, S. Wanzong, A. Walther, and D. Botambekov, 2016: **PATMOS-x cloud climate record trend sensitivity to reanalysis products**. Remote Sens., 8, doi:10.3390/rs8050424.

▶ Gravelle, C. M., J. R. Mecikalski, W. E. Line, K. M. Bedka, R. A. Petersen, J. M. Sieglaff, G. T. Stano, and S. J. Goodman, 2016: **Demonstration of a GOES-R satellite convective toolkit to "bridge the gap" between severe weather watches and warnings: An example from the 20 May 2013 Moore, Oklahoma, tornado outbreak.** Bull. Amer. Meteor. Soc., 97, 69-84.

▶ Greenwald, T. J., R. B. Pierce, T. Schaack, J. Otkin, M. Rogal, K. Bah, A. Lenzen, J. Nelson, J. Li, and H.-L. Huang, 2016: **Real-time simulation of the GOES-R ABI for user readiness and product evaluation.** Bull. Amer. Meteor. Soc., 97, 245-261.

▶ Griffin, S. M., K. M. Bedka, and C. S. Velden, 2016: **A method for calculating the height of overshooting convective cloud tops using satellite-based IR imager and CloudSat cloud profiling radar observations**. J. Appl. Meteor. Climatol., 55, 479-491.

▶ Heidinger, A., M. Foster, D. Botambekov, M. Hiley, A. Walther, and Y. Li, 2016: Using the NASA EOS **A-train to probe the performance of the NOAA PATMOS-x cloud fraction CDR.** Remote Sens., 8, doi:10.3390/rs8060511.

▶ Holz, R. E., S. Platnick, K. Meyer, M. Vaughan, A. Heidinger, P. Yang, G. Wing, S. Dutcher, S. Ackerman, N. Amarasinghe, F. Nagle, and C. Wang, 2016: **Resolving ice cloud optical thickness biases between CALIOP and MODIS using infrared retrievals.** Atmos. Chem. Phys., 16, 5075-5090.

▶ Key, J., X. Wang, Y. Liu, R. Dworak, and A. Letterly, 2016: **The AVHRR Polar Pathfinder climate data records.** Remote Sens., 8, doi:10.3390/rs8030167.

▶ Kossin, J. P, K. A. Emanuel, and S. J. Camargo, 2016: **Past and projected changes in Western North Pacific tropical cyclone exposure**. J. Climate, 29, 5725–5739.

▶ Kulie, M. S., L. Milani, N. B. Wood, S. A. Tushaus, R. Bennartz, and T. L'Ecuyer, 2016: **A shallow cumuliform snowfall census using spaceborne radar.** J. Hydrometeor., 17, 1261-1279.

▶ Letterly, A., J. Key, and Y. Liu, 2016: **The influence of winter cloud on summer sea ice in the Arctic**, 1983-2013. J. Geophy. Res.: Atmos., 121, 2178-2187.

▶ Li, J., P. Wang, H. Han, K. Li, and J. Zheng, 2016: **On the assimilation of satellite sounder data in cloudy skies in numerical weather prediction models.** J. Meteorol. Res., 30, 169-182.

▶ Liu, Y. and J. R. Key, 2016: **Assessment of Arctic cloud cover anomalies in atmospheric reanalysis products using satellite data**. J Climate, 29, 6065–6083.

▶ Menzel, W. P., D. C. Tobin, and H. E. Revercomb, 2016: **Infrared remote sensing with meteorological satellites**. Adv. At., Mol., Opt. Phys., 65, 193-264.

▶ Mielikainen, J., B. Huang, and H.-L. A. Huang, 2016: **Optimizing Purdue-Lin microphysics scheme for Intel Xeon Phi coprocessor**. IEEE J. Sel. Top. Appl. Earth Observ. Remote Sens., 9, 425-438.

▶ Orf, L., R. Wilhelmson, and L. Wicker, 2016: **Visualization of a simulated long-track EF5 tornado embedded within a supercell thunderstorm**. Parallel Computing, 55, 28-34.

▶ Otkin, J. A., M. C. Anderson, C. Hain, M. Svoboda, D. Johnson, R. Mueller, T. Tadesse, B. Wardlow, and J. Brown, 2016: **Assessing the evolution of soil moisture and vegetation conditions during the 2012 United States flash drought**. Agric. For. Meteor., 218-219, 230-242.

▶ Petersen, R. A., 2016: **On the impact and benefits of AMDAR observations in operational forecasting, part 1: A review of the impact of automated aircraft wind and temperature reports**. Bull. Amer. Meteor. Soc., 97, 585–602.

▶ Pettersen, C,, R. Bennartz, M. S. Kulie, A. J. Merrelli, M. D. Shupe, and D. D. Turner, 2016: **Microwave signatures of ice hydrometeors from ground-based observations above Summit, Greenland**.

Atmos. Chem. Phys.,16,4743-4756.

▶ Plokhenko, Y., W. P. Menzel, R. Knuteson, and H. E. Revercomb, 2016: **Mathematical aspects of the meteorological interpretation of satellite hyperspectral infrared measurement part 1: Statement of the inverse problem for estimation of the cloud absorption vertical profile**. Int. J. Remote Sens., 37, 1601-1619.

▶ Rabin, R. M., I. Gultepe, R. J. Kuligowski, and A. K. Heidinger, 2016: **Monitoring snow using geostationary satellite retrievals during the SAAWSO Project**. Pure Appl. Geophys., 173, 3085-3102.

▶ Rink, T., W. P. Menzel, L. Gumley, and K. Strabala, 2016: **HYDRA2: A multispectral data analysis toolkit for sensors on Suomi-NPP and other current satellite platforms**. Bull. Amer. Meteor. Soc., 97,1283–1294.

▶ Roman, J., R. Knuteson, T. August, T. Hultberg, S. Ackerman, and H. Revercomb, 2016: **A global assessment of NASA AIRS v6 and EUMETSAT IASI v6 precipitable water vapor using ground-based GPS SuomiNet stations**. J. Geophy. Res.: Atmos., 121, 8925–8948.

▶ Sromovsky, L. A., K. H. Baines, P. M. Fry, and T. W. Momary, 2016: **Cloud clearing in the wake of Saturn's Great Storm of 2010-2011 and suggested new constraints on Saturn's He/H2 ratio.** Icarus, 276, 141-162.

▶ Tobin, D., R. Holz, F. Nagle, and H. Revercomb, 2016: **Characterization of the Climate Absolute Radiance and Refractivity Observatory (CLARREO) ability to serve as an infrared satellite intercalibration reference**. J. Geophy. Res.: Atmos., 121, 4258-4271.

▶ Veglio, P., D. C. Tobin, S. Dutcher, G. Quinn, and C. C. Moeller, 2016: **Long-term assessment of Aqua MODIS radiance observation using comparisons with AIRS and IASI**. J. Geophy. Res.: Atmos., 121, 8460–8471.

▶ Wagner, T. J. and J. M. Kleiss, 2016: **Error characteristics of ceilometer-based observations of cloud amount**. J. Atmos. Oceanic Technol., 33, 1557-1567.

▶ Wimmers, A. J. and C. S. Velden, 2016: **Advancements in objective multisatellite tropical cyclone center fixing**. J. Appl. Meteor. Climatol., 55, 197–212.

**For a complete list of publications visit: go.wisc.edu/lx74ac**

# Awards

▶ Michael Pavolonis, AAS Earth Science and Applications Award for "developing cutting-edge methods to convert satellite data into actionable information for mitigating hazards caused by volcanic eruptions and severe convection"

▶ Tommy Jasmin, awarded M.S. degree from the UW-Madison Department of Atmospheric and Oceanic Sciences for his thesis, "Addressing future challenges of sustainability and human health through unbiased monitoring of trends in economic development, energy use, and air quality using satellite remote sensing"

▶ Jun Li, awarded UW-Madison Distinguished Scientist prefix

▶ Leigh Orf, IDC High Performance Computing Excellence Award for the computational project, "Unlocking the Mysteries of the Most Violent Tornadoes"

▶ William L. Smith, AIAA Losey Atmospheric Sciences Award for "visionary and pioneering hyperspectral resolution sounding techniques"

▶ Hank Revercomb, elected Fellow of the American Meteorological Society for "outstanding contributions to advance the atmospheric and related sciences, technologies, applications"

▶ Jim Kossin, AMS Journal of Climate Editor's Award for "careful, thoughtful, and insightful reviews that significantly improved the quality of manuscripts"

▶ Michelle Feltz, UW-Madison Department of Atmospheric and Oceanic Sciences Lettau Award for outstanding master's thesis titled, "Guidance for stratospheric temperature products: Comparing cosmic radio occultation and AIRS hyperspectral infrared sounder data"

▶ Jim Kossin, NOAA NCEI Special Act Award for "research-to-operations work with the National Hurricane Center"

▶ Brad Pierce, NOAA Administrator's Award for "for providing robust, real-time, simulated data of the next generation geostationary satellite imagers, reducing risk in post-launch operations"

# From orbit to classroom

## Weather satellite GOES-16 extends beyond its mission and into the classroom

After a successful mid-November launch in 2016, the GOES-R weather satellite has reached its destination more than 22,000 miles from Earth. As of mid-January, the Geostationary Operational Environmental Satellite (GOES), a joint program between NASA and the National Oceanic and Atmospheric Administration (NOAA), entered in a lock-step rotation with the Earth and provide continuous weather coverage over the continental US.

As researchers and engineers continue to get the system refined and calibrated, school teachers from around the country are already taking their experiences from the launch back to the classroom, through a multi-year program spearheaded by Margaret Mooney, director of education and public outreach at the UW-Madison Cooperative Institute for Meteorological Satellite Studies (CIMSS). That program culminated in a two-day workshop at the launch.

To Mooney, the GOES-R project is an exceptional and grassroots way to reach students through their teachers and further engage them in science, technology, engineering and mathematics (STEM).

"Every aspect of STEM is represented in many ways," says Mooney. "The science part is the biggest component and is well-represented through the design of the experiments and the data that will be used in atmospheric, meteorological, and climate sciences in teachers' classrooms."

Mooney has been working with teachers through the GOES-R Education Proving Ground, which began three years ago with six core educators, including Brian Witthun and Craig Phillips, eighth grade science teachers at Jack Young Middle School in Baraboo, Wisconsin. They were among 23 educators from around the US to participate in the CIMSS program and witness the launch at Cape Canaveral, Florida.

GOES-R (now called GOES-16) launches from Cape Canaveral, Florida at the very last minute of the launch window, 23:42 UTC November 19, 2016 Credit: NASA.

"As a teacher, I feel it is important for our students to see the connection between weather forecasts and how we are able to get that information using satellites," says Phillips. "Our lessons focus on the science of satellites and how improved weather data makes for more accurate predictions and ultimately helps save lives."

Prior to the GOES-R launch, Witthun and Phillips taught sections about satellite meteorology and how it relates to numerous other scientific fields in their classrooms. During the planning and construction phases of GOES-R, the middle school teachers collaborated with staff at CIMSS and the NOAA GOES-R Education Proving Ground to create lesson plans and online tools for students to use for different units on weather, meteorology, and satellites. The online tools teach students about GOES-R and its ability to capture high resolution images, while other lessons focus on basic principles of satellite meteorology such as resolution and image coloring. Witthun and Phillips shared their four lesson plans with teacher colleagues at the launch workshop and discussed ways to teach students about satellites and the science behind atmospheric phenomena.

"It has been exciting to be a part of the GOES-R mission from early on," says Phillips. "We've had the fortune to learn about every aspect of the program and we are able to use it to build a successful lesson plan that will resonate with our students."

The two Wisconsin teachers agree: having seen and experienced the GOES-R launch in person will benefit their students down the road.

"Getting to see the launch really brings everything full-circle," says Phillips. "Whenever you're teaching something you're

passionate about, and when you are involved in the process like we have been, that enthusiasm translates to the classroom and the kids pick up on that as well."

The GOES-R weather satellite is the next step in the evolution of geostationary weather satellites, with the first launching more than 40 years ago. Scientists at CIMSS have been involved with each generation of geostationary satellite since imagers were first placed on orbiting satellites in the 1960s.

Compared to previous geostationary imagers, the Advanced Baseline Imager (ABI) on GOES-R has three times the number of spectral bands available to view different parts of the Earth's atmosphere and weather patterns. GOES-R, via the ABI, also has four times greater spatial resolution compared to current satellites in orbit and can capture data five times faster, sending images of Earth as often as every 30 seconds. The upgraded components of the GOES-R mission gives researchers and forecasters the tools they need to improve weather predictions and increase warning times.

In addition to the ABI, GOES-R includes the Geostationary Lightning Mapper (GLM), which can track lightning activity to determine if a storm is intensifying and capable of producing tornados. Other instruments monitor space weather such as solar winds and flares capable of damaging other satellites, disrupting communications systems and power grids on Earth.

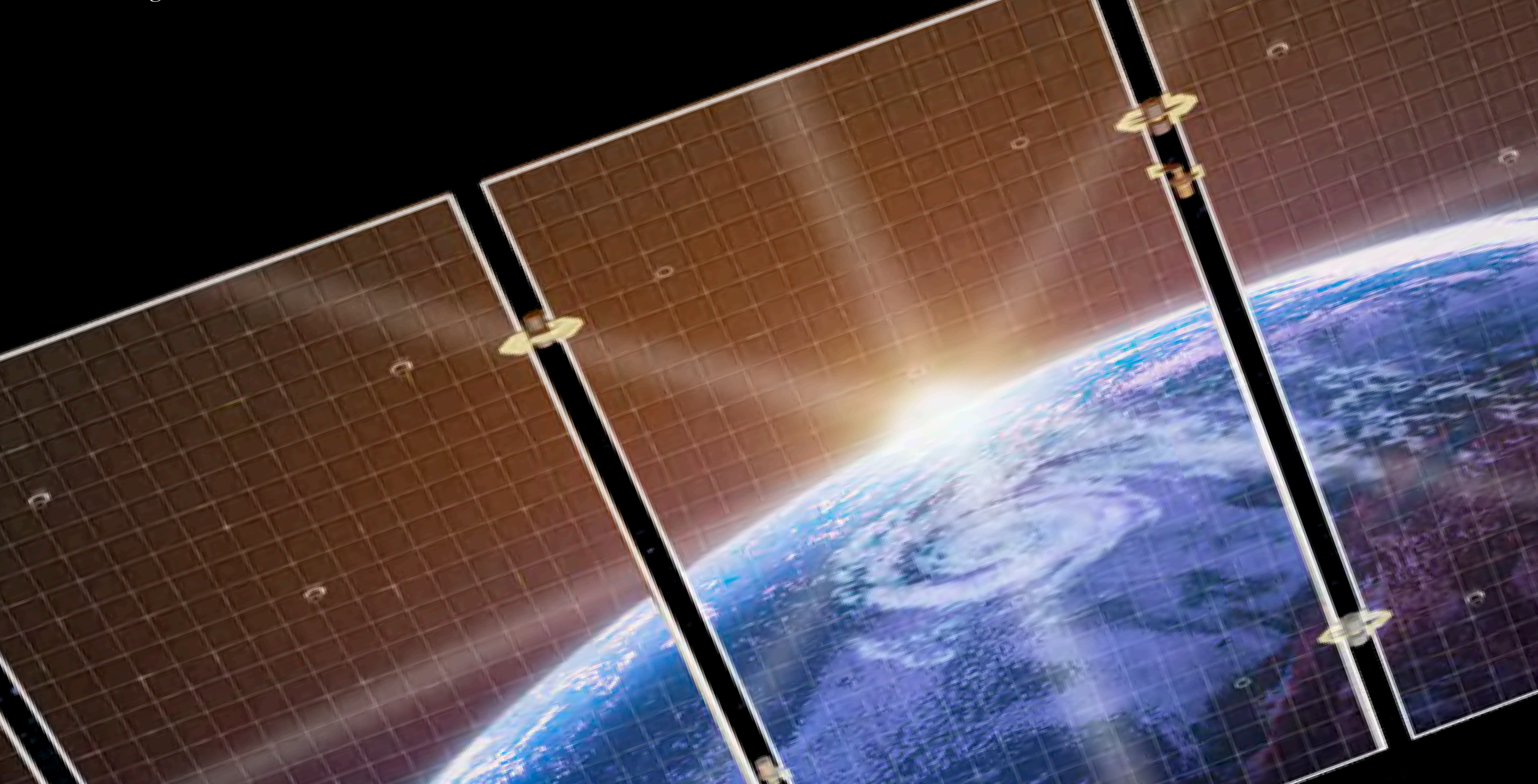
Following its launch on November 19, 2016, the GOES-R satellite is expected to send back its first data and images in early 2017. GOES-R is the first in a series of new geostationary satellites scheduled to be launched in the coming years through 2025.


School teachers from around the country gathered at Kennedy Space Center in Florida to learn about GOES-R and share ways to bring meteorological science into the classroom. Credit: Margaret Mooney CIMSS EPO.

Looking ahead, Mooney is encouraged by the excitement surrounding the GOES-R launch and its ability to reach beyond its meteorological mission.

"Through programs like GOES-R," says Mooney. "We hope to get more young people engaged in STEM fields and inspire them toward scientific careers so that they can tackle challenges facing society."

**| Eric Verbeten**



# Hank Revercomb: Fellow of the American Meteorological Society

Pioneering, precision, and accuracy are the watchwords of Hank Revercomb's career and contributions to the United States meteorological satellite program. His peers, and the American Meteorological Society, agree.

Revercomb, senior scientist and former director at the University of Wisconsin-Madison (UW-Madison) Space Science and Engineering Center (SSEC), was nominated by his peers and elected a 2017 Fellow of the American Meteorological Society for his achievements and contributions to the atmospheric sciences. His leadership on an intricate lineage of satellite-, aircraft-, and ground-based instruments has left an unmistakable imprint on the quality of atmospheric observations that have proven critical to better weather forecasts.

William L. Smith, UW-Madison professor emeritus and colleague of nearly forty years, led the nomination. "It did not take me long to realize that Dr. Revercomb was a most gifted physicist," wrote Smith. "His scientific and engineering excellence in the measurement of environmental variables for operational weather prediction and research have led to today's operational satellite sounding instruments."

Revercomb's curiosity about methods to characterize the thermodynamics of gaseous systems extends back to his 1972 dissertation on the Boltzmann equation. This equation describes transport properties, such as thermal conductivity, when a fluid is not in equilibrium, as in the atmosphere.

This expertise made him a natural fit for the research teams at SSEC, then under the leadership of SSEC founder Verner Suomi. Suomi, already leading the development of instruments for U.S. satellite programs, hired Revercomb away from a postdoc position to work with fellow physicist from graduate school, and good friend, Larry Sromovsky. The two set to work on developing the nation's first geostationary satellite sounding instrument, the Visible Infrared Spin Scan Radiometer (VISSR) Atmospheric Sounder (VAS) – putting Revercomb's graduate studies to immediate use.

The VAS was developed to fly on early geostationary satellites to collect information about the vertical distribution of atmospheric properties, such as moisture and temperature. The accuracy of mesoscale forecasts, at the time, was limited by the quality of vertical soundings. Meteorologists were seeking better data to construct more refined and localized weather forecasts.

But in this era, especially under the high-energy, idea-laden leadership of Suomi, there were numerous projects underway. Whether it was the study of Earth's atmosphere, or that of an outer planet, a connectivity between these seemingly disparate themes would emerge over time.

Revercomb and Sromovsky had become engrossed in the VAS instrument project when they teamed with Suomi on a new endeavor to make better climate measurements: the Earth Radiation Budget Observing System. The Earth radiation budget work grew organically out of Suomi's studies in the late 1950s to measure the balance between incoming solar energy and outgoing reflected and thermal energy from the Earth – this radiation flux measurement is important to understanding Earth's climate.

Revercomb and Sromovsky invented a new type of radiometer, the Fast Active Cavity Radiometer, specifically designed to measure the Earth radiative flux from a small rotating spacecraft. The radiometer never flew, but provided beneficial experience with hardware innovation.

Joe Taylor (left) and Hank Revercomb (right) examine the Scanning-HIS during the 2006 Costa Rica Aura Validation Experiment. Credit: Paolo Antonelli. Opposite: Hank Revercomb on the Space Science and Engineering Center roof, University of Wisconsin-Madison. Credit: Bill Bellon.

Dave Tobin (left) and Hank Revercomb (right) during the 2006 Costa Rica Aura Validation Experiment. Credit: Dan LaPorte.

Further capitalizing on their growing expertise, the trio, Suomi, Revercomb, and Sromovsky, would develop yet another radiometer that would successfully return detailed measurements of the atmosphere of Venus from the three small entry probes on NASA's Pioneer Venus Mission.

"Venus fits in the puzzle of the Earth," says Revercomb. Studying its atmospheric composition, weather systems, and clouds can lead to new ideas to increase understanding about Earth.

Revercomb's life-long collaboration with Smith would begin during this same period, too. Smith and his team of National Oceanic and Atmospheric Administration (NOAA) scientists had relocated from Washington D.C. to UW-Madison to establish systems for processing the VAS temperature and water vapor data.

By 1980, the VAS instrument design was finalized and it launched on GOES-4 that same year, demonstrating its value over polar orbiting satellites for continuous observation. But even before its launch, Smith recognized the need for a sensor that could deliver profiles with better vertical detail than was possible with VAS.

Revercomb and Sromovsky accepted the new challenge to devise a spectrometer that could improve on the VAS spectral resolution from geostationary orbit. Their method involved the use of a Fourier Transform Spectrometer, an instrument that provides high quality information about spectral properties and that lends itself to rigorous mathematical analysis.

This was a pivotal point in Revercomb's career, marking a shift in focus to develop FTS instruments for atmospher-

continued ▸▸

ic science. One of his goals moving forward would be to advance the science behind high spectral resolution observations as the next step in improving the resolution of soundings to improve forecasts.

In 1981, not content with the status quo, Smith and Revercomb collaborated with NASA, NOAA and industry partners, the Santa Barbara Research Corporation and Bomem, Inc., to design a new High-resolution Interferometer Sounder (HIS) instrument for flight on a geostationary weather satellite. Alongside the satellite instrument, the two scientists created a version of the HIS that would fly on NASA aircraft, allowing testing of the hardware much closer to home.

Revercomb led the hardware and radiance analysis portion of the experiment that would successfully demonstrate the hyperspectral resolution sounding concept envisioned by Smith. Furthermore, Revercomb discovered that the HIS could deliver observations of much higher accuracy than the state-of-the-art infrared observations at that time. He used subsequent HIS observations to significantly improve calculations of atmospheric radiation.

"We've continually tried to minimize the difference between measurements and calculations because those differences are really what limits the retrieval of atmospheric properties and their use for weather forecasting," said Revercomb.

The HIS was deployed in numerous field experiments from 1985 until 1998, collecting data and contributing to the understanding of ice clouds and ozone holes in the atmosphere among many other meteorological studies. By the end of the decade, Revercomb's team further refined the HIS instrument with a new cross-track scanning version, the Scanning-HIS, which is still flying in many satellite validation and atmospheric research campaigns today.

In the HIS, Revercomb, with his instrument team, and Smith, with his retrieval team, had demonstrated the principles for what would later become the operational instrument on NOAA's polar orbiting satellites. But to achieve an operational instrument, NOAA imposed an additional design constraint: the new instrument could not take up a larger footprint on the spacecraft than NOAA's current sounder, the HIRS (High resolution Infrared Radiation Sounder).

Once again calling on SBRC and Bomem for assistance, Revercomb executed a plan to design the Interferometer Thermal Sounder (ITS), meeting NOAA's challenge.

According to Smith, this development led to the second generation of sounding instruments flying on current satellites. In fact, wrote Smith, an adaption on the design for the ITS, would become the Cross-track Infrared Sounder (CrIS) instrument now flying on the Suomi National Polar-orbiting Partnership (S-NPP) satellite. The CrIS remains a critical instrument on the next U.S. polar-orbiting satellite, the Joint Polar Satellite System (JPSS), scheduled to launch in 2017.

Revercomb's influence on advancements in hyperspectral sounding cannot be overstated. Not only did the HIS instrument influence U.S. satellite sounding capabilities, the same interferometer concept was adopted by Europe for the Infrared Atmospheric Sounding Interferometer (IASI) currently flying on MetOp, its series of polar orbiting satellites. On the geostationary side, he has led the conceptual design for an imaging hyperspectral sensor, an instrument expected to further improve severe weather warnings in the future.

Today, these vertical measurements of moisture and temperature are being assimilated into forecast models where "the combination of CrIS and IASI in the premier European Center model have had the largest impact on the accuracy of global weather forecasts, more so than any other data type," says Revercomb.

Despite the success of HIS, funds for routine flights of the instrument were limited. So necessity being the mother of invention, Smith suggested they turn it upside down and operate it on the ground. Revercomb led the development of the early version of this up-looking instrument, the Atmospheric Emitted Radiance Interferometer (AERI).

Under the U.S. Department of Energy Atmospheric Radiation Measurement program, Revercomb's UW-Madison team has made AERI observations robust, resulting in improvements crucial to atmospheric radiative transfer calculations for applied weather and climate research.

"The highly accurate radiance spectra from AERI makes it possible to retrieve nearly continuous vertical measurements of temperature, water vapor, and trace gases that provide an unparalleled view of the boundary layer," says Revercomb.

The AERI collaboration with the DOE continues to grow as networks of AERIs are configured to gather data that will help further refine the nation's weather and climate applications.

Intertwined with Revercomb's scientific pursuits are his interactions and collaborations with other scientists. He would be the first to admit that most advances in science do not emerge out of solitary pursuits, but rather, through the contributions of many – from scientists, to engineers, to craftsmen, to students, and support staff.

SSEC researcher Joe Taylor echoes this belief. In 2000, as a member of a Canadian instrument team, Taylor crossed paths with SSEC's Scanning-HIS team during an international collaboration to study the environment of South Africa using satellite sensors and aircraft instruments. Taylor left that experiment very impressed with the expertise of Revercomb's Scanning-HIS group.

*"One thing that sets him apart is something that I can only describe as instinct."*

The two would meet again a few years later when Taylor was invited to join the Scanning-HIS group at UW-Madison. This partnership fostered collaboration with Laval University in Canada, typical of many such international collaborations initiated by Revercomb during the course of his career.

"One of the things that sets him [Revercomb] apart is something that I can only describe as instinct. That is, his gut feeling is almost never wrong – he draws on his past experiences and his deep mathematical and scientific knowledge gained over the years and he is always right on," says Taylor. "It's uncanny."

In addition, Revercomb is someone who works until the problem is solved, tireless in that regard, says Taylor.

He motivates the whole team. Taylor describes Revercomb as "someone who will see the good side in everything, or try to find the good side even if it is not obvious to others."

Taylor received his Ph.D. from Laval University while working at SSEC with Revercomb as his co-adviser. His interest in precision measurement techniques meshed with Revercomb's current project: the Absolute Radiance Interferometer (ARI) slated to be part of the NASA Climate Absolute Radiance and Reflectivity Observatory (CLARREO). Partners include NASA, Harvard University, and ABB Bomem of Quebec, Canada.

Revercomb's interest in obtaining accurate measurements extends well beyond any specific geographic region: his vision encompasses global satellite measurements of climate change, at a time when these data are critical to decision-making. In fact, the CLARREO mission was recommended on its merits for development by the 2007 Decadal Survey of the National Research Council, Earth Science and Applications from Space and was included in the President's budget for 2016-2017, though the ARI has not yet been selected for development.

"With the ARI, we can make a highly accurate measure of the climate based on what we see at the top of the atmosphere, prove the accuracy on orbit, and we'll have that record forever," says Revercomb. "Then, we can go back a decade later and see how it is different."

Revercomb's excitement is palpable when he describes the possibilities inherent in the ARI or ARI-like instruments. "By putting the emphasis on accuracy over continuous measurements, we can convincingly detect changes, or long-term trends. It is like planting a stake in a glacier to see how much the ice has changed over time," says Revercomb.

The overarching idea is to eventually fly these types of instruments, or arrays of them, tailored to make climate measurements.

According to Revercomb, there is an urgent need to address the two timescale extremes of weather and climate: geostationary sounding instruments are necessary to meet immediate needs for monitoring atmospheric stability to improve severe weather warnings, whereas, CLARREO measurements, over decades, are needed to support societal decisions for dealing with long-term climate changes.

"Each of them is extremely important right now," says Revercomb. "One addresses a threat to life and property, directly and immediately, and the other addresses a major threat to the future of our society. All of these things have consequences and we need to be more effective in leading the way to achieving successful monitoring systems."

Ever the optimist, Revercomb, remains confident that the commitment to monitoring Earth's climate from space will emerge as a federal priority.

"Whether he is working with an instrument on the ground, on aircraft, or on satellites, Revercomb has exhibited great leadership, vision, and sound engineering and science practice," says Smith. "He has provided valuable systems to the U.S. government for improving environmental research and operations for the benefit of people around the world."

**| Jean Phillips**

# Weather in Motion

## A look back at Earth's first movie debut

On December 7, 1966, the world's first geosynchronous Applications Technology Satellite (ATS-A) launched from its pad at Cape Canaveral. Two weeks later, the satellite reached its orbit over the equator. Images from ATS-I – and the movies constructed from them – would revolutionize the way we look at Earth and its weather. Motion pictures of Earth's weather would soon become the new norm – benefitting atmospheric research and forecasting everywhere.

ATS-I's historic journey started in the mid-1960s with a proposal to NASA to build the first geosynchronous satellite. Around the same time, the late Verner Suomi (founder of the UW-Madison Space Science and Engineering Center) and UW engineering professor Robert Parent wanted to capitalize on the geosynchronous orbit of ATS to better observe Earth's weather patterns.

Their proposal led to an innovative design called the Spin-Scan Cloud Camera, which sensed visible or reflected radiation.

"The object of this experiment is to continuously monitor the weather motions over a large fraction of the Earth's surface," wrote Suomi, citing the information gaps left by polar orbiting satellites. "Even though near Earth weather satellites have provided an impressive array of visual and infrared observations of the Earth's weather on a nearly operational basis, the synchronous satellite affords another opportunity to gain a better understanding of the global weather circulation, the key to better weather prediction."

According to Suomi, the premise was simple: "The weather moves, not the satellite."

By utilizing the satellite's rotation while in geosynchronous orbit, ATS-I was able to capture full-disk images of Earth and beam them back every 20 minutes, revealing never before seen detail of cloud motion. ATS-I and its spin-scan camera were fixed over the Pacific Ocean, which Suomi and Parent described as being "the 'boiler' of the giant atmospheric heat engine."

The spin-stabilized spacecraft, shaped like a large drum, measured 4.4 ft. long and 4.6 ft. in diameter. Relative to today's satellites, ATS-I was compact, but marked the beginning of a long series of geosynchronous satellites to come.

Shortly after receiving the first images, Suomi produced a rough, yet functional, video of Earth and its cloud formations over the Pacific Ocean in January 1967. Suomi took his short film to a conference in Washington D.C. the following week where he received a standing ovation from the audience of scientists and administrators.

The video quality would quickly improve with the help of Suomi's graduate student Fritz Hasler, whose interest in engineering and filmmaking led him to develop an efficient method for compiling all of the ATS-I scans, aligning them into a motion picture. The team would later produce several videos with footage from ATS-I. Hasler described the communities' initial reception of the first videos to have quickly gone from a sense of curiosity and intrigue to a rapid high-demand for more of these kinds of videos with improved detail.

Prior to the launch of ATS-I, the world had seen only snippets of Earth's surface, with the first in 1946 coming from cameras strapped to WWII V2 rockets. These cameras were only able to capture images of the clouds and parts of the Earth's surface.  It wouldn't be until 1966, when NASA's Lunar Orbiter 1 took the first photo of Earth from the Moon as it surveyed its surface for potential landing spots for the upcoming Apollo 8 mission. The Lunar Orbiter captured these images just months before ATS-I would send back its motion pictures.

Less than a year after ATS' first launch, ATS-III went into orbit carrying a newly designed camera made by Suomi and Parent, this time located over the Atlantic Ocean and South America, viewing parts of North America and Africa. In

November 1967, ATS-III sent back the first color images of Earth, which were similarly compiled into movies.

ATS-I set in motion a series of new geosynchronous satellites to be used for both communications and meteorology. Beyond their immediate scientific uses, the captivating images would become commonplace in nearly every media, from textbooks to posters, to film, screen savers, and postcards. Geosynchronous satellites would continue to send data which would dramatically improve our ability to forecast weather events.

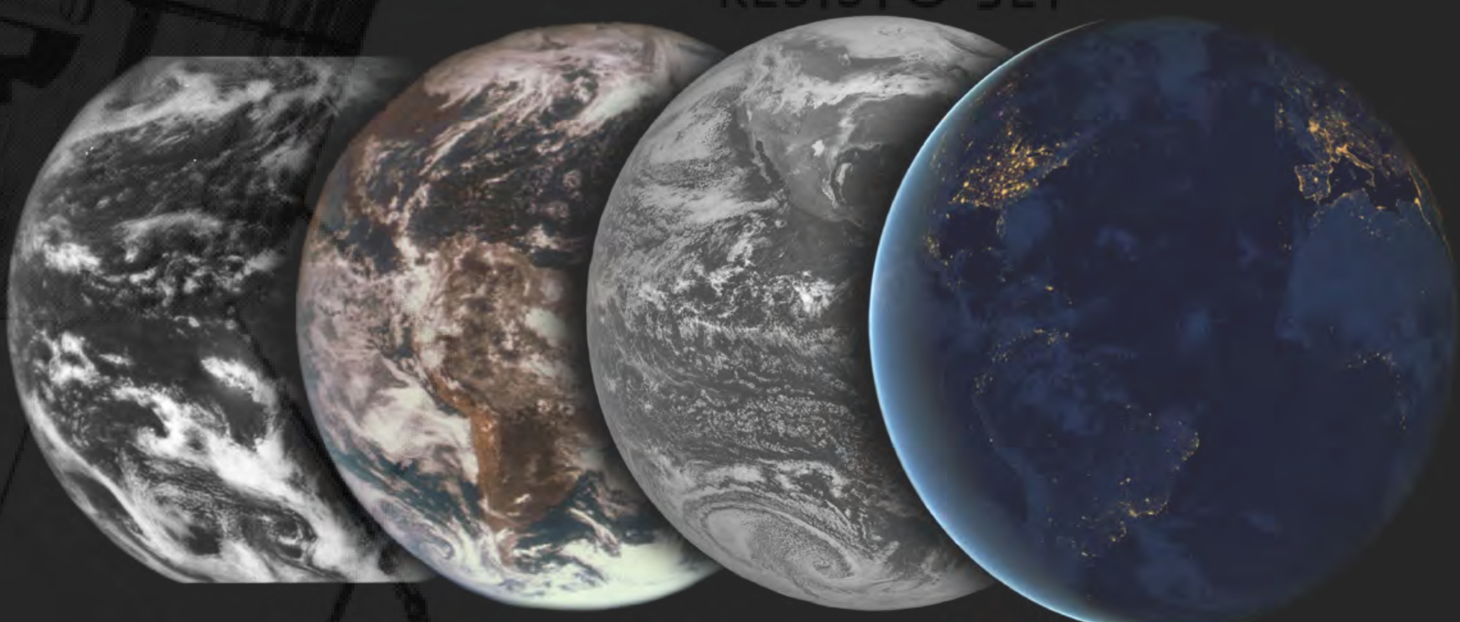
UW-Madison, the birthplace of satellite meteorology, is so-known because of Suomi's vision to use satellites as a platform for viewing and learning about Earth and its atmosphere. His legacy, and that of ATS-I, can be seen today through the succession of satellites which followed, continuously advancing our understanding of the Earth.

See the videos from ATS-I and ATS-III by going to:
ssec.wisc.edu/news/articles/9433

**| Eric Verbeten**

## 50 years of Earth:

**Full disk images taken over the past 50 years from geostrationary and polar orbiting satellites, from left to right: ATS-I (1966), ATS-III (1967), GOES-15 (2010), Suomi NPP (2012).**



Space Science and Engineering Center
Cooperative Institute for Meteorological Satellite Studies
University of Wisconsin-Madison
1225 W. Dayton Street
Madison WI 53706
ssec.wisc.edu/through-the-atmos