JPSS

SCIENCE SEMINAR ANNUAL DIGEST 2017

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ANNUAL DIGEST CONTRIBUTIONS

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FROM THE SENIOR PROGRAM SCIENTIST

The JPSS-1 spacecraft, now NOAA-20, successfully launched on November 18th. The JPSS Program and the nation are looking forward to seeing the capabilities of NOAAs newest polar-orbiting satellite rapidly transition into operations. NOAA-20 joins the NOAA/NASA Suomi National Polar-orbiting Partnership (Suomi NPP) to provide even more data and products to feed weather forecast models around the world. This 2017 Joint Polar Satellite System (JPSS) Science Seminar Digest continues the tradition of presenting articles that document the value of JPSS data and products to a wide variety of environmental endeavors. Every month one of our stakeholders provides a seminar showing how they use JPSS data in their projects. We hope that these articles will spur further dialog on new applications that leverage JPSS capabilities.

Considered the backbone of the global observing system, data from polar-orbiting satellites are critical for forecasting weather three to seven days in advance and monitoring the global environment. JPSS provides critical environmental observations to support NOAA's overarching mission to "understand and predict changes in weather, climate, oceans, and coasts".

Within JPSS, Program Science provides guidance for the science quality of the data and products derived from the instruments aboard the spacecraft. The Proving Ground and Risk Reduction (PGRR) Program—managed by Program Science—supports user demonstration by stimulating interactions between technical experts from the JPSS Program, university partners, and key user stakeholders. Established in 2012, the PGRR program aims to test, learn and share ways to strengthen the use of data and products from the JPSS. It is through the PGRR that Program Science receives user feedback on the impact of Suomi NPP/JPSS data, which is helpful for identifying the improvements needed for products and applications. The information received by the PGRR is fed back to the Center for Satellite and Applications (STAR) calibration and validation (Cal/Val) teams who then use it to build and/or improve the products. This feedback provides a valuable loop between the product user and developer or researcher. The entire Program Science efforts would not be possible without the outstanding interactions between the JPSS Program, STAR, the NOAA cooperative institutes, government and international partners, government contractors, and of course the user community.

In addition to the launch of NOAA-20, 2017 will be remembered for several other key milestones. The River Ice and Flooding Initiative responded to requests from the Federal Emergency Management Agency (FEMA) to provide flood products to assist in flood events following Hurricanes Harvey and Irma which impacted the Southeast states. JPSS also delivered analyses and products from the Visible Infrared Imaging Radiometer Suite (VIIRS) for Puerto Rico and the surrounding islands. These analyses and products showed huge decreases in nighttime light levels due to the power outages that followed Hurricane Maria. JPSS imagery and flood products also showed some remarkable events in California, including the end of the five-year record breaking drought that followed unusual snowfall amounts and spring rains tied to atmospheric rivers.

Some additional tangible benefits derived from our PGRR Initiatives this year included:

The Fire and Smoke Initiative. This year yielded a busy and highly active fire season. According to the National Interagency Coordination Center, which oversees state and federal responses, 54,000 fires have consumed just short of nine million acres—an area nearly the size of New Jersey and Connecticut combined. The loss of life and structures seemed to be on almost every nightly news report. An important dimension

under this initiative is the assimilation of VIIRS Fire Radiative Power into the High-Resolution Rapid Response (HRRR) smoke model, which could not have come at a better time. Forecasters from NOAA's National Weather Service (NWS) were able to evaluate the HRRR smoke models and provided invaluable feedback to the HRRR developers who used it to tailor the algorithms to maximum advantage.

The River Ice and Flooding Initiative. The VIIRS flood product has been under development since 2013. It has shown its value in big and small floods around the globe. The product's success led to the development of a similar one using data from the Geostationary Operational Environmental Satellite-16 (GOES-16) that can be blended with the VIIRS product to ensure maximum coverage and timeliness. This capability was critical as the nation faced the twin catastrophes of Hurricanes Harvey and Irma. Hurricane Harvey was the costliest tropical cyclone on record, inflicting nearly $200 billion in damage, primarily from widespread flooding in Texas, Louisiana, and Mississippi. Hurricane Irma was the most intense Atlantic hurricane to strike the United States since Katrina in 2005. Irma brought record floods to Jacksonville Florida, and flooded parts of coastal Georgia and South Carolina. The VIIRS flood products were a vital part of the FEMA daily planning calls for weeks as decisionmakers tracked flood water extent and the timing of the waters' recession.

NUCAPS Sounding Initiative. Satellite-based vertical temperature and moisture soundings have long proven to be a valuable asset to forecasters evaluating pre-storm convective environments. Annual evaluations by NWS forecasters of this product at the Hazardous Weather Testbed (HWT) in Norman Oklahoma continued in 2017. Feedback from previous years resulted in changes in the NOAA Unique Combined Processing System (NUCAPS) algorithms to allow for automated modifications of the soundings at lower levels and horizontal cross sections of the data across wide geographic areas. The Initiative Team has also successfully brought NUCAPS Soundings from the European satellites into the HWT. These soundings help cover the early morning in situ sounding gap. With these satellite soundings, forecasters will have access to vertical temperature and moisture data throughout the day.

The Arctic Initiative. Created to provide a forum for JPSS data and product providers, developers, and users, to determine how JPSS products can best be used to support Arctic missions. The initiative leverages existing Arctic working groups to identify key data and how it can be most effectively accessed and visualized. It also increases the use of JPSS/Suomi NPP products for Arctic applications and explores experimental products as necessary to meet the needs users in the Arctic. The initiative team is gearing up for the first ever arctic product demonstration of JPSS operational and experimental products in the Spring of 2018.

The JPSS Program released a new Call for Proposals to encourage additional work by its industry, academic, and research partners on the use of JPSS in a wide range of areas.

I would like to thank each of the contributors and editors, and numerous partners for their dedicated efforts to provide you this digest. I would also like to give special thanks to my Program Science staff, JPSS Communications, and the NOAA JPSS Program Office, for their ongoing support in the development of this digest; and to the authors and editors. It is through our collective efforts that we can present this information to you. I hope you enjoy reading this digest and that you find it to be a worthwhile resource.

Mitch Goldberg
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U.S. Department of Commerce

FROM THE PROGRAM DIRECTOR

November 18, 2017 was a beautiful night at Vandenberg Air Force Base located just off the Pacific Coast some 150 miles northwest of Los Angeles. Everyone was ready for the launch of the Joint Polar Satellite System-1 (JPSS-1). It was a great thrill to see it lift off in a blast of fire and smoke, to join the Suomi-NPP spacecraft in orbit. It was just less than a year ago that I was at Cape Canaveral watching the Geostationary Operational Environmental Satellite-16 (GOES-16) launch into space. As the Program Director for GOES-R and then JPSS programs I had unique insights into the challenges of ensuring the operational transition of our nation's most significant technological and scientific satellite advances in decades. While I am honored to help bring JPSS-1 across the finish line to a successful launch, the person that drove this program down the length of the field was Harry Cikanek. Harry served for just over five years as the JPSS Program Director and his outstanding leadership and technical expertise stabilized and sharpened the focus of this critical program. He remains a vital resource and a stalwart partner to the JPSS Program as the Director of the NOAA Center for Satellite Applications and Research (STAR).

Even as we put JPSS-1, now NOAA-20, through its post-launch paces on its way to operations we are looking forward to JPSS-2, JPSS-3, and JPSS-4. We are taking actions to maintain a robust polar-satellite constellation not only for our own national interests, but to fulfill our commitments to our international partners. All of the instruments for JPSS-2 through JPSS-4 are under contract. The JPSS-2,-3,-4 Spacecraft Critical Design Review (CDR) was held in late October 2017. The CDR was passed by the review team with no liens. One change in the program is that the CERES instrument is being replaced with the NASA-procured Radiation Budget Instrument (RBI) on JPSS-2 and beyond. The RBI completed its CDR in September 2017. The VIIRS for JPSS-2 was delivered in December 2017 and the VIIRS components and subsystems for JPSS-3 and -4 are progressing according to schedule. The hardware for the Cross-track Infrared Sounder (CrIS) is progressing with optical mechanical assembly vibration completed. The hardware for the Advanced Technology Microwave Sounder (ATMS) is progressing and new IF amplifiers are being developed. Everything is on track for us to maintain the 31 July 31, 2021 launch readiness date for JPSS-2.

As the JPSS-1 instruments continue their checkout and the data begins to flow, we continue to leverage the data and products from Suomi-NPP. Suomi-NPP is a cornerstone of NOAA's integrated observing system, providing microwave and infrared radiances that help make up part of the 85% of the data assimilated into the global forecast models. The JPSS-1 spacecraft will be placed in orbit 50 minutes (half-an-orbit) in front of the Suomi-NPP spacecraft. Once JPSS-1 has completed its post-launch calibration-validation period it will become the primary NOAA spacecraft in the afternoon orbit. While Suomi-NPP continues to operate the nation will enjoy a wealth of polar data and imagery supporting near-term and long-term forecast decisions. These 50 minutes will be especially critical providing more frequent satellite-based temperature and moisture soundings, and day-night band (DNB) imagery that have proven so valuable in pre-convective environments and in tracking changes in tropical cyclone movement and intensity. The addition of McMurdo Antarctica to the JPSS-1 communications architecture will decrease the latency for data and products ensuring their availability to forecasters to assist them in handling rapidly changing weather events.

Suomi-NPP capabilities were invaluable to the Federal Emergency Management Agency (FEMA) and other first responders as they dealt with the disasters of Hurricanes Harvey and Maria. The Suomi-NPP VIIRS flood product was able to define the areal extent of the flood waters of Hurricane Harvey before it was safe to send personnel in for ground-based observations. The DNB was able to capture daily changes in light levels on Puerto Rico and the surrounding islands even while most roads and runways were blocked with downed trees and debris. FEMA personnel in the impacted areas expressed their appreciation for these products and will be expecting JPSS support for future environmental disasters.

Our Proving Ground and Risk Reduction Program (PGRR) remains robust. We are now in our third PGRR Call-for-Proposals to help identify initiatives that will help our users optimize the operational use of current capabilities and determine leading edge research efforts to evaluate possible new applications. Since 2012, teams of developers, the academic community, and algorithm experts have joined with our JPSS staff to exploit Suomi-NPP capabilities to help our users' better meet their mission requirements. Combining these efforts into various initiatives has allowed these experts to work closely together to identify key activities and timelines to bring basic concepts to reality. Our PGRR work is looking for ways to bring geostationary capabilities that when blended with those from the JPSS polar-orbiting system would allow users to leverage the strengths of both systems. Satellite flood products and smoke forecasting are key examples of bringing these satellite data and products together for the greater good.

The articles in this digest capture examples of how our users are putting JPSS capabilities to use. We have found that this type of user advocacy provide a compelling case defining how critical satellite data is to every NOAA mission. For every example provided here, there are many more that have yet to be documented. I anticipate that the 2017 Science Digest will encourage continued dialog among developers, users and the JPSS Program to determine additional actions that can be taken to lead to even greater success.

Greg Mandt
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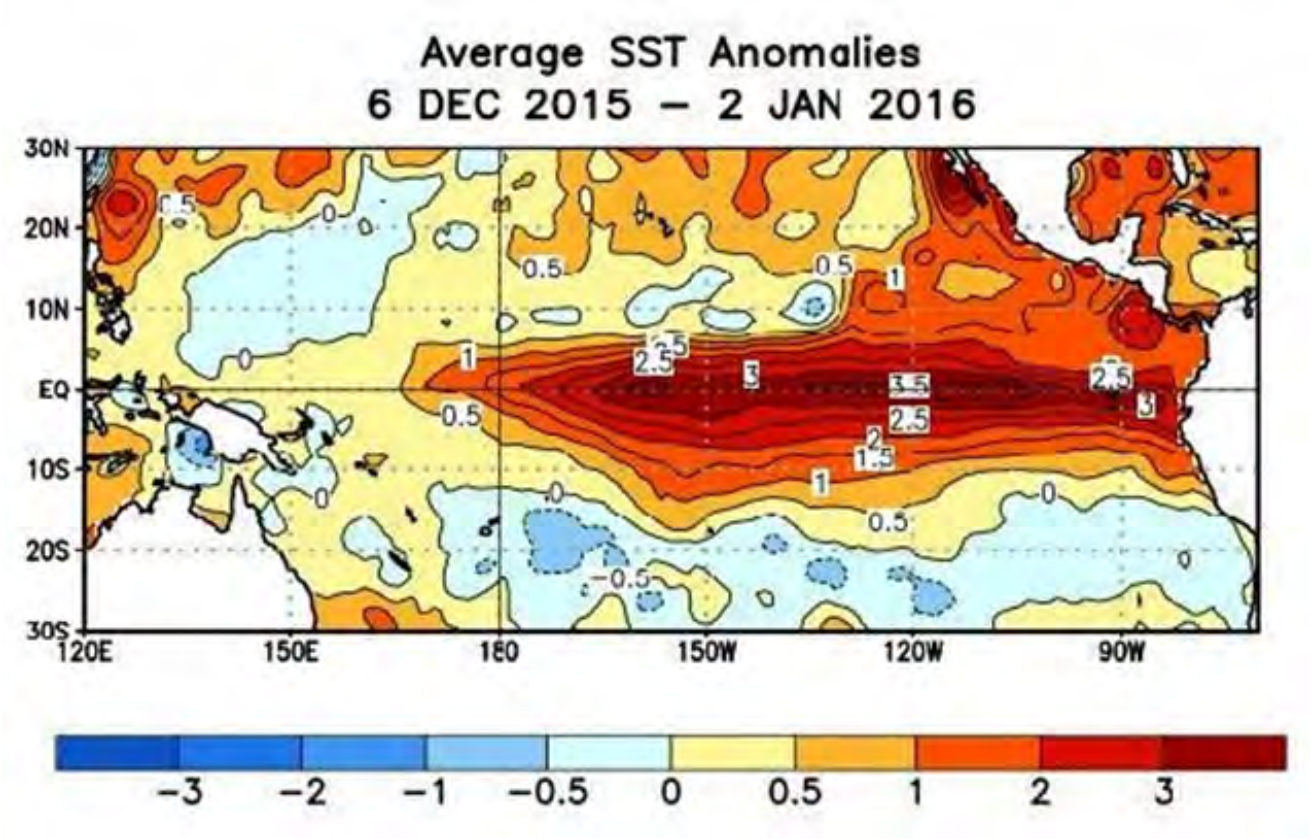
FEATURED ARTICLES

THE ROLE OF SUOMI-NPP IN THE EL NIÑO RAPID RESPONSE FIELD CAMPAIGN

The information in this article is based, in part, on the October 24, 2016 JPSS science seminar presented by Chris Barnet, Science and Technology Corporation.

Additional contributors: Ryan Spackman (STC at NOAA/ESRL), Brad Pierce (STAR), Antonia Gambacorta (STC), Mitch Goldberg (JPSS), Nadia Smith (STC), Jonathan Smith (STC), Jim Davies (SSEC) Tom King (STAR), Bill Sjoberg (JPSS), and many more.

Summer 2015 NOAA Climate Forecasts—Strong El Niño very likely in winter 2015–2016, with potentially large U.S. and global impacts.

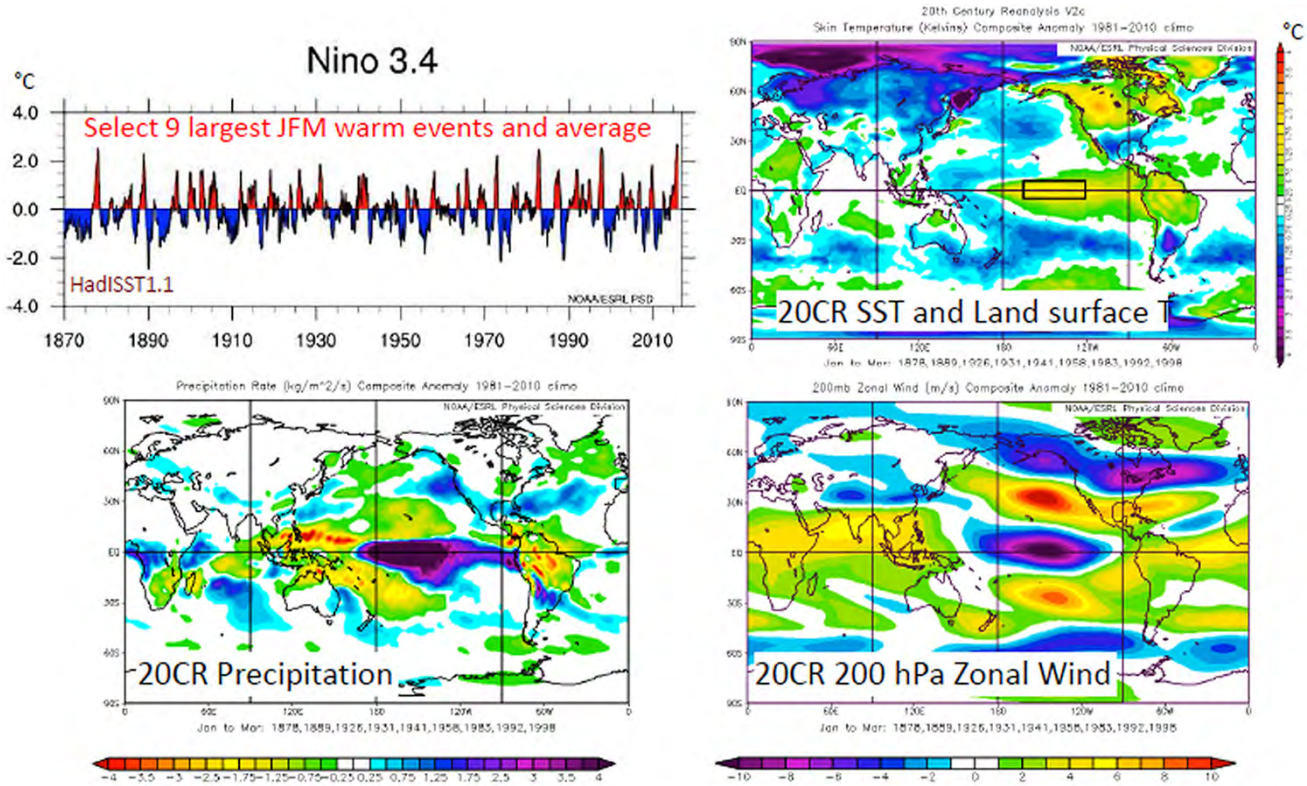


SST Departures (°C) in the Tropical Pacific during the last four weeks. NOAA, ENSO: Recent Evolution, Current Status and Predictions. Accessed from: https://www.ncdc.noaa.gov/monitoring-content/sotc/drought/2015/12/noaa-nws-cpc-160104-enso_evolution-status-fcsts-web.pdf

OPPORTUNITY OF A LIFETIME

The warm phase of the El Niño Southern Oscillation (ENSO) or El Niño is associated with a warm ocean current in the tropical Pacific Ocean. It is one of the most important environmental phenomena on Earth because it alters the global atmospheric circulation, and distorts weather patterns across the globe[1]. The extensive impacts of the tropical Pacific ocean-atmosphere system on global weather and climate patterns during El Niño events are well documented. This region, known to have the largest changes in sea surface temperature (SST) due to the ENSO cycle, is considered the cradle of the El Niño, and therefore represents the ideal location to observe and document the phenomenon. It is however, a remote and data-sparse region. Thus like many remote regions it faces the challenges associated with in situ data collection including accessibility, and a general lack of in situ infrastructure.

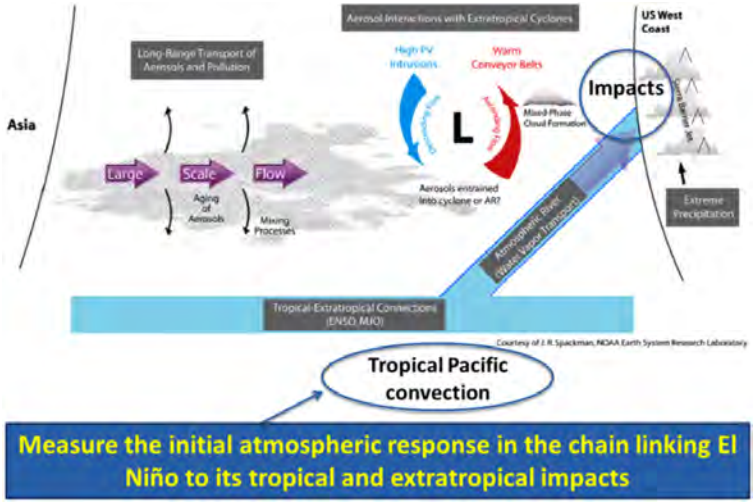
The Oceanic Niño Index (ONI) is the National Oceanic and Atmospheric Administration's (NOAA) primary[2] indicator for monitoring the phenomenon. According to NOAA, an index of 0.5°C or higher indicates that the east-central tropical Pacific is significantly warmer than usual—the classic hallmark of El Niño conditions. In the summer of 2015 forecast models signaled an unusually large anomaly suggesting the likelihood of a relatively rare strong El Niño during the winter of 2015–16. Consistent with model predictions, oceanic and atmospheric conditions in the equatorial Pacific indicated a significant event comparable to historical large events such as the 1877–78, 1982–83, and the 1997–98.



Maps from the NOAA-CIRES 20th Century Reanalysis version 2c (Compo et al. 2011, go.usa.gov/XTd). ACRE, NOAA's NCEI, and 65 organizations are key partners providing historical observations to 20CR.

This was a rare scientific opportunity for scientists from the Joint Polar Satellite System (JPSS) along with their colleagues from NOAA's Earth System Research Laboratory/Physical Sciences Division (ESRL/PSD) to study an extreme climate event while it was occurring. But, they had a dilemma at hand. Could they mount a significant field campaign in a relatively short duration of time? They also faced the additional constraint of working in an isolated region. Conventional wisdom on El Niño stipulated that there simply wasn't enough time. But, if accomplished, this campaign, which planned to use targeted observations from the tropical Pacific Ocean, would pave the way for a historical record that would help advance studies and understanding of El Niño as well as improve predictions of future events.

Challenging the conventional wisdom, and leveraging their extensive field campaign experience, scientists at NOAA/OAR/ESRL/PSD initiated an ambitious field campaign, dubbed the El Niño Rapid Response (ENRR).



Following a late December/early January authorization to operate, and a fast approaching El Niño event, the ENRR team resorted to an on-the-fly ad hoc plan, which led to a swift campaign launch on January 19 all the way through March 10, 2016 (www.esrl.noaa.gov/psd/enso/rapid_response/). The goal of this campaign was to establish the initial tropical atmospheric response linking El Niño to its global impacts. The campaign drew together coordinated observations from various sources including

radiosonde launches from the NOAA Gulfstream IV (G-IV) aircraft, Kiritimati (Christmas) Island, and the Ronald H. Brown research vessel. The G-IV was deployed from Honolulu International Airport in Hawaii and took measurements of the moisture transport across the central and eastern tropical Pacific. It supported twenty-two 8-hour flights and deployed roughly 25–35 dropsondes per flight. The Global Hawk (GH) was able to cover three 24-hour flights on February 15, 16 and 21 which aimed to evaluate transport from the extratropical Pacific on the US West Coast. The GH flights coordinated by the NOAA Sensing Hazards with Operational Unmanned Technology (SHOUT) program and provided 89 dropsondes from the three flights. The Scripps Institution of Oceanography organized complementary flights targeting atmospheric rivers over the North Pacific. The flights, made on February 15, 18 and 21 from Air Force C-130 aircrafts, were deployed from both Hawaii and California and provided 285 dropsondes at the western and eastern portions of atmospheric rivers. Surveys from the NOAA R.H. Brown vessel from February 16 to March 18 assisted the campaign with information on atmospheric and oceanic conditions in eastern tropical Pacific (8S to 8N, at 140W and 125W). They deployed ~6 rawinsondes per day. Finally, two rawinsondes were launched every day from a fixed point in the tropics (Kiritimati Island, 1.9N, 157W). In total, the campaign deployed over 1200 dropsondes and rawinsondes.

JPSS scientists deployed real time soundings from the Cross-track Infrared Sounder (CrIS), and the Advanced Technology Microwave Sounder (ATMS) instruments aboard the Suomi NPP satellite. The real time data, which was available via direct broadcast assets from Corvallis Oregon and Honolulu Hawaii, provided guidance for aircraft flights while the JPSS soundings helped to characterize the thermodynamic field in regions that could not be measured with in-situ observations. Leveraging off efforts from previous field campaigns, JPSS scientists employed the science code from the NOAA-Unique Combined Atmospheric Processing System (NUCAPS) (Gambacorta et al., 2013) to provide additional near real time context for the in-situ measurements. NUCAPS relies on a technique called 'cloud clearing' to remove the effect of clouds so that atmospheric information can be obtained all the way to the surface, the region that is most relevant for most weather applications, also in presence of clouds. In addition, the data collected from the campaign provided opportunities for unique datasets for validating the NUCAPS satellite products.

Scientists at NOAA/OAR/ESRL/PSD will utilize the large volume of data collected during the campaign, including the NPP NUCAPS products, to study the interaction of moisture originating in the central equatorial Pacific with the mid latitudes. As in, they would have to take a number of measurements in the tropical pacific convective region, i.e., south of Hawaii near the equator, map this into how it was transported by weather systems into the mid latitudes and observe the impacts in regions across the nation.

USING SUOMI NPP DATA TO DEFY DISTANCE AND CONVENTIONAL WISDOM

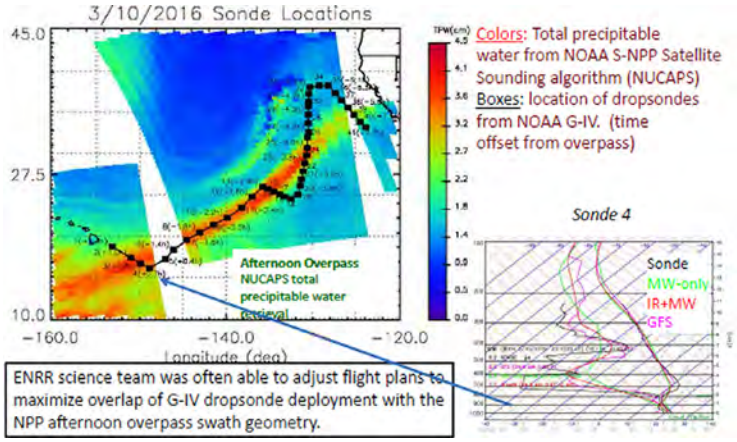
With vantage points anywhere from hundreds to thousands of miles above the Earth's surface, Earth observation satellites can easily capture data over relatively wide areas, including the far reaches of the central Pacific Ocean. Atmospheric field campaigns complement the satellite observations, which provide information and insight into weather, climate, and other aspects of Earth's global environment. They typically employ some combination of measurements from various sources including aircraft- and/or ship-based, satellite-, balloon- and ground-based, and advanced analytical methods. Aircraft platforms are considered to be one of the most effective methods of data collection in field campaigns. They possess the high flexibility needed to achieve close temporal and spatial coincidence with satellite overpasses almost everywhere on the globe and under most weather conditions. Nevertheless, weather conditions, and especially those that are severe in nature, can impose substantial challenges to operations on the ground, in the air, or over water. Thus, accurate and timely situational information, specifically weather data, is essential to decision support

Researchers at the NOAA ESRL Physical Sciences Division in Boulder, Colorado during a daily forecast briefing for the ENRR Campaign. (Credit: Barb DeLuisi). https://www.flickr.com/photos/noaa_esrl/24871539871/in/album-72157661879457833/

systems across a broad range of service areas including aviation. Real-time weather data that delivers knowledge of weather processes can help aircraft crews recognize and avoid hazardous flight conditions, including severe weather. Examples include accurate and near real-time information of the intensity or location of convection or features that reveal atmospheric instability. Given the remoteness of the central Pacific Ocean, the ENRR flight crews would need as much awareness of the domain as possible.

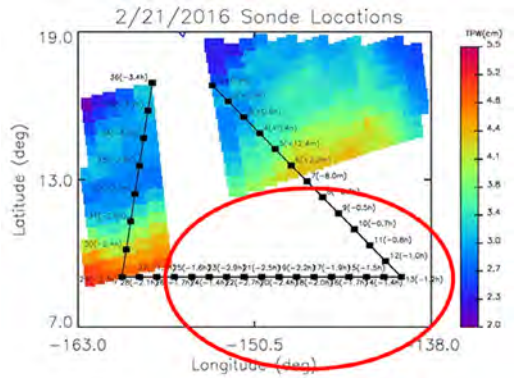
The JPSS Proving Ground Sounding Initiative provided an opportunity to participate in the ENRR field campaign. The NUCAPS science team, under direction of Dr. Chris Barnet, prepared morning and afternoon overpasses from Suomi NPP Microwave-only and combined Infrared and Microwave sounding retrievals and compared them with NCEP's Global Forecast System (GFS) 3 to 9 hour forecasts. Data from the Suomi NPP morning overpass at 1:30 am (~12:30 UT = 2:30 HST = 7:30 EST) was manually processed to generate graphics called "skew-T" plots. The skew-T plots were made available to the forecasters in Hawaii to utilize in the daily forecast briefings. The normal NPP processing typically provides soundings within ~2 hours of acquisition on the satellite. Direct broadcast, can provide the same data within minutes of acquisition by the satellite for a region near the receiving antenna. Data from the 1:30 pm overpass (~0:30 UT = 14:30 HST = 19:30 EST) was processed from the Honolulu and the Corvallis direct broadcast stations (the former only when GH for C-130's were airborne). Skew-T plots were delivered to the crew aboard the aircraft in near real time. This data provided the crew an in-flight snapshot of what to expect along the planned dropsonde locations.

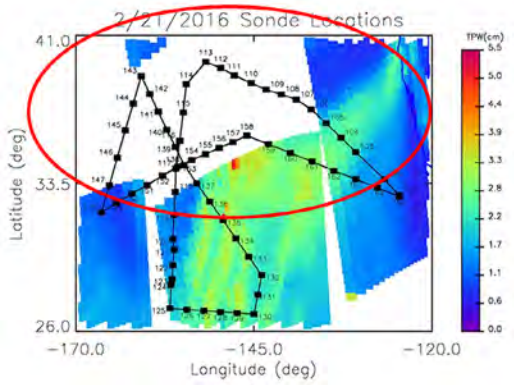
Roughly 24 hours later the archived Suomi-NPP data was re-processed to create a synopsis for the entire Pacific domain. Again, the NUCAPS science code was used to provide the campaign's science team additional diagnostic information about the NUCAPS soundings (e.g. averaging kernels). This provided a quick-look comparison with data from other sources including dropsondes, rawinsondes, the NCEP/GFS, and satellite soundings. These retrievals were also valuable for the following day's flight planning discussion.



LIMITATIONS IN REAL TIME DATA COLLECTION

Impediments to data collection in remote environments include inaccessibility as well as the scarcity of in situ infrastructure. Direct broadcast infrastructure has made it possible to acquire real time data in these environments. This infrastructure is important as it avails high resolution weather data that increases situational awareness, and enables operators to make informed decisions based on their surrounding situation. While the direct broadcast platform has helped reduce data latency, a significant disadvantage is the limited window of data antennas can see. On most days of the campaign, the Hawaii antenna did not "see" far enough South to be useful for flight planning. The illustration above shows gaps in data (circled), because the antenna in Hawaii could not see as far south as the CrIS instrument. Therefore all the data captured beyond this point, which could have been useful, was rejected during the calibration process. Similarly, on most days the Corvallis antenna didn't "see" far enough West for Global Hawk coverage (right). As post processing applications had access to full coverage data, the ENRR science analysis was not impacted by these gaps. With JPSS 1 this issue will be mitigated with two ground stations, ensuring much lower data latencies for future real time applications.





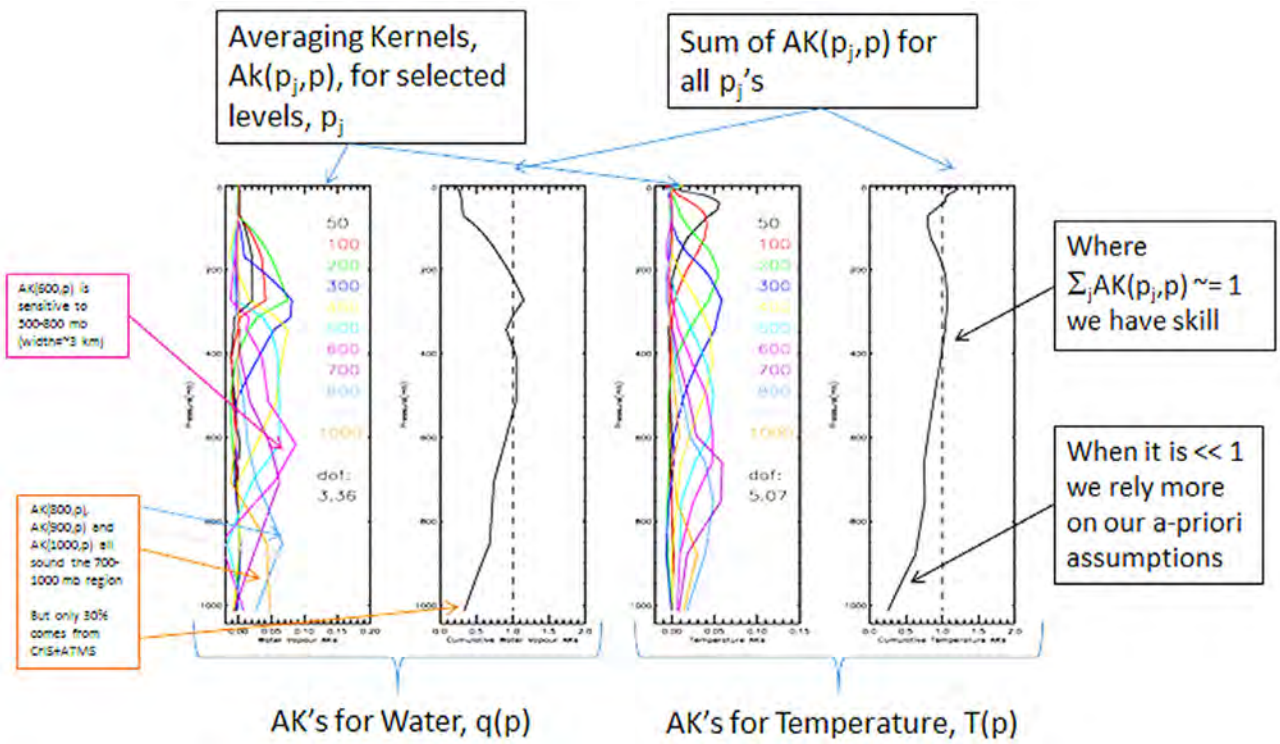
POST FLIGHT CAMPAIGN RESEARCH: THE EL NIÑO RAPID RESPONSE AND RESEARCH PHASE ("ENR^3")

Upon successful conclusion of the campaign, a new phase of the mission has started: the El Niño Rapid Response and Research (ENR^3) campaign. This post flight phase of the mission is focused on the full analysis of the data collected during the flight campaign. Previous campaigns such as CalWater 2014 and 2015, have demonstrated that a correct knowledge of the vertical structure present in the atmosphere is central to the correct forecast of water vapor transport and landfall. For this reason, a large effort of this post flight campaign phase is being devoted towards computing the average magnitude and understanding the sources of difference found between in situ measurements and the GFS forecast. NUCAPS data will complement this research. Correlative differences between NUCAPS and the GFS forecast at the same location of the in situ measurements will provide additional context to the analysis. Furthermore, the average difference between NUCAPS and the GFS will be extended to the entire 3-month period of the campaign, including missing flight days. This information will be used to assess whether the ensemble of in situ measurements collected during the flight campaign is capable of representing the full variability occurred during the 2015–2016 El Niño anomaly. This application is an innovative example of the synergistic use of satellite data in the context of weather and climate applications.

Another important aspect of the post flight campaign phase is the development of an innovative validation methodology of NUCAPS soundings, computed via averaging kernels. The NUCAPS retrieval code uses a subset of few hundreds of CrIS and all of the 22 ATMS channels to solve for temperature and moisture profiles. A physical retrieval, such as NUCAPS must compute satellite radiances as accurately as possible. In the case of NUCAPS, this is done on a 100 pressure level grid. The native retrieval product is output on these

100 levels; however, the retrieved profiles are typically smoother than that. The physics behind atmospheric sounding limits soundings to a broad vertical region of the atmosphere, what is known as the vertical averaging kernel[3]. NUCAPS soundings are smoother in the vertical domain than rawinsonde or model-derived soundings and have vertically correlated errors. Proper use of soundings requires knowledge of the error covariance matrix or, equivalently, the averaging kernel to properly describe the retrieval.

Application of averaging kernels enables understanding how smooth the satellite data really is. This information is critical to a forecast because it enables separating the physical vertical structures found in a retrieval profile (such as thermal inversions or dry layers aloft) from retrieval artifacts. The large ensemble of in situ data collected during the ENRR field campaign is now being used to develop this methodology and perform the first demonstration of the value of NUCAPS averaging kernels. Lessons learned from this experiment will be key for future training of weather forecasters on the proper use of NUCAPS soundings under all different types of geophysical regimes.



Example of Averaging Kernels (AK) for an ENRR scene.

LESSONS LEARNED

Understanding the vertical structure of water vapor under fast developing regimes is crucial to forecast integrated vapor transport correctly. The 2014 CalWater campaign suggested NUCAPS retrievals from CrIS and ATMS could improve land falling forecasts. In CalWater 2015 the JPSS science team demonstrated the capability to provide real time direct broadcast NUCAPS retrievals to a field campaign. During the ENRR 2016 campaign the NUCAPS science team actively participated to flight planning decisions and post mission analysis.

POTENTIAL AREAS TO EXPLOIT NUCAPS

In the summer of 2018 NOAA will take part in a multi-agency field campaign dubbed the Fire Influence on Regional and Global Environments Experiment (FIREX). The demonstrated capability to use NUCAPS

temperature and water vapor soundings for flight planning and post mission analysis will be applicable to the FIREX campaign, whose focus will be on atmospheric trace gas composition. By 2018, NUCAPS will be operationally processed in CrIS full resolution mode. This will enable enhanced trace gas retrieval with respect to the current lower spectral sampling. NUCAPS full spectral resolution trace gases from CrIS are expected to be comparable to existing NUCAPS trace gas retrievals from existing hyper spectral sounders like AIRS and IASI. The combination of a consistent NUCAPS trace gas product from multiple instruments and in real time will enable users with improved context for fire detection and trajectory model validation or initialization.

SUMMARY

The central Pacific—a remote data sparse region—has a significant impact on downstream weather both in the USA and globally. With a goal to establish the initial tropical atmospheric response linking El Niño to its global impacts, the ENRR provided a unique data set of high resolution observations during a rare El Niño event. It also served up an opportunity to illustrate the value of Suomi-NPP satellite observations and to validate and improve upon the NUCAPS applications.

Footnotes

[1]Michelle L'Heureux, May 5, 2014. "What is the El Niño—Southern Oscillation (ENSO) in a nutshell?" https://www.climate.gov/news-features/blogs/enso/what-el-ni%C3%B1o%E2%80%93southern-oscillation-enso-nutshell

[2]https://www.climate.gov/news-features/understanding-climate/climate-variability-oceanic-ni%C3%B1o-index

[3]This material was presented in the 2015 JPSS Science Seminar Annual Digest article titled "The Innovative Use of JPSS Satellite-Based Soundings for Weather Applications". http://www.jpss.noaa.gov/assets/pdfs/science_publications/2015_science_seminar_digest.pdf

References

Craig, C. (2012). Improving flight condition situational awareness through Human Centered Design. Work: A Journal of Prevention, Assessment and Rehabilitation, 41, 4523–4531. Available online at: http://content.iospress.com/download/work/wor0031?id=work%2Fwor0031

Dahlman, L., Climate Variability: Oceanic Niño Index, 2009, Available at: https://www.climate.gov/news-features/understanding-climate/climate-variability-oceanic-ni%C3%B1o-index

Gambacorta, A., C. Barnet, W. Wolf, M. Goldberg, T. King, N. Nalli, E. Maddy, X. Xiong, and M. Divakarla (2012), The NOAA Unique CrIS/ATMS Processing System (NU- CAPS): First light retrieval results, in Proceedings of ITSC-XVIII, International TOVS Working Group (ITWG), Toulouse, France.

Gambacorta, A., C. Barnet, and M. Goldberg (2015), Status of the NOAA Unique CrIS/ATMS Processing System (NUCAPS): Algorithm development and lessons learned from recent field campaigns, in Proceedings of ITSC-20, International TOVS Working Group (ITWG), Lake Geneva, Wisconsin, USA.

Gambacorta et al., The NOAA Unique CrIS/ATMS Processing System Algorithm Theoretical Basis Documentation, 2013, http://www.ospo.noaa.gov/Products/atmosphere/soundings/nucaps/docs/NUCAPS_ATBD_20130821.pdf

Gambacorta et al., An all-weather, global and physically based inversion algorithm for hyper spectral microwave and infrared sounders: the NOAA Unique Combined Atmospheric Processing System (NUCAPS), in preparation, BAMS, 2017.

L'Heureux, M., May 5, 2014. "What is the El Niño—Southern Oscillation (ENSO) in a nutshell?" https://www.climate.gov/news-features/blogs/enso/what-el-ni%C3%B1o%E2%80%93southern-oscillation-enso-nutshell

McPhaden, M.J., Delcroix, T., Hanawa, K., Kuroda, Y., Meyers, G., Picaut, J. & Swenson, M. (2001). The El Niño-Southern Oscillation (ENSO) Observing System. Observing the Ocean in the 21st Century (eds C.J. Koblinsky & N.R. Smith), pp. 231–246. Australian Bureau of Meteorology, Melbourne, Australia. Available online at: http://www.pmel.noaa.gov/tao/proj_over/pubs/OceanObs99.pdf

NOAA National Centers for Environmental Information, State of the Climate: Synoptic Discussion for December 2015, published online January 2016, retrieved on February 14, 2017 from http://www.ncdc.noaa.gov/sotc/synoptic/201512.

NOAA/JPSS., "NOAA Celebrates Five-Year Anniversary of Suomi NPP Launch," Oct. 28, 2016, URL: http://www.jpss.noaa.gov/news.html?87

Schiermeier, Quirin. "Hunting the Godzilla El Niño". Nature 22 October. 2015: 526, 490–491. doi:10.1038/526490a

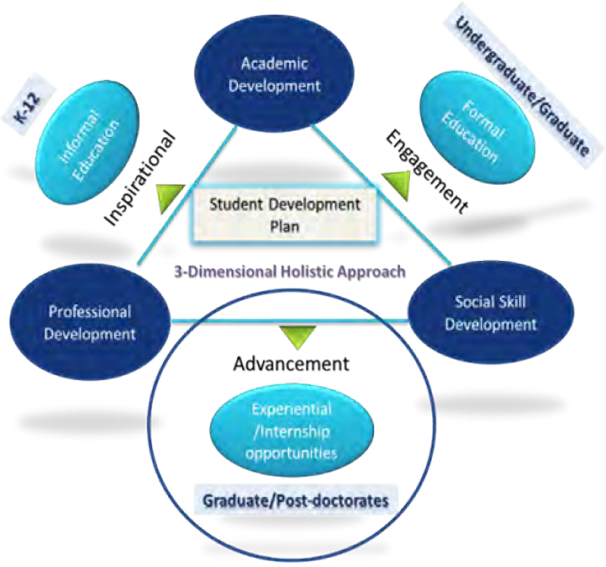
JPSS STUDENTS PROFESSIONAL AND ACADEMIC READINESS WITH KNOWLEDGE IN SATELLITES (SPARKS)

A unique research and training model for NOAA's Next Generation STEM workforce

The information in this article is based, in part, on the November 21, 2016 JPSS science seminar presented by Shakila Merchant, NOAA CREST Center, City College of New York, NY, Murty Divakarla and Mike Wilson, IMSG.

The mission of the National Oceanic and Atmospheric Administration (NOAA) is to "understand and predict changes in climate, weather, oceans, and coasts, to share that knowledge and information with others, and to conserve and manage coastal and marine ecosystems and resources." This mission, deeply rooted in science, service and stewardship has helped cultivate a workforce that is rich in science, technology, engineering, and mathematics (STEM). NOAA also has a broad portfolio of cross-cutting areas of responsibility, which are addressed through several organizations including the National Environmental Satellite, Data, and Information Service (NESDIS). For NESDIS, these cross-cutting areas of responsibility are exercised though the data, information, products, and services generated from its satellite missions. NESDIS expands its science enterprise, by partnering with NOAA Cooperative Institutes, (CIs) and NOAA Cooperative Science Centers (CSCs) to help advance NOAA mission sciences, and increase environmental literacy through the use of NOAA satellite imagery and data. NOAA CIs and CSCs are academic and non-profit research institutions that demonstrate the highest level of performance and conduct research, education and training that supports NOAA's Mission Goals and Strategic Plan. An example is the NOAA-Cooperative Science Center for Earth System Sciences and Remote Sensing Technologies (CREST) center headquartered at the City University of New York (CUNY). The center, whose goals echo the statements expressed in NOAA's strategic science and education mission plan[1], specializes in education and workshop development that advance NOAA mission science as well as promote a diverse workforce in all aspects of the environment, encouraging stewardship and increasing informed decision-making for better society and the nation. Research at CREST focuses on topics such as sensor development, satellite remote sensing, ground-based field measurements, data processing and analysis, modeling, and forecasting, mostly using Satellite Data. In addition to this is a student training component that includes seminars, summer internships with NOAA and with industrial partners, and a school-year research assistantship.

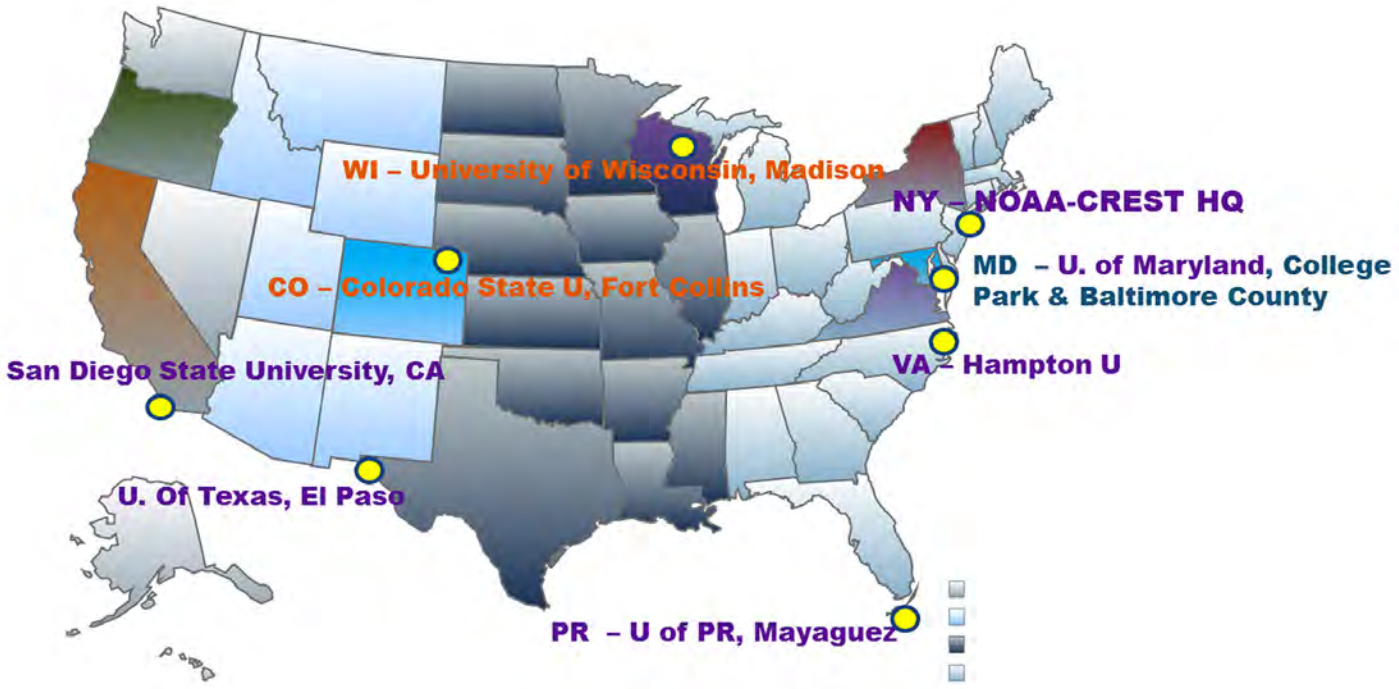
The CREST student development plan emphasizes a three dimensional holistic approach that exploits all ranges of education from K-12 through post graduate levels. Set to inspire curiosity in the early stages of education, the program includes a K-12 curriculum and outreach component that sets to engage and inspire through informal motivational instruction. This serves as a pipeline to developing core competency at the undergraduate to graduate levels, which finishes with workforce readiness and recruitment at the post graduate level.

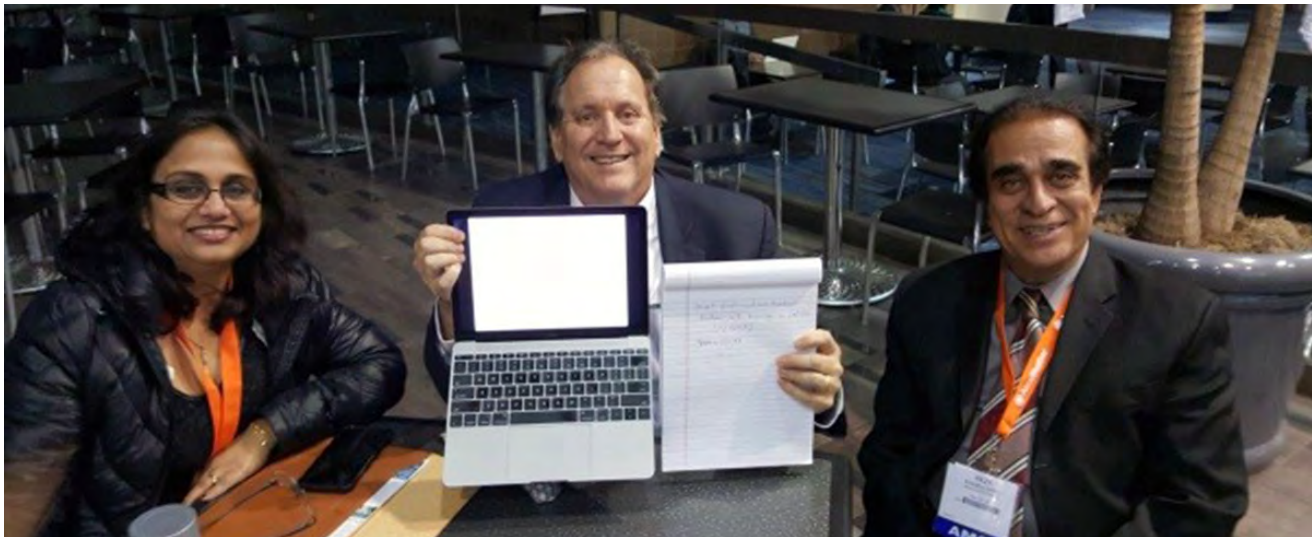


Since 2001, the CREST program, majorly funded by NOAA's Educational Partnership Program with Minority Serving Institution (EPP/MSI) has helped increase professional opportunities for groups that have been traditionally underrepresented in NOAA related science missions. The center has also been able to conduct NOAA mission aligned sciences and at the same time recruit, train and graduate more than 700 students (70 percent from groups that have been traditionally underrepresented). Upon graduation these students have moved on to explore potential career interests in various levels of government, academia and private industry. The CREST program is assigned to NOAA-NESDIS, yet, only 9 graduates (roughly one-percent) joined NOAA. While the graduation and workforce entry numbers indicate the program's success, the low recruitment at NOAA exposed a paradox. An introspective look revealed that if these numbers needed to increase, there would have to be a shift in the training paradigm, and key in this was to create "the right motivators." This sparked the fire to create an internship program, or JPSS—Students Professional and Academic Readiness with Knowledge in Satellites (SPARKS) Initiative, which would help fulfill areas of core competency in NOAA, especially from underrepresented minority populations.

CREST CONSORTIUM ACROSS THE U.S. REGION

CREST leads a consortium of universities, including Hampton University, University of Puerto Rico at Mayaguez, California State University, and University of Maryland Baltimore County. In addition to the consortium, CREST also partners with other NOAA CIs including the Cooperative Institute for Climate and Satellites (CICS) at the University of Maryland in College Park, the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin-Madison, and the Cooperative Institute for Research in the Atmosphere (CIRA) at the Colorado State University, as well as industrial partners like Raytheon, Northrop Grumman and the I.M. Systems Group (IMSG), Inc. While the primary assignment of NOAA CREST is to NESDIS, its members also work in close collaborations with other NOAA line offices including the National Weather Service (NWS), the Office of Atmospheric Research (OAR), and the National Ocean Services (NOS).

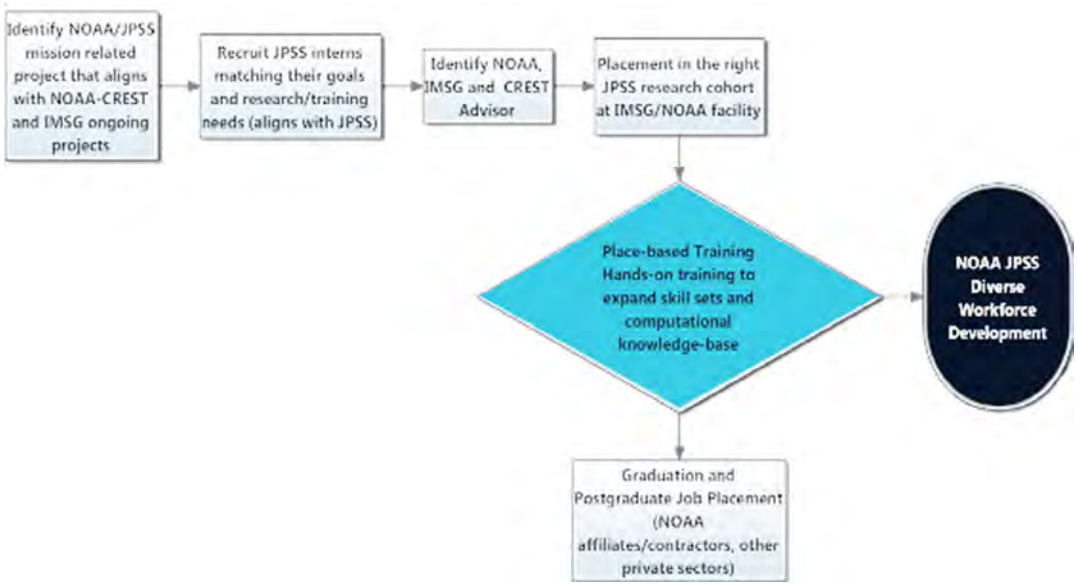




IGNITING THE SPARKS IN NOAA WITH THE JPSS PGRR

The plan to form the JPSS–SPARKS Initiative was executed at the 96th American Meteorological Society (AMS) Annual Meeting in New Orleans, Louisiana. The Initiative, led by CUNY/CREST in partnership with IMSG and NOAA/JPSS, would familiarize graduate students with the JPSS program as well as the research to operations process in the NESDIS, Center for Satellite Applications and Research (STAR) through internships.

The pilot program, a 10-week training course, opened in the summer of 2016 to four graduate students from CREST hosted by a team of IMSG scientists. The program introduces students to the JPSS satellite missions through rigorous and relevant instruction. JPSS delivers key global observations that are used for forecasting severe weather events like hurricanes and blizzards days in advance, and assessing environmental hazards such as droughts, forest fires, poor air quality and harmful coastal waters. In addition, students work on real-world projects, giving them hands-on experience with product algorithm research and development, calibration/validation, the fundamentals of the research to operations (R2O) process, programming languages, as well as the standards used in the operational implementation of the JPSS science algorithms.



BEYOND THE CLASSROOM: CREATING PROFESSIONAL EXPERIENCES

The first five weeks of training, or phase one, included daily morning workshops led primarily by staff from IMSG. These workshops focused on the skills needed specifically for research-to-operations. Students learned how (1) science and programming interact in the R2O environment; (2) changes are integrated through the review process; and (3) to write code to standards. The morning workshops also provided an opportunity for the students to be part of a real working environment. The morning sessions set the stage for afternoon seminars that exposed students to the JPSS mission, products, and pioneering research from the state-of-the-art instrument complements. In phase two, the students applied the skills they had learned in the previous weeks as they worked on their research ideas. This second phase—which began at the end of week five and ran until the end of the course—took the students out of the classroom and placed them into a real-world working environment under the mentorship of scientists at STAR. This six-week mentor guided research gave them time to refine and develop their ideas into tangible products.

OUTCOMES AND IMPACTS

Learning outcomes were related to an increase in the knowledge-base on NOAA related sciences. Research highlights from 2016 included the use of Satellite-Based NOAA Unique Combined Atmospheric Processing System (NUCAPS) to examine temperature and humidity profiles of the atmospheric boundary layer (ABL) over the Washington D.C. metro area, and an evaluation of the VIIRS radiative signal from the Fort McMurray wildfire in the province of Alberta, Canada. Metrics were collected at the beginning and at the halfway point of the training program. The first week served as a baseline to adjust planned lectures, while the fifth week tested knowledge immediately after workshops ended. By the fifth week the students were able to build from a basic understanding to language-specific skills, which were shown by their increased coding abilities in languages such as C++, Fortran 90, and Perl.

	Topics Covered	Week 1	Week 5
1	General Program Knowledge of the JPSS Mission	10%	100%
2	Coding in Fortran 90, C++, and PERL.	10%	75%
3	Coding Standards/Configuration Management	0	50%
4	Algorithm Change Process	0	25%

As part of their training students have also produced some scientific publications, and given presentations at national level conferences such as the American Geophysical Union (AGU), the American Meteorological Society (AMS), the International Geoscience and Remote Sensing Symposium (IGARS), and the NOAA CoRP and NOAA-CREST Annual Symposium. In addition, the SPARKS initiative is increasing the visibility of the JPSS program among scientific and particularly student communities that directly align with NOAA's long term goals for a Weather Ready Nation (WRN); healthy coasts, resilient coastal communities, and an informed society anticipating and responding to climate and its impacts. Future plans include the continuation of the JPSS educational outreach and program, and expansion to accommodate students from other universities.

SUMMARY

The JPSS SPARKS Program was implemented to help build a robust pathway to a STEM related workforce in NOAA mission science, and increase job ready skillsets particularly in NOAA-JPSS mission related science.

With the program putting its best foot forward to inspire the next generation of NOAA scientists, students participating in the SPARKS program now have access to state-of-the art JPSS instruments, algorithms for developing sensor and environmental data records (SDRs/EDRs) and product applications. NOAA's next generation scientists are also being exposed to the programming languages used in operations as well as the steps involved in transitioning research into operations. Future plans include the continuation of the JPSS educational outreach and program, and expansion to accommodate students from other universities and other NOAA contractor/private sectors.

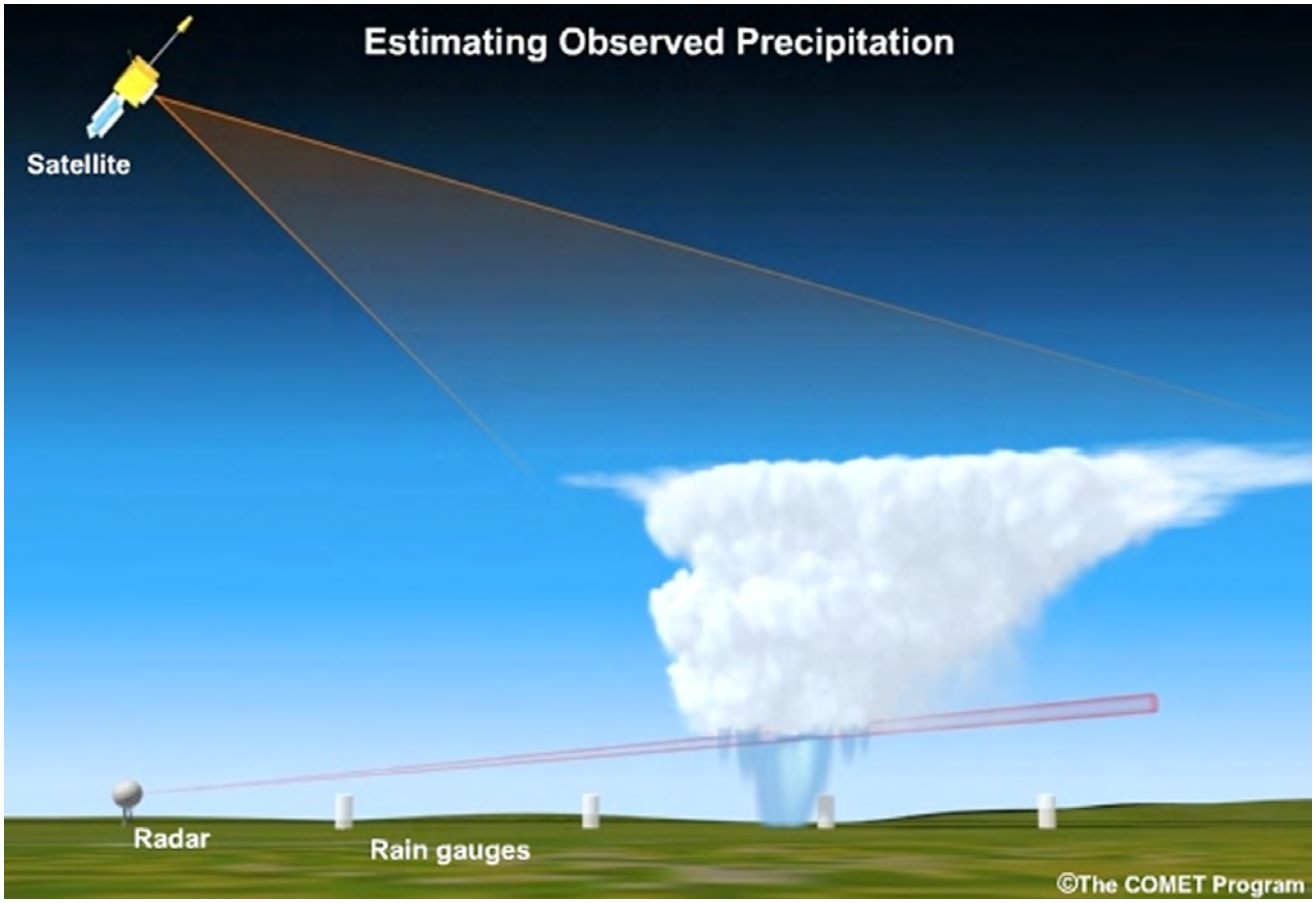
NESDIS, which supports NOAA's cross-cutting areas of responsibility though the data, information, products, and services generated from its satellite missions, is very diverse in the types of jobs it offers. These jobs range from research to operations, systems engineering, algorithm development, requirement analysis, and satellite operations. That means there are lots of opportunities available for its next generation workforce. This SPARKS Initiative has leveraged its knowledge of programs such as JPSS to create curriculum and instructional models that are providing NOAA related research and technical skills to students at the beginning of their career path. In addition this initiative is delivering hands-on skills to groups that have been traditionally underrepresented in NOAA related science missions, further helping to cultivate a diverse STEM educated workforce.

Footnotes

[1]National Oceanic and Atmospheric Administration (NOAA) (2015). NOAA Education Strategic Plan, 2015–2035. http://www.oesd.noaa.gov/leadership/edcouncil/docs/2015-Strategic-Plan-FullText.pdf

HYDROLOGIC APPLICATIONS OF CLOUD PRODUCTS FROM THE VISIBLE INFRARED IMAGING RADIOMETER SUITE (VIIRS)

The information in this article is based, in part, on the December 19, 2016 JPSS science seminar presented by Andi Walther, Samantha Tushaus, Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin-Madison, and Andrew Heidinger, NOAA/NESDIS Madison, WI.



Clouds are an important part of the atmosphere, in large part due to their influence on global weather and climate. Clouds act like a blanket by trapping the Sun's energy and warming the Earth. This attribute also affects the speed at which the Earth's surface cools by curbing the rate at which the trapped heat radiates back into space. Some clouds produce precipitation, an essential part of the hydrological cycle that replenishes the Earth's water supply. Precipitation measurements support a wide range of applications, including those in meteorology and hydrology such as weather and flood forecasting, flood control, and now-casting of severe storms. While the oft-used surface-based rain gauges and weather radars produce high quality precipitation measurements, they have several limitations. Chief among them are limited spatial coverage, especially over oceans, mountains or remote regions. On the other hand, satellites provide consistent coverage over large parts of the globe. Their remotely sensed precipitation measurements complement surface-based measurements and fill in the large observational gaps in regions with little to no surface coverage.

DERIVING CLOUD PROPERTIES FROM SATELLITE MEASUREMENTS

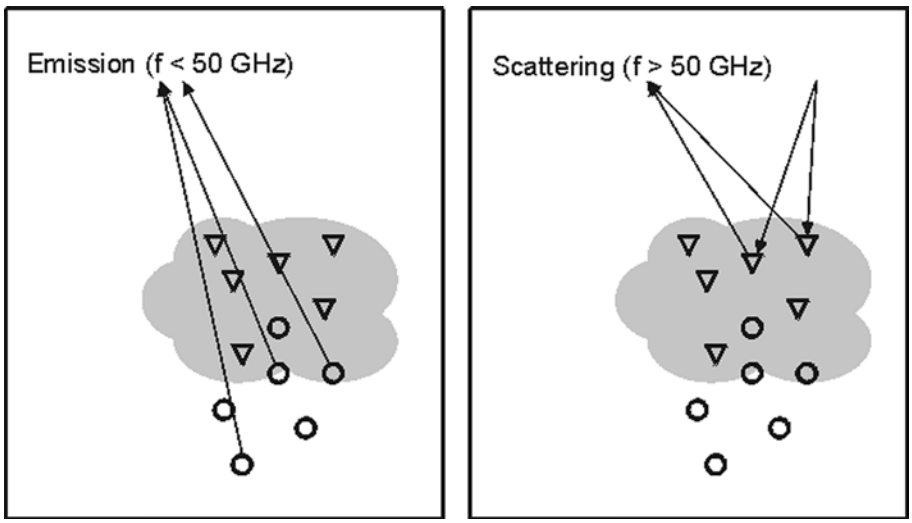
Earth observation satellites, including geostationary and polar-orbiting satellites, are the only source of global retrievals of various cloud properties, and precipitation measurements can be inferred from the data collected by infrared and microwave sensors on these satellites. The sensors' differing spectral domains, as well as other benefits/costs associated with the different spectra, can result in discrepancies in retrieved cloud properties. One such polar-orbiting satellite with multiple sensors is the Suomi National Polar-orbiting Partnership (Suomi NPP), the first mission in the Joint Polar Satellite System (JPSS).

Microwave observations, flown exclusively on low-earth orbiting satellites, like those from the Advanced Technology Microwave Sounder (ATMS) instrument on Suomi NPP, produce more accurate precipitation

measurements because the wavelengths are sensitive to the radiation emitted from or scattered by rain droplets and ice particles in clouds. In general, better accuracy is achieved over water surfaces as compared to land; the microwave background signal from oceans is more continuous as opposed to land, which can be highly variable, thus, sensors have to rely on ice-scattering over land. In addition, measurements from polar-orbiting satellites tend to be sparse and often miss important precipitation events, however, using a "constellation" of microwave sensors, including Suomi NPP, can provide near global coverage every 3–4 hours.

The rationale employed in using the infrared (IR) spectral range of a satellite sensor to measure cloud top properties like temperature and altitude, is based on the correlation between cloud top temperature and precipitation: thick, cold clouds rain more often than thinner clouds. Traditional IR techniques show skill at characterizing rain from cold convective clouds, but there are difficulties in using satellite IR observations to discriminate between, for example, thick anvil cloud (which is not precipitating) and the core of a thunderstorm. IR sensors may also mistake certain types of clouds for others, and struggle to capture rain in warm clouds. While their measurements may be more inaccurate than those from microwave sensors, IR sensors on board geostationary satellites provide a more complete representation of precipitation with a considerable higher temporal resolution. Many data sets combine the excellent space/time resolution from geostationary estimates with the better accuracy of microwave estimates.

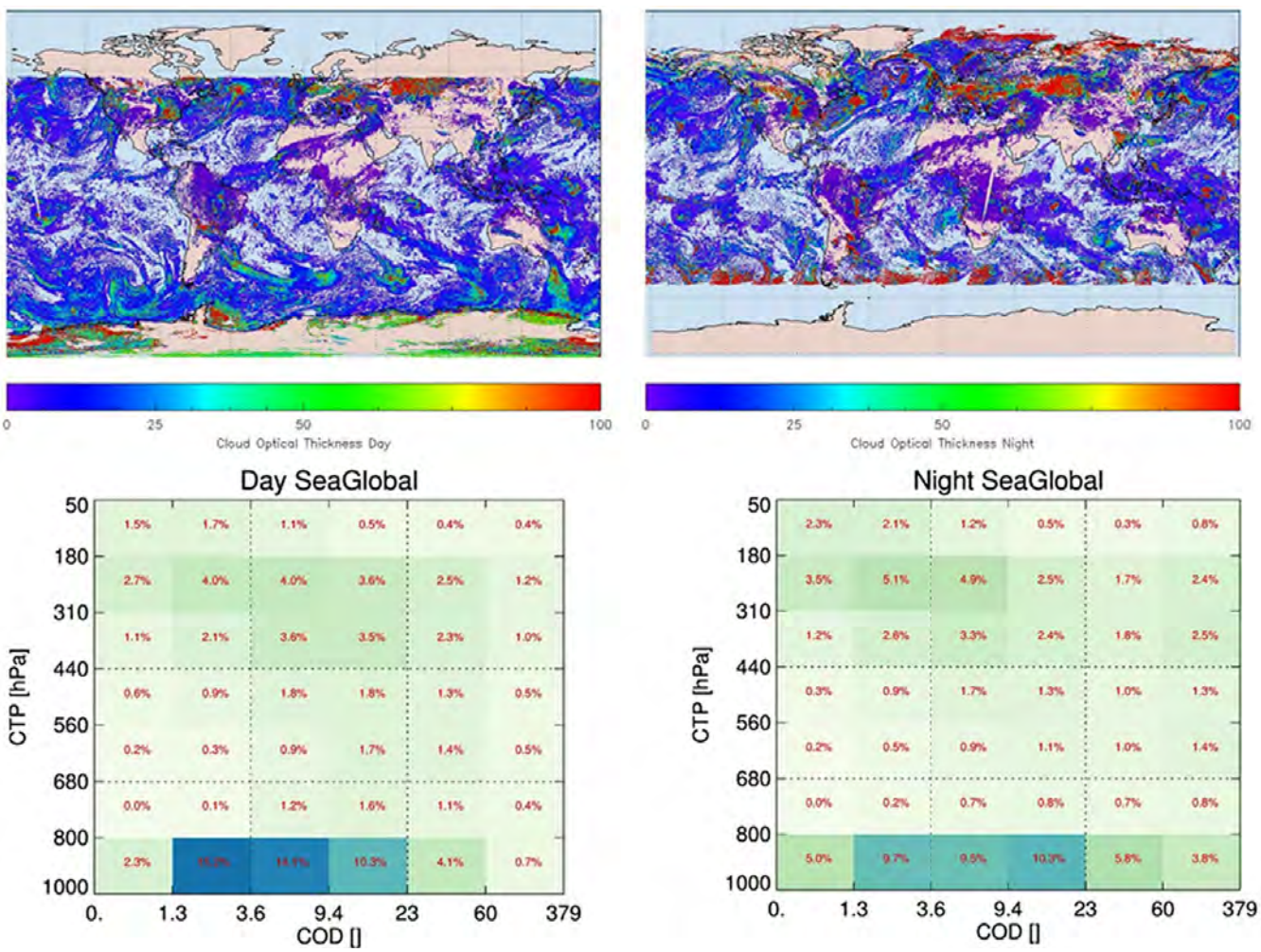
One technique being investigated in the Hydrology Initiative is to use the cloud products derived from the visible and near-infrared (VIS/NIR) observations from the Visible Infrared Imaging Radiometer Suite (VIIRS), an instrument on the Suomi NPP satellite. At these frequencies, rain is optically very thin compared to clouds, so a satellite cannot measure rain that is underneath clouds. Using a conceptual model in which cloud microphysics describe the processes which control formation and fallout of cloud droplets, cloud droplet size and cloud water content may be correlated with precipitation. The VIS/NIR method complements the IR and microwave techniques since it provides skill at detecting low precipitation rates from small-scale, lower level, liquid phase clouds, which are often missed by the other techniques.



One of the biggest challenges in retrieving cloud properties occurs at nighttime when many features of the environment, including clouds, are difficult to observe without solar illumination. Since cloud properties underpin many derived meteorological and hydrological products that are needed day and night, including snowfall and aircraft icing threats, scientists in the JPSS Proving Ground and Risk Reduction Program's (PGRR) Hydrology Initiative are exploring ways to improve NOAA-related hydrological applications using water vapor and precipitation products from the Suomi NPP.

HYDROLOGIC APPLICATIONS OF CLOUD PRODUCTS FROM THE VIIRS DAY/NIGHT BAND: TRANSCENDING THE LIMITATIONS OF NIGHTTIME OBSERVATIONS

The lack of reliable satellite-based cloud property retrievals at night represents a critical gap in studying the daily cycle of cloud optical properties and derived products on a global and local scale. The Suomi NPP satellite carries an instrument that is highly sensitive to low levels of VIS/NIR light. The Visible and VIIRS instrument collects a variety of data corresponding to different bandwidths of light. Its Day/Night Band (DNB) in particular collects observations of nighttime light across the globe at 750-meter resolution to monitor and analyze environmental features like clouds. Capitalizing on the nighttime observation ability provided by the DNB, a JPSS PGRR Hydrology Initiative project team, overseen by the algorithm working group at the University of Wisconsin-Madison, has developed a cloud properties retrieval scheme for nighttime observations called the Nighttime Lunar Cloud Optical and Microphysical Properties algorithm (NLCOMP)[1]. This potential source of nighttime information is of great import for forecasting applications such as nocturnal precipitation, icing threats, and conditions in high-latitude regions, such as Alaska, that are challenged by extensive periods of darkness. The retrieval scheme is based on a lunar irradiance model developed specifically for the DNB [Miller and Turner, 2009]. Its output, when sufficient moonlight and other emission sources (e.g. city lights) are masked out, generates consistent global mosaics between daytime and nighttime scenes (see figure below).



Histogram of Cloud Optical Depth/Cloud Top Pressure covering a 10-day period of data from January 2015.

Building upon proven methods from the NOAA Enterprise Algorithm known as Daytime Cloud Optical and Microphysical Properties (DCOMP) [Walther and Heidinger, 2012], project team scientists from the Hydrology Initiative have made improvements in other nighttime cloud product retrievals, such as cloud type, layer, and cover. These proof-of-concept applications of the nighttime products are important first steps in including this information in existing NOAA applications.

SENSITIVITY STUDIES COMPARING VIIRS OBSERVATIONS AGAINST GROUND TRUTH

Cloud Water Path/Effective Radius (REF)/Cloud Optical Depth (COD)

To examine whether cloud properties provide the information content to detect rain and estimate rain rates, precipitation estimates from VIIRS were compared against ground-based data. In one test, VIIRS cloud properties collected over 5 days were matched with surface precipitation measurements from NEXRAD, the Next-Generation Radar network managed by the National Weather Service. Figure 1 shows information related to the presence (shaded) and magnitude (different panels) of precipitation measured by NEXRAD or inferred from VIIRS DCOMP cloud properties. This study shows that more than 70% of clouds with an effective radius (REF) of 30 microns or more, and cloud water path (CWP) of more than 700mm, are precipitating clouds (red areas in left image of Figure 1). It is obvious from this sensitivity study that high optical thickness, effective radius, and cloud water path are necessary conditions for a precipitating cloud, and also give a hint to the frequency of higher intensity rain (middle and right image of Figure 1). These studies cover both day (DCOMP) and night (NLCOMP), and explore how thresholds on the effective radius (REF) and cloud water path (CWP) can optimize the agreement between VIIRS and NEXRAD.

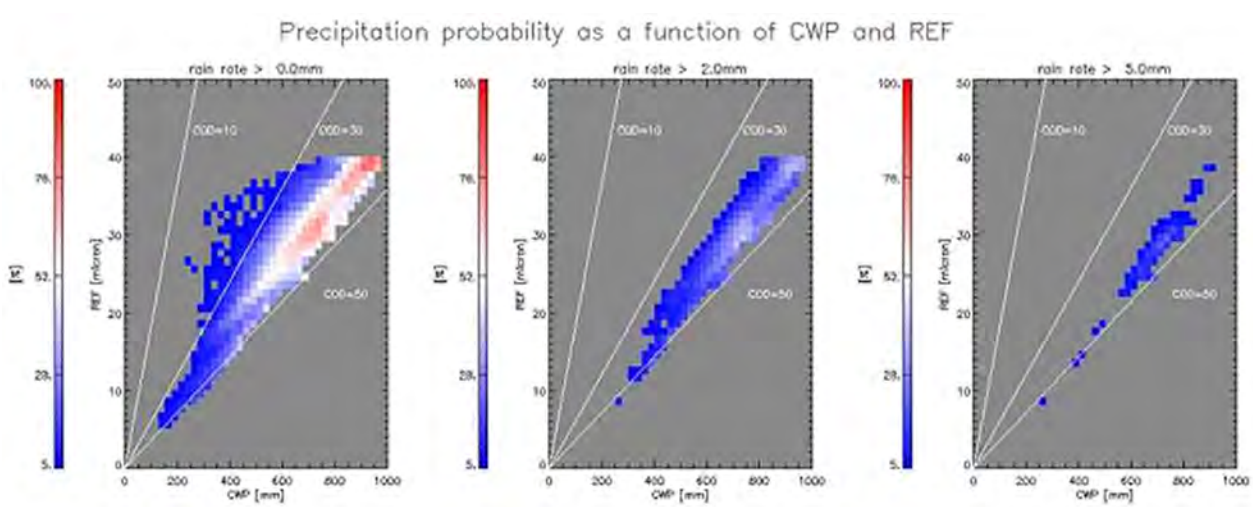


Figure 1: The images show the precipitation frequency as a function of cloud properties from VIIRS. The left image shows the percentage of pixels with rain in NEXRAD data for given cloud water path, effective radius and optical thickness values. The middle and right image shows the same but the percentage of rain over 2mm per hour and 5mm per hour intensity, respectively.

Other Cloud Properties

Comparison to ground-based data show that other cloud properties also hold some information content useful for detecting rain and estimating rain rates. These properties include an estimated geometrical thickness of precipitating cloud, called the rain column, and a comparison of the overall cloud top temperature (CTT) to the

warmest CTT in a given area. Future versions of the VIIRS VIS/NIR precipitation products will use these other cloud properties to further improve the skill in precipitation detection and rate estimation.

Assumption: The smaller the cloud geometrical thickness, the higher rain rate.

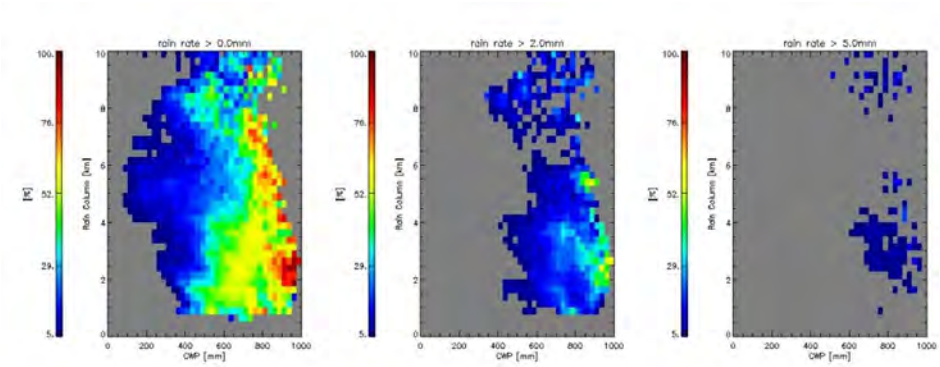


Figure 2: Same as Figure 1, but for rain column vs Cloud Water Path

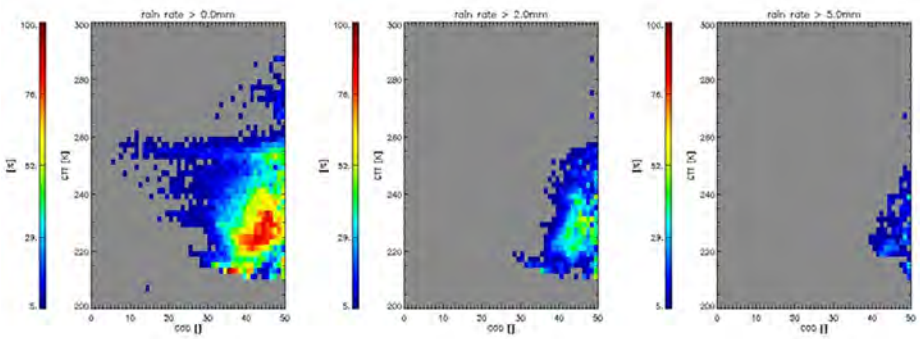


Figure 3: Same as Figure 1, but for Cloud Top Temperature vs. Cloud Optical Thickness

The results of the current sensitivity studies show less information content coming from these cloud properties in comparison to REF/CWP study for quantitative rain rate estimates, but some valuable information for cloud detection is still available (left images of Figure 2 and Figure 3).

RAIN RATE RETRIEVAL FROM VIS/NIR

Using comparison studies between VIIRS and NEXRAD, and based on a paper by Roebeling and Holleman, [2009], the project team scientists from the Hydrology Initiative developed a rain rate retrieval algorithm from VIS/NIR measurements for VIIRS and other current sensors in space. Figure 4 shows an example for the April 2016, Texas flood event.

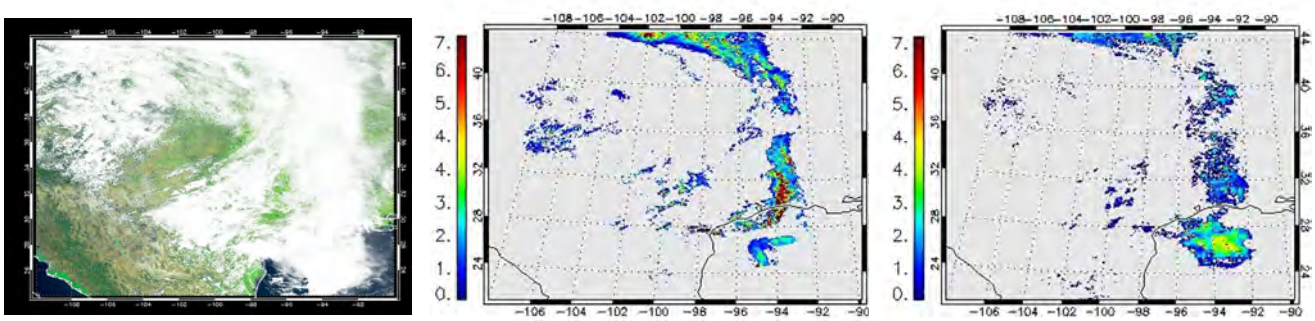


Figure 4 Example of VIS/NIR rain rate retrieval: left image shows a true color image over Texas on 18 April 16 UTC; Middle image is ground-based precipitation radar mosaic; right image shows the rain rate [mm/hour] output of the VIS/NIR algorithm.

OUTLOOK

With support from the JPSS Risk Reduction Program and Hydrology Initiative, this project demonstrates the utility of the precipitation information contained in the VIIRS cloud microphysical products. This information certainly complements that from the ATMS microwave sounder and traditional IR-only techniques and provides skill in characterizing low levels of precipitation from water-phase clouds. This information is often difficult to extract from microwave and IR techniques. Initial extension into the use of the VIIRS Day-Night-Band Lunar Reflectance (the NLCOMP algorithm) has shown promise in deriving precipitation at night with sufficient moonlight. Future efforts include developing these techniques to the point where they can be integrated into the existing JPSS and GOES-R Precipitation Applications.

SUMMARY

While no single sensor is ideally suited for detecting and characterizing all types of clouds, most of the uncertainties can be reduced by satellites as they extract different parameters from clouds, to help determine properties such as height, type, optical thickness, cover, and so forth. In addition, satellites provide data at much higher spatial and temporal resolutions that is not available from other sources. Scientists also use this data to run various tests using complex retrieval algorithms to infer cloud from the amount of Visible and IR radiation measured.

NLCOMP has enabled the generation of consistent global mosaics between daytime and nighttime scenes. Even though this application is still in infancy, it is an important step towards high quality retrievals of cloud microphysical properties at night, and in closing the gap in the daily cycle of cloud optical properties and derived products on a global and local scale.

Footnotes

[1]Published in Walther et al. 2013.

References

Miller, S. D., and R. E. Turner, 2009: A dynamic lunar spectral irradiance dataset for NPOESS/VIIRS Day/Night Band nighttime environmental applications, IEEE Transactions on Geoscience and Remote Sensing, 47(7), 2316-2329.

Roebeling, R. A., and I. Holleman, 2009: SEVIRI rainfall retrieval and validation using weather radar observations, J. Geophys. Res.,114

Walther, A. and A.K. Heidinger, 2012: Implementation of the Daytime Cloud Optical and Microphysical Properties Algorithm in PATMOS-x. J. of applied Meteorology and Climatology, 51(7), 1371-1390.

Walther, A., A. K. Heidinger, and S. Miller, 2013: The expected performance of cloud optical and microphysical properties derived from Suomi NPP VIIRS day/night band lunar reflectance, J. Geophys. Res. Atmos., 118, 13,230–13,240.

CONNECTING SATELLITE OPERATORS AND DATA USERS ACROSS THE GLOBE

World Meteorological Organization Virtual Laboratory (VLab) For Education And Training In Satellite Meteorology

The information in this article is based, in part, on the January 18, 2017 JPSS science seminar presented by Bernie Connell, Colorado State University.

VLab links between Centers of Excellence (represented by their national flag) and their supporting satellite operators (highlighted in yellow). Status: November 2012.

Environmental satellites play a major role in gathering continuous information from space—of large-scale weather systems and other features on the Earth's surface—which helps us to better understand how the earth works. The ability to observe weather systems and other environmental phenomena in locations not possible with conventional methods has made environmental satellites the backbone of the Global Observing System (GOS). Weather systems cannot be confined within geographic boundaries, they move around the planet. While they affect billions of people around the world, their impacts are most strongly felt at local levels. Second to this, only a few countries including the United States of America (U.S.), Canada and China operate weather satellites. The World Meteorological Organization (WMO), an agency of the United Nations, facilitates data sharing activities between satellite data providers and users across the globe.

Nearly 90 percent of the data assimilated into the forecast models comes from satellites. Data from the Suomi National Polar-orbiting Partnership (Suomi NPP), the first next-generation polar-orbiting satellite in the Joint Polar Satellite System (JPSS) constellation, and the National Oceanic and Atmospheric Administration's (NOAA's) primary polar-orbiting satellite, has been assimilated into these models since early 2012. Its next generation sensors deliver critical environmental data to key users including NOAA's National Weather Service (NWS) and others around the world. This data helps ensure that weather service agencies across the globe can generate forecasts and prepare their communities for impending weather events. The exchange and exploitation of weather data is not new. In the late 1800's maritime activities were predicated upon shared weather data. Today, many of these data sharing activities are facilitated through the WMO. But even with data sharing, some user communities in the GOS are not in a position to properly exploit the wealth of satellite data, products and services available, and therefore are not able to reap the full benefits of these operational satellite systems. In 2000, the Coordination Group for Meteorological Satellites (CGMS) and the Space Programme of the WMO established the Virtual Laboratory for Education and Training in

Satellite Meteorology (VLab) to enhance the utilization of data and products from the meteorological and environmental satellites operated by WMO Members across the globe.

The Nation's environmental satellites provide billions of dollars in benefits through improved early warnings of severe weather like hurricanes, tornadoes and blizzards, and through assessments of environmental hazards such as droughts, forest fires, poor air quality and harmful coastal waters, as well as the provision of information that feeds the decision support systems (DSS) of industries such as transportation, energy, agriculture and so forth.

VIRTUAL LABORATORY FOR EDUCATION AND TRAINING IN SATELLITE METEOROLOGY

The Virtual Laboratory for Education and Training in Satellite Meteorology (VLab) is a collaborative effort joining CGMS satellite operators across the globe with WMO regional training centers of excellence (CoEs) that specialize in satellite meteorology. The VLab also seeks to globally share knowledge, experience, methods, and tools related to satellite data, especially in support of the WMO members that have limited resources. Over time, satellite training for forecasters has been used to supplement gaps in education and as means to present new and improved operational products.

The VLab Network: Satellite operators and Centres of Excellence

Eight satellite operators

- Chinese Meteorological Administration (CMA)
- Argentinian National Space Activities Commission (CONAE)
- EUMETSAT
- Brazilian National Institute of Space Research (INPE)
- Japan Meteorological Agency (JMA)
- Korea Meteorological Administration (KMA)
- National Oceanic and Atmospheric Administration (NOAA)
- Roshydromet

The Centres of Excellence

- Argentina (Buenos Aires and Cordoba)
- Australia (Melbourne)
- Barbados (Bridgetown)
- Brazil (Cachoeira Paulista)
- China (Beijing and Nanjing)
- Costa Rica (San Jose)
- Kenya (Nairobi)
- Morocco (Casablanca)
- Niger (Niamey)
- Oman (Muscat)
- Republic of Korea (Gwanghyewon)
- the Russian Federation (Moscow and St Petersburg
- South Africa (Pretoria)

Presently eight satellite operators (shown above), including the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), and the Federal Service for Hydrometeorology and Environmental Monitoring of Russia (ROSHYDROMET) have established training activities to best meet their users' need for increased skills and knowledge in using satellite data. The satellite operators collaborate with WMO approved training Centres of Excellence (CoEs) (shown above) to share and exchange training materials as well as best practices for training member WMO countries, particularly within their WMO Region.

The US, NOAA's Office of the Chief Learning Officer (OCLO) oversees training for the National Weather Service. NWS training developers include the Forecast Decision Training Division (FDTD), the Warning Decision Training Division (WDTD), and the Training Center. Training developers external to NWS include the Cooperative Institute for Research in the Atmosphere (CIRA), the Cooperative Institute for Meteorological Satellite Studies (CIMSS), COMET, the Short-term Prediction Research and Transition Center (SPoRT), and

the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS). The Virtual Institute for Integrated Satellite Training (VISIT) and the Satellite Hydrology and Meteorology (ShyMet) are run collaboratively by CIRA and CIMSS. Training resources from the groups and programs mentioned above are used directly, or leveraged, to support international training activities under VLab. NOAA also supports international training activities directly through its NCEP International Desks. The training activities, while primarily focused towards national weather service agencies, are also applicable to academia, managers from the public and private sectors, weather enthusiasts, the media, as well as the general public.

A key goal for the VLab is to provide support to education and training among the members of the WMO by developing and delivering training around the various competency frameworks. These include events designed to build the capacity of users such as monthly virtual weather and climate sessions through Regional Focus Groups (RFGs). RFGs are co-organized by the CoEs and satellite operators to widen access to training resources and events to countries within the regional area of VLab CoEs.

NOAA, through training activities from the JPSS and Geostationary Operational Environmental Satellite R-Series (GOES-R) programs is helping the international user community (forecasters, researchers, and managers) enhance their utilization of data and products. These activities include synergy between the International Desks at NOAA's Weather Prediction Center (WPC), teaching and learning approaches, as well as lessons learned along the way; visitor training sessions, and regular virtual monthly focus group sessions.

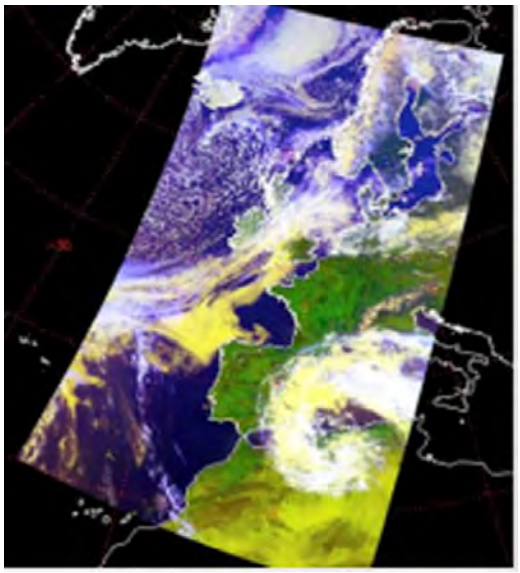
TRAINING EVENTS WEEKS

VLab members are encouraged to participate in regularly scheduled training events. These events feature topics of particular interest and address key data use areas identified by the WMO or by satellite operators such as NOAA. These events take place online and have dedicated themed sessions which are presented successively. Some training sessions may last as long as a week. In addition, the VLab encourages the

translation of training material and presentation of training in more than one language. Selected training material is currently translated into the six official languages of the WMO (i.e. Arabic, Chinese, English, French, Russian and Spanish).

For some time now, the VLab has been organizing a series of online events about the direct readout capabilities of polar orbiting systems. Information on these events as well as dates and registration instructions are posted online at www.wmo-sat.info/vlab/calendar-of-events.

Examples



Direct readout capabilities have become a cornerstone of many operational activities for weather service agencies across the globe. In the U.S. for example, prior to the use of direct broadcast networks, the time needed to retrieve satellite data for time sensitive applications took more than 100 minutes. The antenna network has cut the process down to less than 20 minutes, making it a critical aspect of enhanced operational applications. The timely delivery and acquisition of global observations facilitates faster forecasting of local weather events. In 2014, instructors from NOAA presented sessions on the direct readout capabilities offered by the JPSS and its impact on operations.

Satellite Direct Readout Events Presentations by Mitch Goldberg and Liam Gumley

This session showcased the direct readout capabilities offered by NOAA's new operational satellite program. The JPSS program, which includes the Suomi NPP satellite, provides critical data that supports: forecasting, environmental assessments, climate variability, and supports the observation, forecasting and mitigation of natural disasters. The JPSS-1 satellite is scheduled for launch in 2017.

As more and more next-generation satellites come online and satellite programs, dissemination systems and forecast and warning operations continue to evolve, the VLab network, a critical link between environmental satellite data providers and the global user community, continues to provide learning activities which are helping ensure that new satellite products are easily understood and accepted as they become available. Suomi NPP, the first in line of NOAA's next generation satellites, is already delivering data in unprecedented amounts and speeds. Its follow-on, JPSS-1, is expected to generate even more data. The newly launched GOES-R (now GOES-16) is expected to add even more data to the GOS. In line with the expectations the new data and imagery from the next generation satellites, the VLab hosted an event aimed to give a

general update on what is available, what is coming next and also provide the opportunity for dialogue. The event, which took place from 16–20 November 2015, featured a selection of webinars from several organization including JMA, CMA, India Meteorological Department (IMD), NOAA, CIRA, EUMETSAT, National Institute for Space Research (INPE), KMA and the COMET Program.

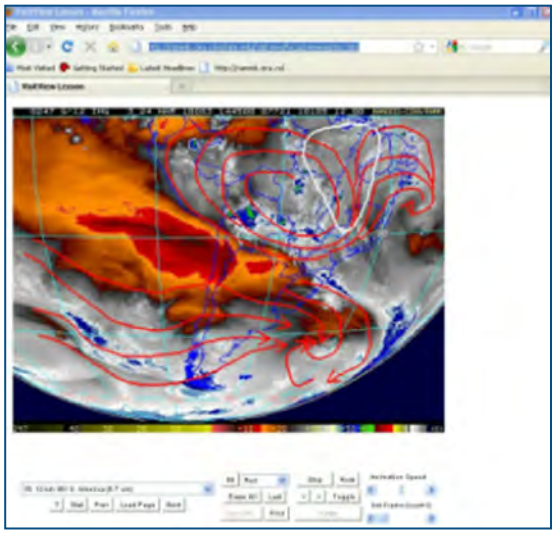
GEONETCAST: 3–5 DECEMBER 2013

The primary mandate of the VLab is education and training in satellite meteorology, and it is fully noted that without access to imagery and products, the training goals are not realized. The user can access the satellite products from the internet, from direct broadcast, or from a Digital Video Broadcast (DVB) dissemination service such as GEONETCast (GNC). The use of GNC allows for the reception of large amounts of imagery and products using low-cost receiving equipment and was the focus of the GEONETCast Event week.

"GEONETCast Americas is the Western Hemisphere component of GEONETCast, a near real time, global network of satellite-based data dissemination systems designed to distribute space-based, air-borne and in situ data, metadata and products to diverse communities". GEONETCast (GNC) is a global initiative under the Group on Earth Observations (GEO) and it was developed in support of the Global Earth Observation System of Systems (GEOSS).

REGIONAL FOCUS GROUPS (RFGS)

VLab CoEs also offer online sessions organized around Regional Focus Groups (RFGs). These regularly scheduled sessions provide a collaborative learning environment to diverse audiences around the world. Participants meet virtually once a month. Topics range from satellite imagery and products, methods to share information on global, regional, and local weather patterns, and ways to use satellite data to better understand severe weather. Complex weather patterns such as El Niño/La Nina have also been discussed. The learning activities provided by RFGs are intended to strengthen regional collaboration amongst professionals, and also provide an easy way to communicate across physical, institutional and social



Screen shot of the VISITview window, taken during a session of the Americas and Caribbean Focus Group.

boundaries. Register for a session or listen to a recorded session from the Americas and Caribbean Focus Group: http://rammb.cira.colostate.edu/training/rmtc/focusgroup.asp

WHAT DRAWS PARTICIPANTS TO RFG SESSIONS?

Many participants are initially introduced to the RFG sessions as students in formal training programs at a CoE, as a visitor to the NOAA WPC International Desks, as a participant to a WMO in-person training, or through a colleague. Students at CoEs and visitors to the NOAA WPC International Desks, both of which later moved into intern forecaster and manager positions, as well as weather enthusiasts were among the most frequently returning participants. Long-term participants, which include skilled and expert users, as well as trainers, participate less frequently and were more likely to join seasonal refresher sessions or those covering higher impact significant weather events.

KEYS TO SUCCESS

The VLab's training efforts, and primarily the online sessions have helped expand the access to training events and training resources across national boundaries. All participants benefit from these sessions' reciprocal exchange of input between the experts and users, and the cooperation and collaboration among the trainers. A wider audience is more likely to engage through their native language. Thus, tutorials and literature translated to native languages have helped connect the VLab to wider audiences, and contributed to its ability to build capacity by communicating across a global landscape with others in their disciplines and also across disciplines.

When asked about the value of attending RFG sessions, the attendees gave positive feedback. A majority of the attendees, 89 percent, expressed that they were able to identify atmospheric and surface features in satellite imagery more readily. After these sessions, 78 percent of the participants felt more confident about their interpretation of satellite images. In addition, 76 percent were more ready to investigate new ways in which satellite data could be utilized in their occupations, while 74 percent felt that they would keep up to date with new satellite technology.

SUMMARY

An effective training program is critical to creating and maintaining the required knowledge and skill levels to optimize the use of current and new satellite capabilities. The VLab is a very successful collaboration that fosters the ability of satellite data users from the global community to understand the basic science underpinning satellite capabilities, and how to integrate this science into their operations, in order to gain the most important operational benefits.

Through the VLab training activities, NOAA's JPSS has been able to help user communities understand the new capabilities provided by data and products derived from its satellites. These outcomes are made possible through various training activities, outreach and education activities, including RFGs sessions and Event Weeks. All come together to encourage participation and help expand the access to training events and training resources across national boundaries.

References

WMO Virtual Laboratory for Education and Training in Satellite Meteorology (VLab). Accessed June 8, 2017. http://www.wmo-sat.info/vlab/

GEONETCast Americas (GNC-A). Accessed October 25, 2016. http://www.geonetcastamericas.noaa.gov/index.html

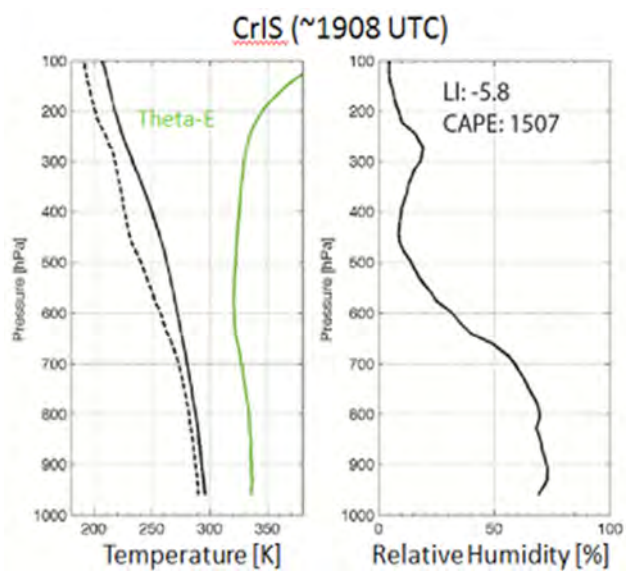
Group on Earth Observations (GEO). Accessed June 8, 2017. https://www.earthobservations.org

ADVANCING HYPERSPECTRAL SOUNDER APPLICATIONS IN THE DIRECT-BROADCAST ENVIRONMENT

The information in this article is based, in part, on the February 23, 2017 JPSS science seminar presented by Elisabeth Weisz, Ph.D., Cooperative Institute for Meteorological Satellite Studies, Space Science and Engineering Center, University of Wisconsin-Madison.

Additional contributors: William L. Smith Sr., Rebecca Schultz, Kathy Strabala, Allen Huang, and Nadia Smith.

Above left: Image shows damage produced by the May 20, 2013 EF-5 tornado, Moore, OK. Photo credit: Doug Speheger, NWS.
Above right: Image from the VIIRS Visible channel shows shadows of overshooting cloud tops.



Severe weather poses various threats to public safety throughout the United States. It causes extensive damage, serious injuries, and at times loss of life. When sufficient warning and lead-time is given to the communities facing potential impact, actions can be taken to lessen the risk of loss of life and property. For high impact weather, especially where time is of the essence, an accurate forecast can make the difference between life and death.

Nowcasting operations, while certainly benefiting from environmental geostationary satellites, can now leverage the capabilities offered by accurate retrievals from hyperspectral sounder radiance measurements under both clear and cloudy sky conditions. Hyperspectral sounding instruments measure top of atmosphere radiance along the full infrared spectrum with several thousand channels, which are sensitive to temperature, water vapor and trace gases at different heights in the atmosphere. Researchers use the radiance measurements to retrieve vertical profiles of atmospheric conditions (e.g. temperature and humidity), as well as cloud parameters (e.g. cloud height, temperature and optical thickness), wind speed and surface conditions (e.g. temperature and emissivity). These capabilities have made them indispensable sources of information about the full state of the atmosphere and therefore indicate great potential value to many remote sensing applications. More importantly, as more measurements from multiple instruments are utilized, this allows for an increased frequency of atmospheric profile, cloud and surface retrievals and this holds great potential for the analysis of severe weather events.

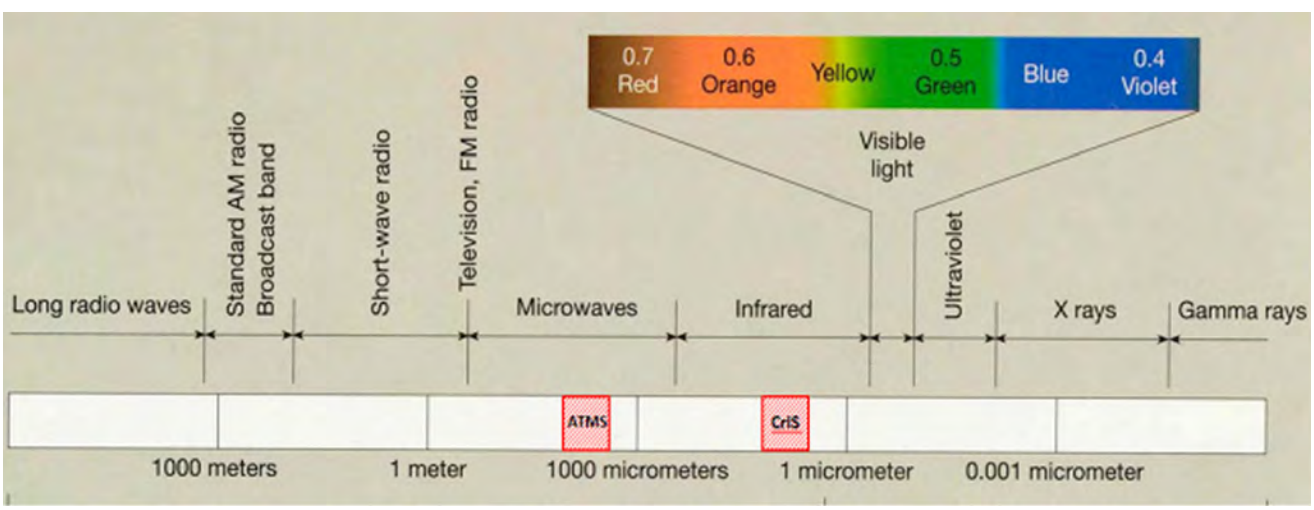
This article provides an overview of research at the University of Wisconsin Cooperative Institute for Meteorological Satellite Studies (CIMSS) supported by the JPSS proving ground (PG) program to identify the differences of the hyperspectral retrieval algorithms, and evaluate the retrieval products by conducting inter-comparisons with independent sources for a variety of atmospheric conditions as well as their potential application in meteorological and environmental real-time operations such as severe weather prediction.

HYPERSPECTRAL SOUNDERS: ENHANCING CONVENTIONAL METHODS OF OBSERVING THE ATMOSPHERE

NOAA's ability to issue timely and accurate forecasts for all kinds of high-impact weather is facilitated by the sounder data that is assimilated from the current fleet of operational satellites. The University of Wisconsin through the JPSS PG program applies the Dual-Regression (DR) retrieval algorithm to data from four polar-orbiting satellites carrying hyperspectral sounding instruments, to develop a variety of polar satellite sounder applications for high-impact weather events. The infrared sounders onboard polar-orbiting satellites are the Atmospheric Infrared Sounder (AIRS) on the NASA Aqua platform, the Cross-track Infrared Sounder (CrIS) on the Suomi National Polar-orbiting Partnership (Suomi NPP) and the Infrared Atmospheric Sounding Interferometer (IASI) one on each of EUMETSAT's Metop-A and Metop-B satellites.

The conventional method for measuring the vertical profiles of the atmosphere is by using upper-air soundings or rawinsondes (a weather balloon carrying a radiosonde). These, along with other sources, including ground-based sensors, observations from ships and aircraft, and other in-situ measurements, imagers, models have helped forecasters determine the development of high impact events such as tornadoes. Data from rawinsondes for example are collected roughly twelve hours apart, and over a small area of coverage. In addition, it takes time for rawinsondes data to be obtained, processed, and run through models. To enhance the spatial coverage, polar orbiting meteorological satellites are now used to measure the vertical profiles of the atmosphere. Converting the satellite radiances to accurate vertical profiles of temperature, moisture, and to other atmospheric and geophysical parameters—a process of creating a retrieval—is essential to local forecast offices for issuing extreme weather warnings.

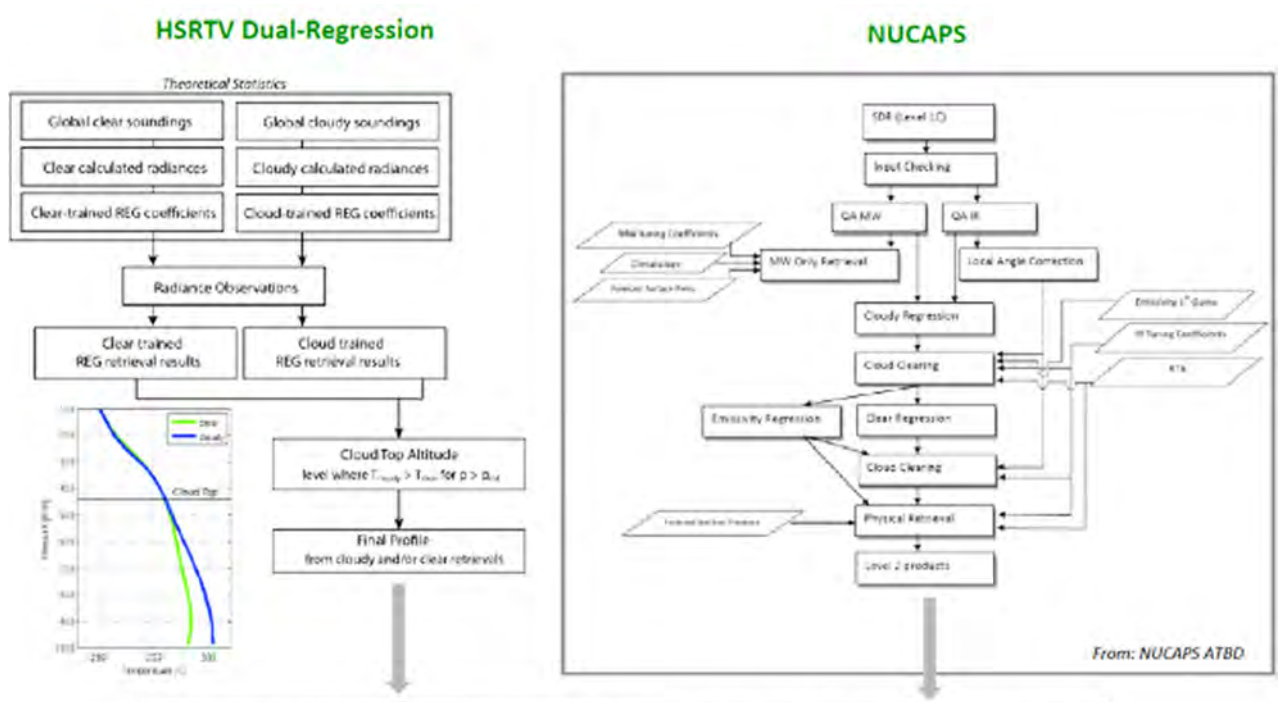
Retrievals from infrared (IR) radiance measurements, obtained under both clear and cloudy sky conditions, provide valuable data to the weather enterprise. As HS IR radiance measurements are the perfect source of supplementary data between ground-based sensors, in-situ measurements, and other sources of data. Moreover, they provide consistent near real-time soundings, surface and cloud information anywhere on the globe, even in regions where traditional data is sparse. With rapidly changing weather conditions where every second counts, and especially when weather conditions can rapidly deteriorate and become life threatening, gaps in coverage can have an adverse effect on forecast skill. In fact, nearly all Numerical Weather Prediction (NWP) impact studies have shown that observations from hyperspectral sounders such as the CrIS have the largest impact for reducing forecast errors.



Satellite sounders (infrared or microwave) measure the radiation emitted by the atmosphere at different wavelength bands (channels) usually given in milli-meters (mm) or micro-meters (μm). The Infrared (IR) channels are usually specified in wavenumbers (inverse centimeters or cm-1) and are related to wavelength as: ν(cm-1) = 10000/λ (μm). The microwave channels are usually specified in frequency units (GHz = 109 Hertz) and are related to wavelength as: f(GHz) = 300/λ(mm).

HS RETRIEVAL ALGORITHMS IN COMMUNITY SATELLITE PROCESSING PACKAGE

There are two hyperspectral retrieval packages that are currently available through the CIMSS Community Satellite Processing Package (CSPP). These are the University of Wisconsin-Madison hyperspectral Dual-Regression (DR) retrieval, and the NOAA Unique Combined Atmospheric Processing System (NUCAPS). CSPP (http://cimss.ssec.wisc.edu/cspp/) supports the direct-broadcast (DB) meteorological and environmental satellite community through the packaging and distribution of open source science software such as the DR retrieval and NUCAPS. The dual-regression (Smith et al., 2012) retrieval technique utilizes measurements from high-spectral resolution infrared sensors such as AIRS, IASI and CrIS. While it does not provide retrievals below thick clouds, it provides retrievals at single FOV resolution (~14km at nadir), essential for detecting small-scale details of temperature, humidity and cloud information. The DR integrates the benefits of regression (i.e., speed and efficiency) and optimal estimation inversion (by accounting for the nonlinearity of the retrieval problem through various additional steps) to produce atmospheric profile, surface and cloud parameters at single FOV resolution. Because it is based on linear regression, it is optimized for speed, which ensures its efficacy in real-time applications. Between 25 and 75 FOVs (depending on the computational resources on hand) can be processed per second, with the entire suite of retrieval parameters provided for each FOV. Altogether, the data received via DB antennas can be processed (i.e., from raw data to calibrated radiances and then to retrieval products) and made available to the weather research, forecasting, and data assimilation community within a few minutes of each satellite overpass. The algorithm is mainly used for research applications.



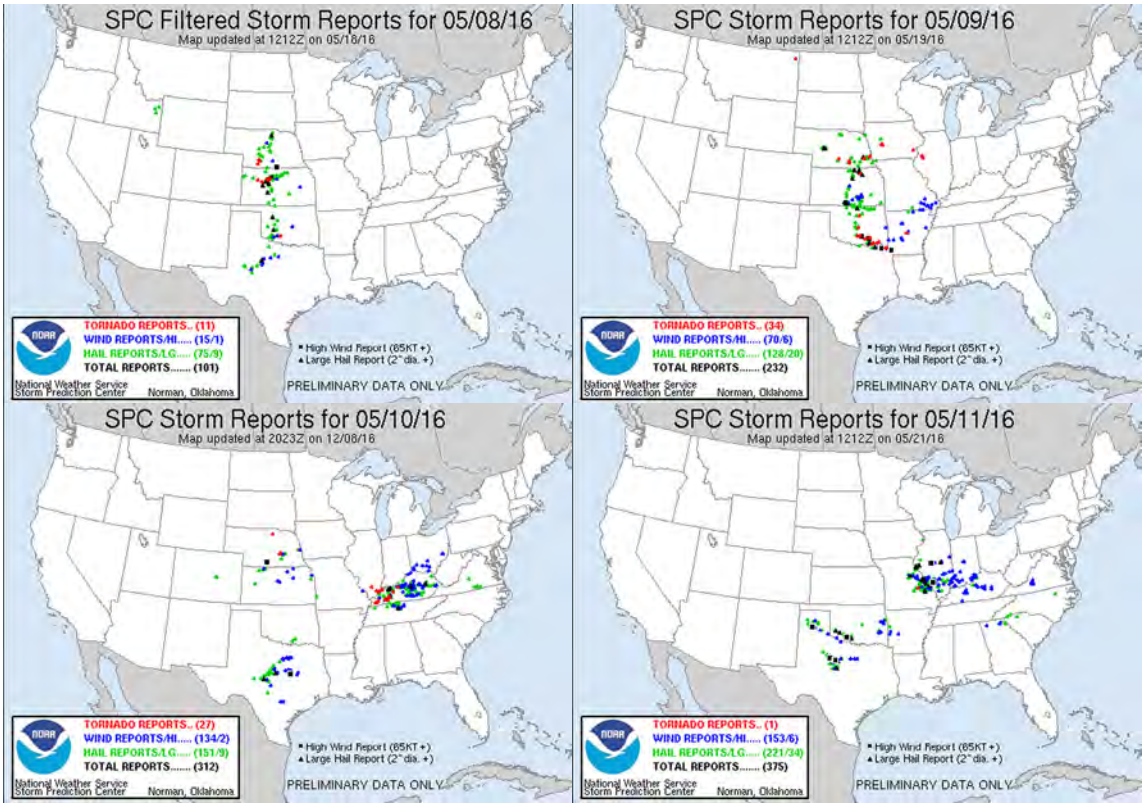
L2 Products: temperature, water vapor and ozone profiles, cloud and surface parameters. NUCAPS also outputs trace gas retrievals such as methane and carbon monoxide.

NUCAPS (Gambacorta 2013) follows the AIRS science team algorithm (which has been processing AIRS and AMSU operationally since 2002) and is currently used to operationally process CrIS data with the help of ATMS (Advanced Technology Microwave Sounder) measurements. NUCAPS relies on a technique called 'cloud clearing' to remove the effect of clouds so that information can be obtained all the way to the surface, the region that is most relevant for most weather applications. Cloud clearing employs the microwave (MW) data from ATMS and uses multiple scenes to remove the effect of the clouds. Therefore, cloud clearing sacrifices spatial resolution (that is approximately 50km at nadir instead of ~14km with single FOV resolution) but since ATMS can see through non-precipitating clouds NUCAPS provides retrievals below most clouds, virtually offering an all-weather capability, although at reduced spatial resolution compared to an IR-only retrieval technique. As can be seen in the diagram below NUCAPS incorporates both regression retrieval and optimal estimation steps.

In summary, the primary differences are that NUCAPS incorporates microwave data and therefore the retrievals are provided at coarser spatial resolution (3x3 instead of SFOV), but they are available below clouds. NUCAPS also implements optimal estimation, which can lead to more refined moisture profiles and trace gas retrievals. Descriptions of the CSPP HS retrieval algorithms, the main differences and their implications on retrieval products are given by Weisz et al. (2015b).

The importance of hyperspectral sounders in environmental and weather monitoring/forecasting is illustrated in Weisz et al (2015a) and in the case described below where hyperspectral retrievals were used to confirm severe weather events that struck Oklahoma in May 2016. Weisz et al. (2015a) illustrated how HS sounders from multiple satellite instruments were leveraged upon to forecast the atmospheric conditions leading up to the Enhanced Fujita (EF)-5 tornado that struck Moore, Oklahoma in May 2013.

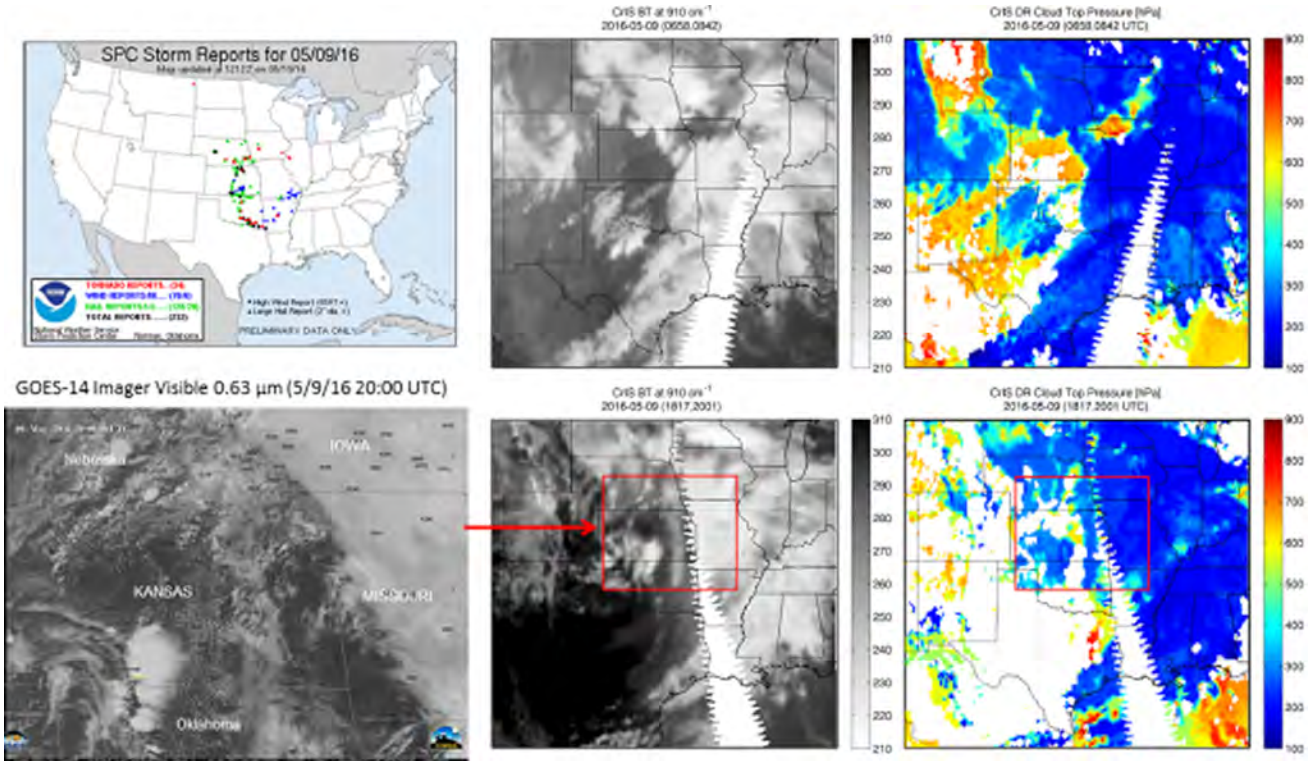
OKLAHOMA TORNADO OUTBREAK, MAY 2016



Severe weather outlook reports from the Storm Prediction Center for May 8–11, 2016.

Severe weather including heavy rains, hail, damaging winds, and tornadoes were observed in the week of May 8, 2016 over the mid-west and southern plains. On May 9, the reports indicated favorable conditions for very large hail around Lincoln, Nebraska. According to the National Weather Service (NWS), these conditions included cold air aloft over low moist air, a lifting mechanism associated with an upper level storm, which moved northeast toward the central plains. In addition, there was a surface warm front positioned over the region.

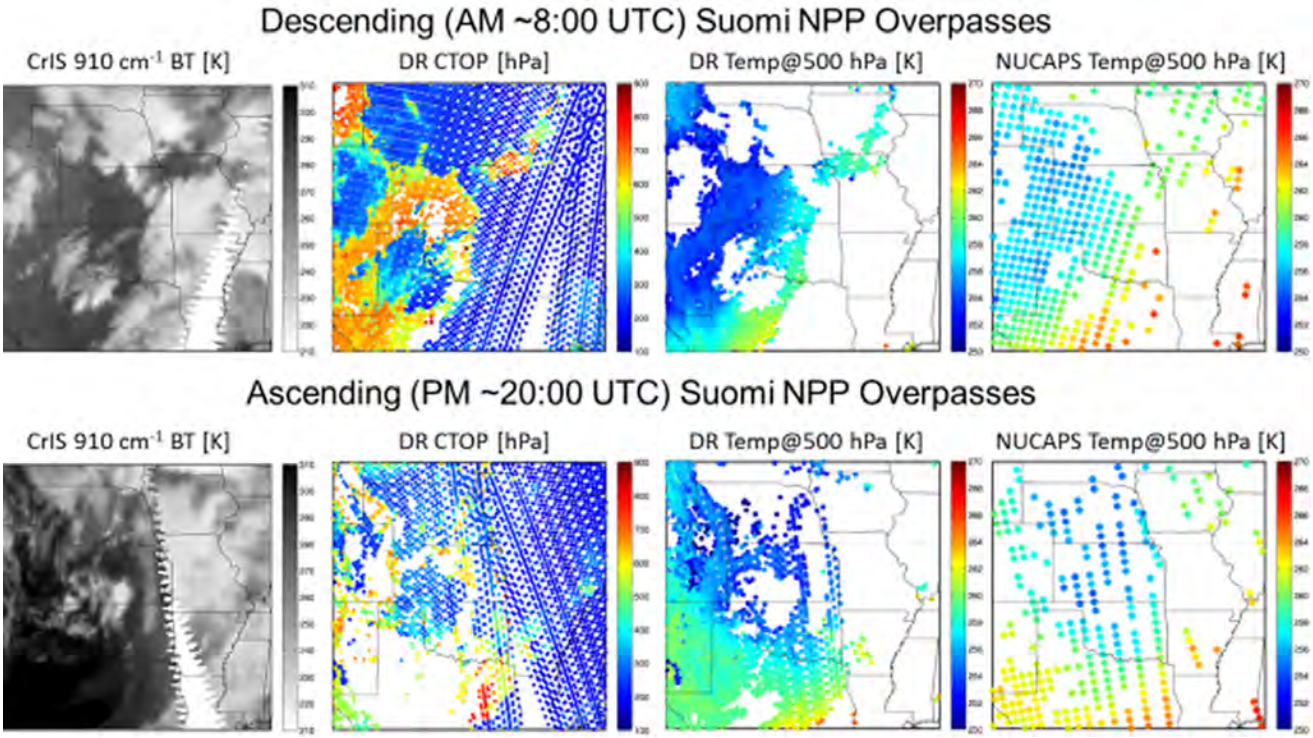
Severe thunderstorms developed along and ahead of a dry line across central Oklahoma during the afternoon of May 9, 2016. Prior to the storms moving into the area, the atmosphere ahead of the dry line in central and eastern Oklahoma had become very unstable. This instability, combined with very strong wind shear associated with a strong trough of low pressure that moved into the Southern Plains from the Southern Rockies, led to supercell thunderstorms that were a part of the four-day severe weather outbreak stretching from Colorado east to Kentucky and Tennessee. The storms moved across central and eastern Oklahoma during the late afternoon evening hours.



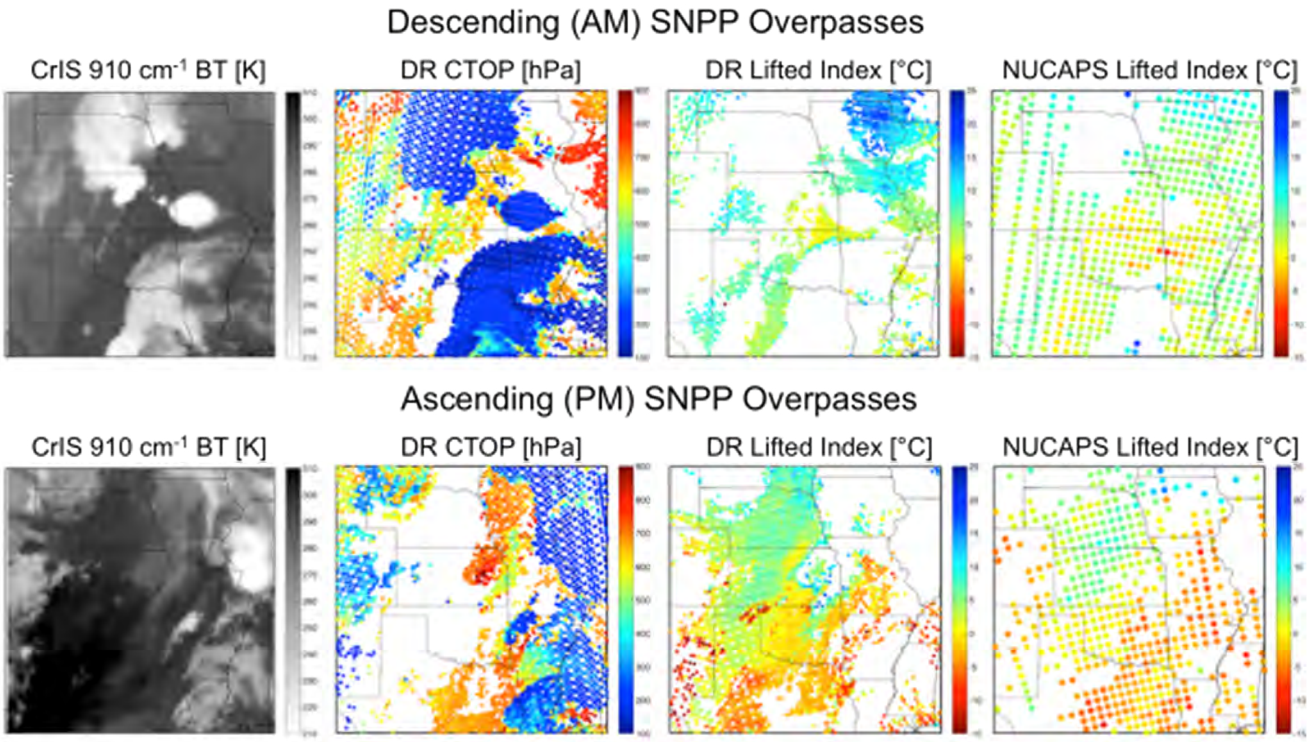
The images above show the NOAA SPC storm report for 05/09/2016 and the GOES-14 visible imagery for a region where most severe weather occurred (left panel). The middle panel shows the brightness temperature of a CrIS window channel for the descending (top) and ascending (bottom) Suomi-NPP overpasses, whereas the right panel shows the corresponding cloud top pressure (CTOP) DR retrievals. The lower panels illustrate a good correspondence between GOES and the CrIS BT and CTOP retrieval products, confirming the DR's capability to correctly detect clouds and retrieve cloud altitude. For example, the deep convection that began to form over the Oklahoma/Kansas border region after 19:00 UTC and produced the first EF-4 tornado of 2016 is visible in both GOES and CrIS images.

COMPARISON WITH DR AND NUCAPS

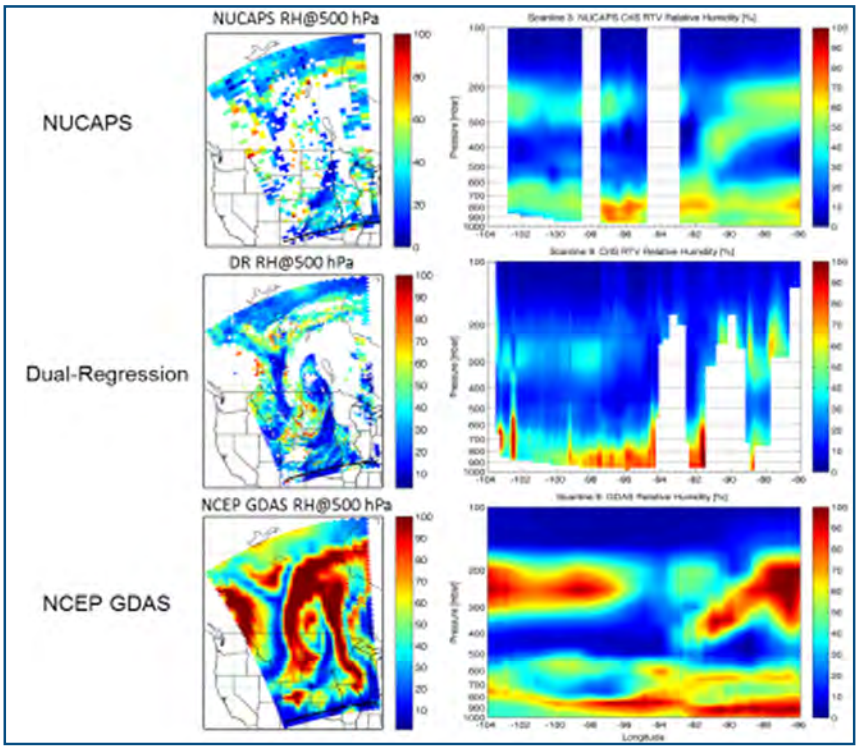
The image below shows the same CrIS BT and DR CTOP values as before but now temperature retrievals at 500 hPa derived from the DR (third panel) and NUCAPS (forth panel) have been added. When comparing DR with NUCAPS retrieval products the differences in spatial resolution is most obvious. As mentioned above DR and NUCAPS retrievals are available, respectively, at single FOV (~14 km) and a 3x3 FOV (~50 km) spatial resolution. Therefore, small spatial scale features, here in air temperature, like the colder regions visible in the western part of the lower DR image are missed by NUCAPS. On the other hand, NUCAPS, because it incorporates MW data, provides more retrieval data yield under cloudy conditions.



On May 11, as the severe thunderstorms continued to move across the Southern plains and into the Midwest, a mesoscale convective system (MCS) produced very large hail across the borders of Missouri and Illinois. Severe weather indices like the Convective Available Potential Energy (CAPE) and the lifted index (LI) are measures of atmospheric instability and critical for determining the potential of convection and severe weather. The DR and NUCAPS temperature humidity profile retrievals were used to derive these atmospheric instability indicators. The figure below describes severe weather occurring on May 11, 2016 in terms of CrIS BTs, the DR CTOP retrievals, as well as Lifted Index from both the DR and NUCAPS, for the descending and the ascending overpasses on May 11, 2016. In the morning NUCAPS provides more yield than the DR, although the regions with the deep and optically thick clouds are not available either. Please note that only qualitatively good NUCAPS retrievals are shown. In the afternoon the DR method is capable of detecting some nice small-scale features in LI, for example over the OK panhandle. Despite these differences, the regions of intense severe weather are detected by both methods with similar LI values. In this instance, the highest levels of instability were found over the entire states of Texas, Oklahoma, Arkansas and Missouri, as well as over eastern New Mexico.



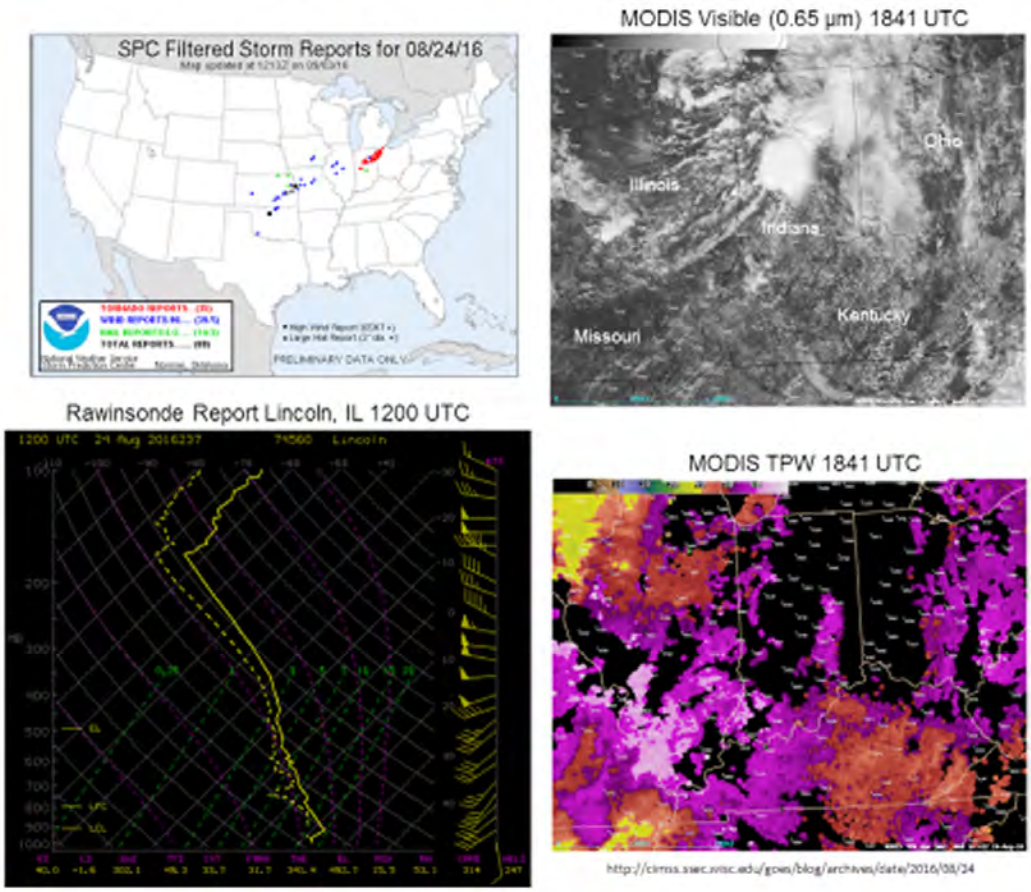
In the figures below relative humidity at 500 hPa and vertical cross-sections obtained from NUCAPS, DR and the National Center for Environmental Prediction (NCEP) Global Data Assimilation System (GDAS) show that taking into account the full granule over a large geographic area the DR seems to offer very similar yield in coverage compared to NUCAPS, and it provides more detail. For the cross section however, the deep convective clouds in the Eastern half are blocked since no DR retrievals are available under optically thick clouds; nevertheless the DR retrieval still provides values from the top of the atmosphere down to the could top, which can give forecasters an idea of the cloud attitude. NUCAPS, on the other hand, provides more yield in the right half of the image. The DR exhibits some artifacts (vertical lines) probably due to cloud contamination—optically thin cirrus (and low-level) clouds are difficult to detect from IR measurements alone because of their low contrast with the surroundings. The vertical features of NUCAPS humidity retrievals, which are derived from cloud-cleared radiances instead, correspond to the GDAS humidity field. It is noted that a global model shows in general less vertical structure than a local model would; furthermore model generated humidity is usually less reliable at levels below approx. 300 hPa.



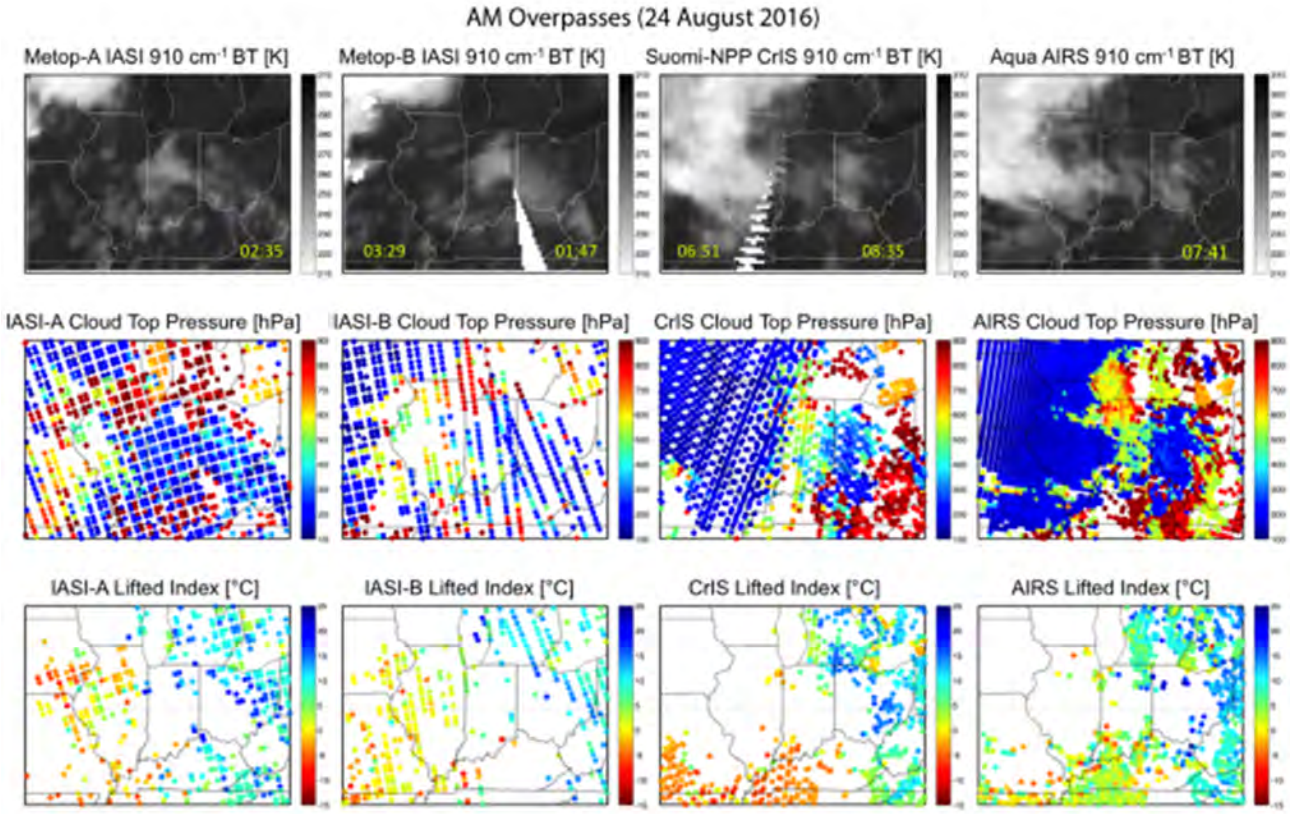
SEVERE WEATHER INDICES FROM OTHER OPERATIONAL SOUNDERS FOR CONSECUTIVE OVERPASSES

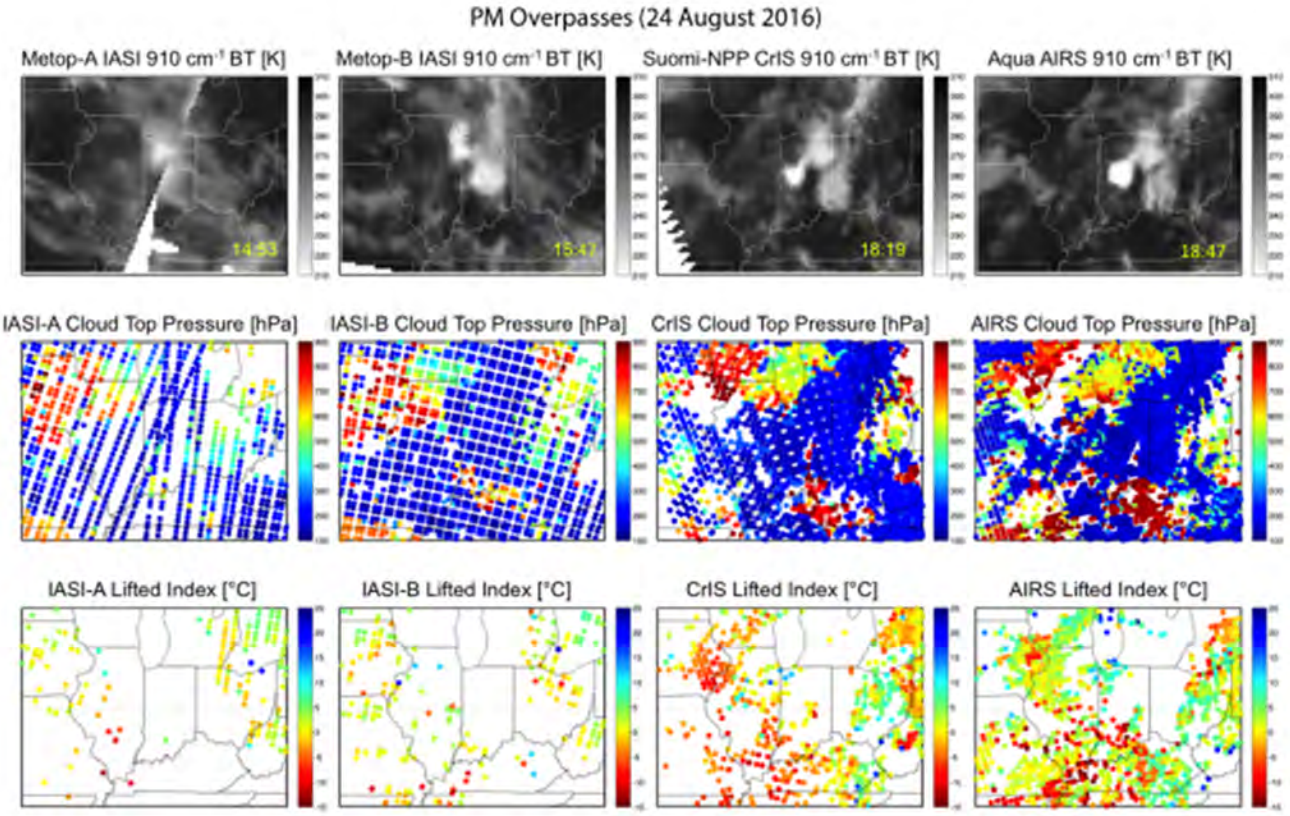
Tornado damage near Roberts/Doty Roads-Woodburn, IN (Scott Jordan Drone Footage/NWS Storm Survey).

On August 24, 2016 there were a total of 22 confirmed tornadoes across Indiana and Ohio. According to the NWS Northern Indiana's forecast area (IWX), a unique combination of extreme low level moisture and a passing upper level disturbance provided the trigger for severe storms. Even though the clouds remained in place for most of the day and it did not get very warm, there was just enough instability to allow storms to develop. There was also a high degree of shear in the lowest levels of the atmosphere, which allowed multiple tornadoes to form.

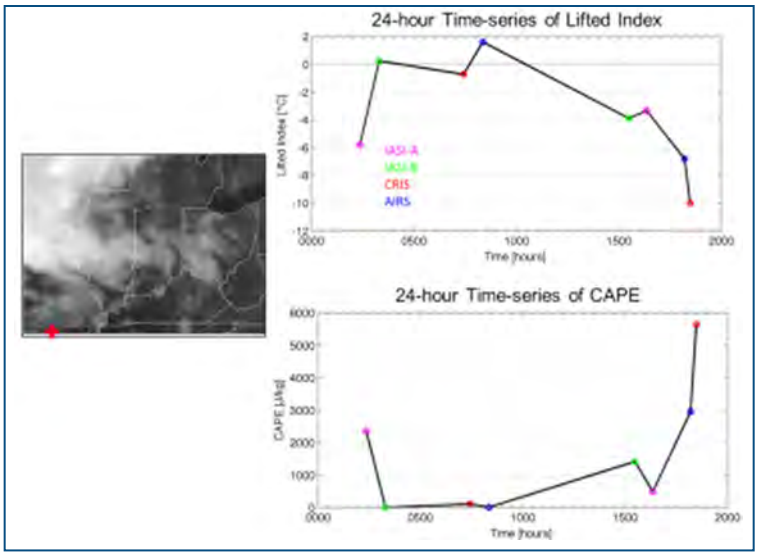


The MODIS imagery (upper right) captured the thunderstorm storm complex over central Indiana. In addition, the MODIS TPW product (bottom right) and the rawinsonde report at Lincoln, IL (bottom left) indicate that moisture was abundant in the region.


AM Overpasses (24 August 2016)
Metop-A IASI 910 cm-1 BT [K]
Metop-B IASI 910 cm-1 BT [K]
Suomi-NPP CrIS 910 cm-1 BT [K]
Aqua AIRS 910 cm-1 BT [K]
02:35
03:29
01:47
06:51
08:35
07:41
IASI-A Cloud Top Pressure [hPa]
IASI-B Cloud Top Pressure [hPa]
CrIS Cloud Top Pressure [hPa]
AIRS Cloud Top Pressure [hPa]
IASI-A Lifted Index [°C]
IASI-B Lifted Index [°C]
CrIS Lifted Index [°C]
AIRS Lifted Index [°C]


PM Overpasses (24 August 2016)
Metop-A IASI 910 cm-1 BT [K]
Metop-B IASI 910 cm-1 BT [K]
Suomi-NPP CrIS 910 cm-1 BT [K]
Aqua AIRS 910 cm-1 BT [K]
14:53
15:47
18:19
18:47
IASI-A Cloud Top Pressure [hPa]
IASI-B Cloud Top Pressure [hPa]
CrIS Cloud Top Pressure [hPa]
AIRS Cloud Top Pressure [hPa]
IASI-A Lifted Index [°C]
IASI-B Lifted Index [°C]
CrIS Lifted Index [°C]
AIRS Lifted Index [°C]

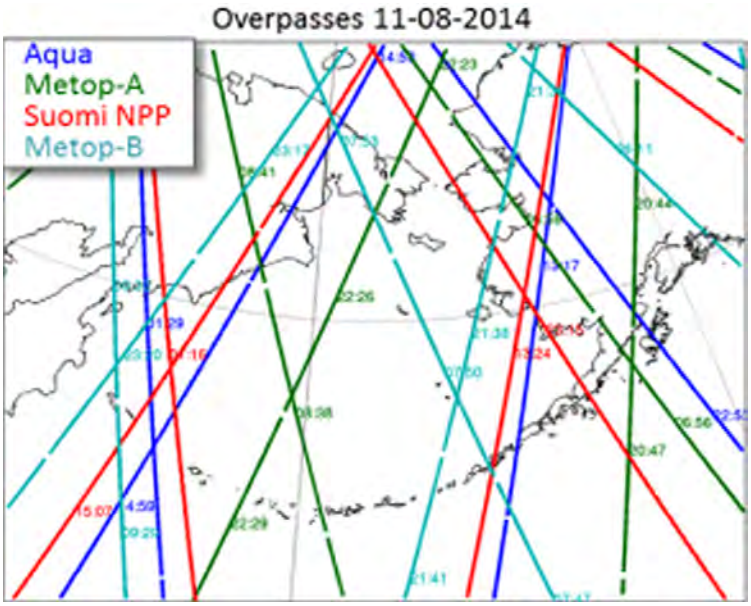
In the following it is shown how consecutive overpasses provide valuable information on convective instability, moisture transport and atmospheric motion. For that researchers compared BT measurements from IASI, CRIS and AIRS on different platforms in consecutive orbits and investigated how clouds and atmospheric stability evolve with time. BT, CTOP and LI dual-regression retrievals are shown above for the morning and afternoon overpasses on 24 August 2016. From the AM overpasses we can see a MCS moves in southeastern direction and reaches Illinois at the time of the S-NPP and Aqua overpasses. The southern part becomes very unstable, most evident in the CrIS LI panel. In the afternoon the thunderstorm complex, depicted previously by MODIS, becomes apparent. Optically thick clouds cover most of the region during the Metop-overpasses, which prevent LI retrievals from IASI. CrIS and AIRS, on the other hand, were able to describe the unstable atmosphere.



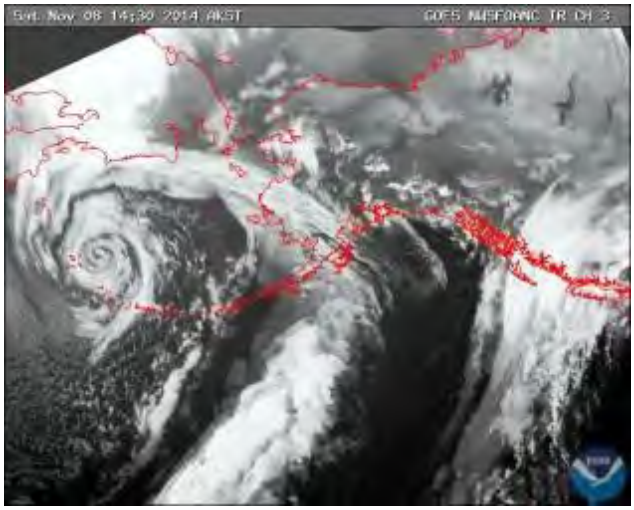
Next, for the same day and the location marked above, they looked at a time series of LI and CAPE over a period of 24 hours. The stability parameters from four sounders, IASI on Metop-A and Metop-B, CrIS and AIRS showed moderate instability followed by some stability that lasted a couple of hours before instability sharply increased beyond 10 UTC, consistent with NOAA SPC's storm reports and MODIS imagery.

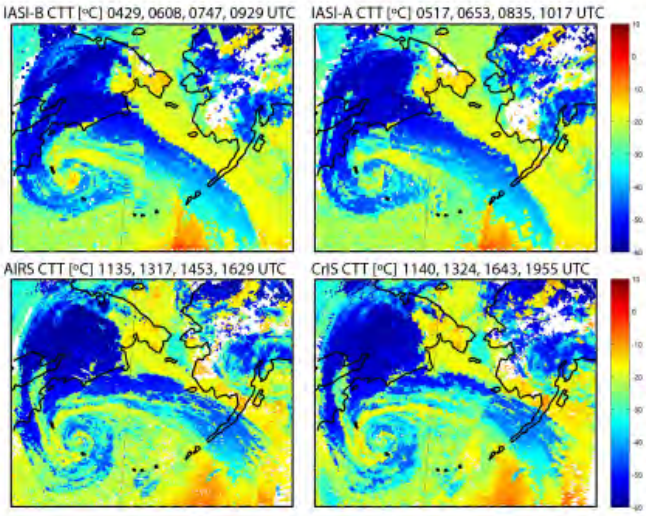
ALASKAN REGION (AR) APPLICATIONS

The hyperspectral sensors are even more important in providing high temporal resolution sounding and imagery for the Alaskan region. The JPSS PG Program has been working with Alaska to use this data to improve their situational awareness of current weather conditions. Alaska's lack of radar, surface stations, and upper air sounding coverage makes satellite data critical to its environmental support missions. The sounder data provides quantitative interpretation of weather imagery (e.g., the altitude of cloud and moisture features). High temporal frequency of polar satellite soundings at these latitudes can be critical to the observation of atmospheric tendencies (e.g., stability change) and moisture transport and wind profiles. The figure on the right shows the frequent overpasses from satellites that carry HS sounder instruments and this data can provide the key input for tracking dangerous winter storms as they quickly pass over the area.



Aqua, Metop A and B, and Suomi NPP passing over Alaska.





As an example of this application, in November 2014 the "Bering Sea Storm" formed from a storm out of the low-level circulation that separated from Typhoon Nuri and became one of the most intense extratropical cyclones ever recorded in the north Pacific. The image below shows the storm as captured by GOES channel 3 (from the NWS Anchorage); and the next images show subsequent IASI, AIRS and CrIS DR cloud top temperature (CTT) temperature retrievals, enabling the study of atmospheric dynamics by means of cloud and moisture motion.

CONCLUSION

Accurate retrievals from hyperspectral sounder (e.g., CrIS) radiance measurements under both clear and cloudy sky conditions are becoming indispensable sources of mesoscale information in a wide range of applications. By providing independent and detailed information about atmospheric vertical structure, clouds and the surface to complement visible imagery and traditional data products, hyperspectral data have the potential to greatly enhance regional weather monitoring and prediction capabilities.

Two hyperspectral retrieval capabilities are currently available through CSPP: the UW hyperspectral DR retrieval and NUCAPS. To promote the use of hyperspectral satellite data in meteorological and environmental real-time operations CIMSS scientist supported by the JPSS PG program identified the differences of algorithms and evaluated retrieval products by conducting inter-comparisons with independent sources for a variety of atmospheric conditions with the focus on severe weather. Severe weather indices, critical measures of atmospheric stability and severity of storms, were derived from hyperspectral sounder temperature and humidity profile retrievals. Stability changes were investigated for the severe weather event that occurred across the Midwest and Southern Plains in May 2016; due to different spatial resolution and algorithm design NUCAPS provides more coverage and DR more spatial detail in the retrieval products but overall the regions of intense weather are correctly identified by each method. The two algorithms provide complementary views of the real atmospheric conditions.

Furthermore, changes in atmospheric stability, dynamics and cloud heights that can be detected from subsequent orbits of multiple satellites (Metop-A, Metop-B, Aqua, S-NPP) provide critical information about severe weather initiation, storm path and intensity changes. This is in particular important in high latitudes, such as the Alaskan region (AR), since polar-orbiting satellite observations are critical to the region's situational awareness weather forecast and warning process.

CIMSS scientists continue to make improvements to the retrieval algorithms in order to optimize spatial and vertical information from the hyperspectral sounders for a variety of real-time applications. For example, ongoing DR work focuses on improving the fine-scale vertical structure of temperature and humidity profiles for data assimilation purposes by applying a de-aliasing adjustment. With this the scientists continue their efforts to increase the use of hyperspectral retrieval products within the DB data user community as well as in weather monitoring and forecasting operations.

References

Smith, W. L., E. Weisz, S. Kirev, D. K. Zhou, Z. Li, and E. E. Borbas (2012), Dual-Regression Retrieval Algorithm for Real-Time Processing of Satellite Ultraspectral Radiances, J. Appl. Meteor. Clim., vol. 51, no. 8, pp.1455–1476, doi: http://dx.doi.org/10.1175/JAMC-D-11-0173.1.

Gambacorta, A., et al. (2013), The NOAA Unique CrIS/ATMS Processing System (NUCAPS): Algorithm Theoretical Basis Documentation, Version 1.0, NOAA Center for Weather and Climate Prediction (NCWCP), 5830 University Research Court 2nd Floor, Office 2684 College Park, MD 20740-3818, USA.

Weisz, E., N. Smith, and W. L. Smith Sr. (2015a), The use of hyperspectral sounding information to monitor atmospheric tendencies leading to severe local storms, Earth and Space Science, 2, 369–377, doi:10.1002/2015EA000122.

Weisz, E., W. L. Smith, N. Smith (2015b) Assessing Hyperspectral Retrieval Algorithms and their Products for Use in Direct Broadcast Applications, 20th International TOVS Study Conference (ITSC-20) proceedings, 28 October–3 November 2015, Lake Geneva, Wisconsin, USA; paper 3.03. Available at http://cimss.ssec.wisc.edu/hiresdb/resources/pub/files/papers/AssessingHSRetr_Weisz_ITSC20_2015.pdf

EXTENDING THE GLOBAL BIOMASS BURNING EMISSIONS PRODUCT (GBBEPX) WITH DATA FROM NEXT GENERATION POLAR-ORBITING SATELLITE SENSORS

The information in this article is based, in part, on the March 20, 2017 JPSS science seminar presented by Shobha Kondragunta, Ph.D., NOAA NESDIS, Center for Satellite Applications and Research.

Biomass burning and smoke aerosols released into the atmosphere negatively impact human health and economy. The nightly newscasts are full of stories of the public's response to wildfires. Entire communities are put at risk from flames as they race through their neighborhoods. People are evacuated and face displacement for weeks or even months as their houses are rebuilt. Businesses are destroyed and the people put out of work and are faced with mounting bills as they try to put their lives back together. Wildfire smoke can sometimes have a higher impact on communities, yet, it may not garner nearly as much attention. This smoke can be transported long distances downwind and endanger people with heart and respiratory conditions. According to World Health Organization, in 2012, an estimated 3 million premature deaths related to outdoor air pollution occurred worldwide. Ozone from Siberian forest fires can impact air quality in the Pacific Northwest United States; smoke from Central America and the Yucatan Peninsula causes lower air quality from Texas to Georgia; some North American and Siberian plumes have even been shown to reach the eastern Atlantic and Europe from the surface through the lower stratosphere (Reid et.al., 2009). This necessitates the availability of information on biomass burning and emissions in near real time for air quality forecasting and monitoring. For the operational decision making process, these data can serve as primary determinants to answer questions regarding the smoke associated with a fire, its location and trajectory, impact on air quality, evacuations, road closures and so forth.

The National Weather Service (NWS) uses many numerical models to forecast smoke transport and air quality. One of the models that the JPSS Program is partnering with is the High-Resolution Rapid Refresh (HRRR) Smoke Modeling System. The HRRR-Smoke model is based on the Weather Research and Forecasting model coupled to Chemistry (WRF-Chem, http://ruc.noaa.gov/wrf/WG11/). The dynamics and physics packages and settings for the meteorology of HRRR-Smoke are based on the experimental version of the HRRR model, which is run in real-time (http://rapidrefresh.noaa.gov/hrrr/) at NOAA/ESRL Global Systems Division (GSD). HRRR-Smoke has been developed to simulate the emissions and transport of smoke from wildfires in real time in high spatial resolution. A simple Gaussian profile is used to determine the diurnal cycle of the fire emissions in the model. Thus, temporal variability of the simulated smoke concentrations in each forecast depends on varying fire emissions, plume rise, also transport of smoke by wind and turbulent mixing, and removal processes. NWS also uses the Hybrid lagrangian Single Particle Integrated Trajectory

(HYSPLIT) and the National Oceanic and Atmospheric Administration (NOAA) Environmental Modeling System Global Forecasting System Aerosol Component (NGAC) to provide smoke and aerosol forecast guidance. The first version of NGAC only had dust, while the second version includes biomass burning aerosols. These models need to know where the fires are located, aerosol and trace gas amounts being emitted, at what height is the plume injected, and the duration of the fire. Satellites have data and products to help provide input to some of these needs. A basic understanding of fires is a helpful first step in setting up a process to leverage satellite capabilities for smoke and aerosol forecasting.

TYPES OF FIRES

Fires and their resultant smoke come in all sizes and shapes as illustrated above, and they do not emit the same amount of aerosols. Several factors accounting for these differences include the fuel type (what is being burned), the weather conditions in the fire area, and whether the fire is controlled or uncontrolled. Unless prescribed, most fires occur from natural phenomena like lightning, or from careless human acts such as a discarded cigarette or a camp fire that is not put out correctly. So often these fires occur with little warning. Thus there is no way models can know a priori where a fire will happen or the amount of aerosols being emitted. Having earned a respectable place in active fire detection, remotely sensed satellite observations also provide important parameters for calculating source emissions, and near real time monitoring of human exposure to smoke. The near real time (NRT) availability of fire emissions data including the location, radiative power and duration (if satellite is in geostationary orbit observing the same fire multiple times in a day) is critical for accurate aerosol forecasts. Let's look at some of the other important variables in aerosol and smoke forecasting.

PLUME INJECTION

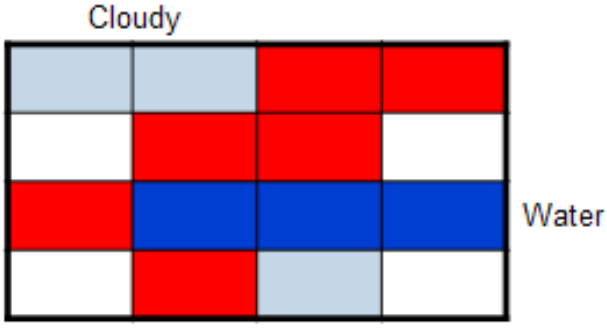
Plume injection, the height that particles can reach after they are ejected from wildland fires, is a critical factor which determines the impact of fire emissions on air quality. If injected into higher elevations, particles from plumes can be transported by prevailing winds to a great distance from their source. This can create hazards to human health and the environment thousands of miles from a burn site. But, a model cannot properly account for a plume's horizontal transport, if its injection is not placed in the correct layer of the atmosphere. The upper boundary of the plume injection is dependent on such things as: the amount of heat

released from the fire, impacting the height that the air will rise; the moisture content of the fire fuels; and the temperature and moisture conditions of the column of air in the fire areas. For example, the smoke plumes in the Peate fire (above left) are almost hugging the surface, whereas the plumes (shown above right) have been injected to a much higher elevation. Thus if the aerosol loading from the plume that is injected into the higher elevations is placed in the surface layer of the atmosphere, that could lead to an over prediction of the aerosols by a model. Similarly, placing the plumes in the Peate fire anywhere besides the lowest level of the atmosphere would also derive incorrect results. Yet, many models fail to properly account for this key input because there is no real time information from satellites.

EMISSIONS

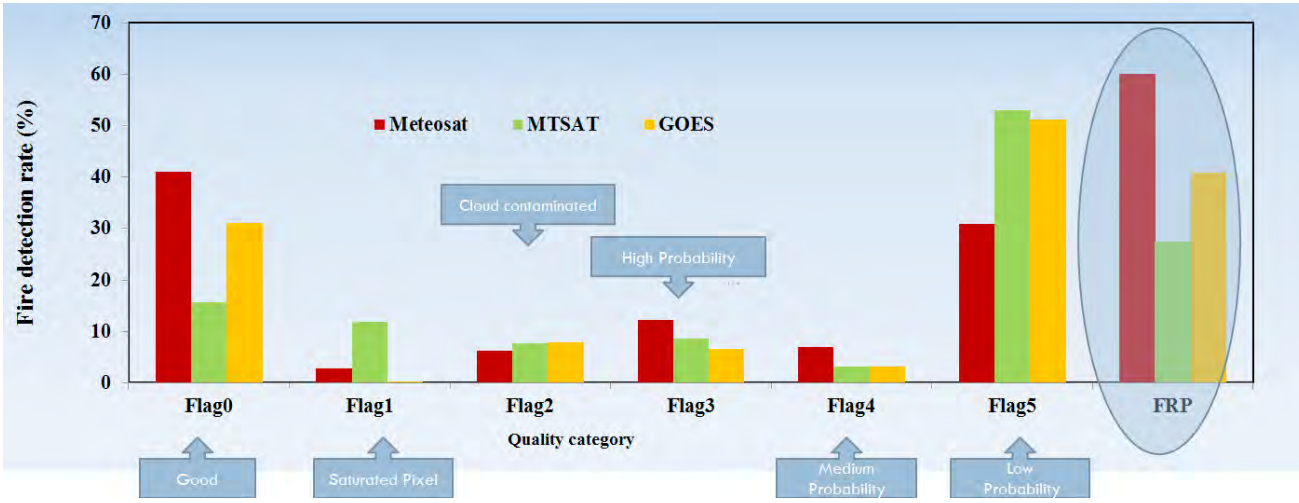
The rate of biomass consumption is a function of area being burned, fuel loading, and combustion efficiency. Ground observations cannot provide a synoptic view of the landscape or information on biomass burning emissions in a timely fashion. Satellite observations are able to show the fire extent across a large area, relatively quickly. Satellite imagery also shows the distribution of smoke associated with fires. Over the years satellite observations have proven to be a vital complement to ground-based and aircraft observations in a wildfire environment.

The Fire Radiative Power (FRP) derived from satellites has become one of the most actively used measurements for quantifying burned biomass. NOAA's operational global biomass burning emissions product (GBBEP) is based on a network of polar-orbiting and geostationary satellite sensors. Geostationary satellites provide observations of diurnal fires every 15–30 minutes. But these observations can sometimes be impacted by factors such as sensor saturation, cloud cover, and background surface, canopy cover, heavy fire smoke, and view angle of satellites. Because geostationary satellites do not cover the high latitudes, a more global view of biomass burning emissions relies on fire observations from polar-orbiting satellites. However, their low overpass frequency limits the application of emission estimates for atmospheric and chemical transport models. The current operational biomass burning emissions product is derived from GOES E, GOES W, and the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on the NASA Aqua and Terra spacecrafts. Suomi NPP VIIRS has been added to the suite in December 2017. Data from Himawari 8 and 9 and GOES-16 will be considered in the future.



The process for determining fire emissions begins when satellite Fire Radiative Power (FRP) products are placed in a model grid measuring 0.25° x 0.315°. As fires cannot burn over water, the "wet" pixels are ignored. Pixels that are collected over clear land are aggregated for each biome type, i.e., forests, savanna, shrubs, grasslands, and croplands. Because it is difficult to tell whether a pixel under a cloud is burning, FRPs for cloudy

land pixels are derived using optimal interpolation. The FRPs for cloudy/missed detections are temporally interpolated for geostationary satellites. The result is seen in the figure below shows the proportion of fire observations with different quality levels using data from different satellites. These observations are assigned flags and only data with good quality are used in deriving emissions.



The algorithm assumes that the shape of the FRP diurnal pattern is similar in a given ecosystem and that the diurnal pattern of FRP for a given fire pixel can be reconstructed by fitting the climatological diurnal curve corresponding to that ecosystem to the detected fire FRP values. This approach reduces the impacts of missing fire observations caused by cloud cover, sensor saturation, etc.

COMPUTING EMISSIONS

Emissions are computed using Fire Radiative Power (MW) and emissions factors (g/Kg) as input per Equation 1.

$$E = FRP*\beta*EF \quad (1)$$

Where E is emissions in units of kg, β is a coefficient in units of kg/MJ derived from lab measurements and EF are emissions factors, also derived from lab measurements and depend on biomass type. FRP is calculated from satellite observations using Equation 2.

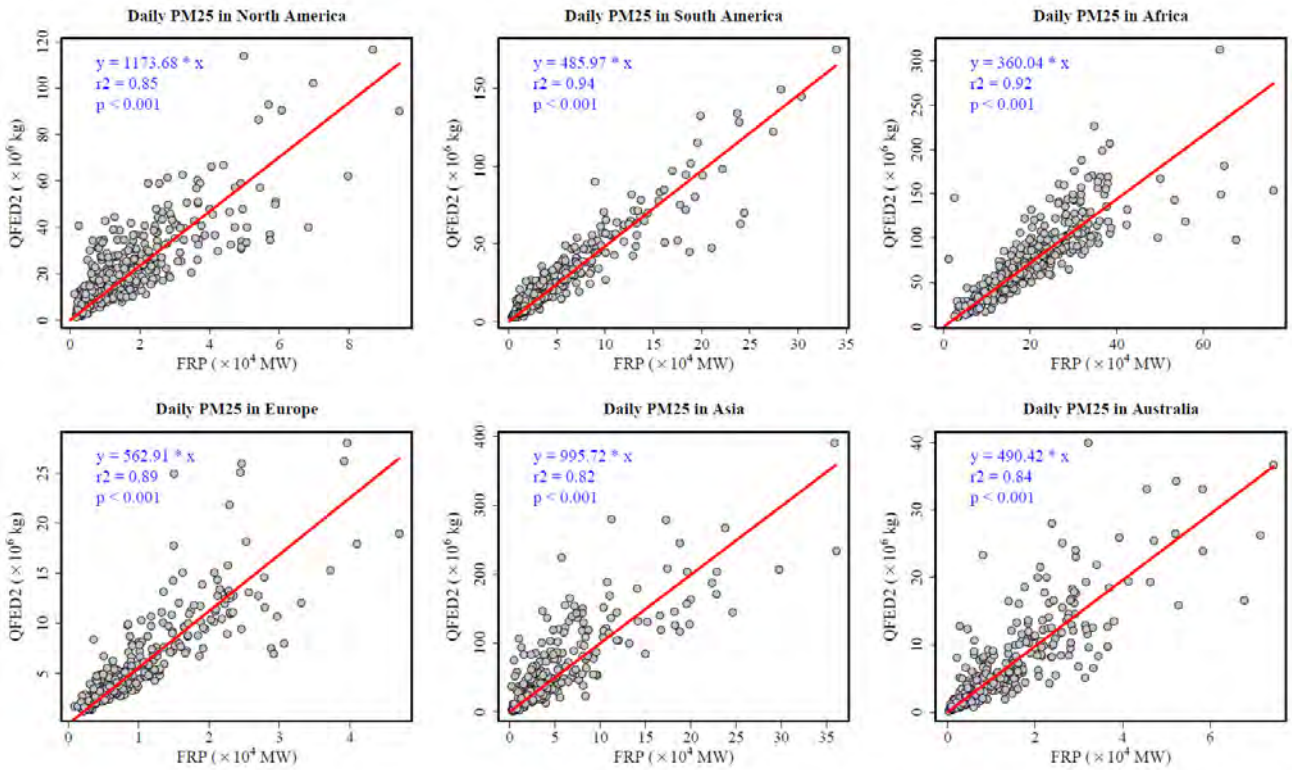
$$\boldsymbol{FRP} = \frac{T\, S_p\, \sigma\, (L_f - L_b)}{c}\, \mathbf{10^{-6}} \quad (2)$$

In Equation 2, S_p is pixel area, σ is Stephan-Boltzman constant, L_f and L_b are radiances for fire and background respectively, and *c* is a constant. The FRP values for fire hot spots from geostationary satellites and polar-orbiting satellites are spatially and temporally interpolated and remapped into the fixed grid prior to calculating emissions using Equation 1.

SCALING FACTORS

Prior to blending emissions from individual satellites, they are all normalized/scaled with respect to MODIS emissions derived using QFED (Quick Fire Emissions Data). This is done to adjust the differences between different emissions dataset which arise due to ability of each sensor to derive FRP accurately. This is done via scaling factors which are determined by correlating each satellite emissions product with QFED data. These scaling factors are a function of biomass types observed in different parts of the globe and are the slope values of QFED emissions (kg) correlated with individual satellite derived FRPs (MW). In the figure below, these scaling factors for VIIRS estimates of PM2.5 (smoke particles) for different regions of the world.

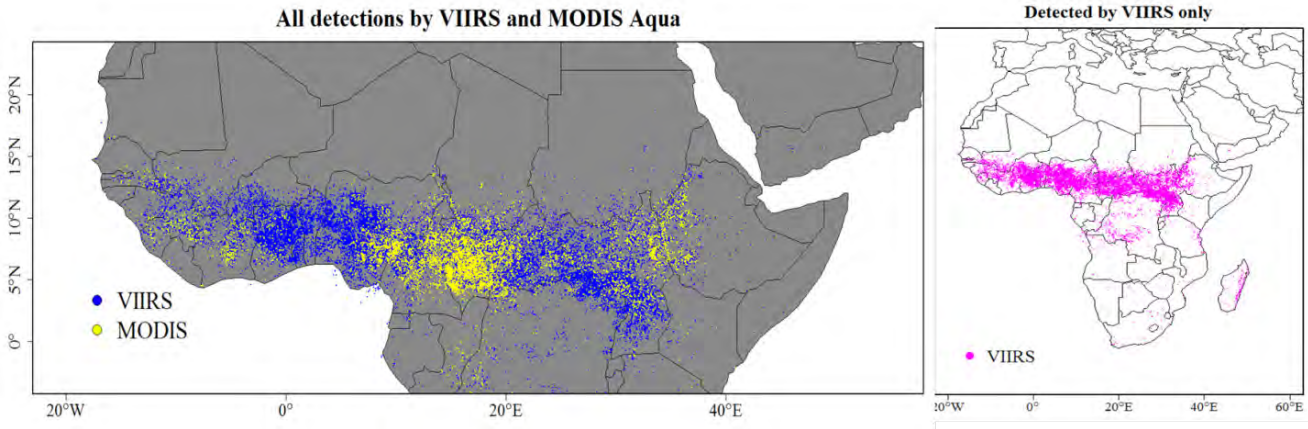
The next section describes VIIRS fire products including FRP to elaborate on why these scaling factors (normalizing to QFED) are needed.



FIRE PRODUCTS FROM THE VISIBLE INFRARED IMAGING RADIOMETER SUITE

The initial VIIRS operational fire product only reported fire location. Additional work resulted in an updated code which provided pixel information and the Fire Radiative Power (FRP) product. These new capabilities became operational within the Suomi NPP Data Exploitation (NDE) system in May 2016. To date, data from May 2016 has been analyzed to understand the product and determine unique scaling factors for VIIRS. In addition, a sample of VIIRS emission data (September 2016 to present) has been provided to the NWS for test runs in NGAC model simulations to demonstrate the value of this NRT fire emissions data in the NWS ability to provide accurate aerosol forecasts in support of various decision support systems.

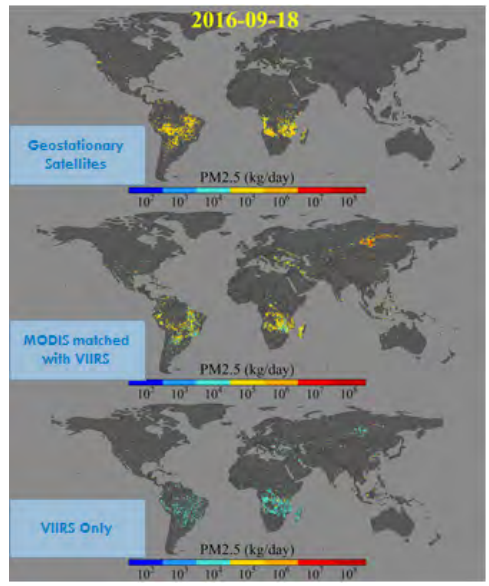
Below is one example from January 9, 2016 which shows all detections from VIIRS and MODIS as well as detections from VIIRS only. In in this example, VIIRS seems to detect more fires than MODIS.

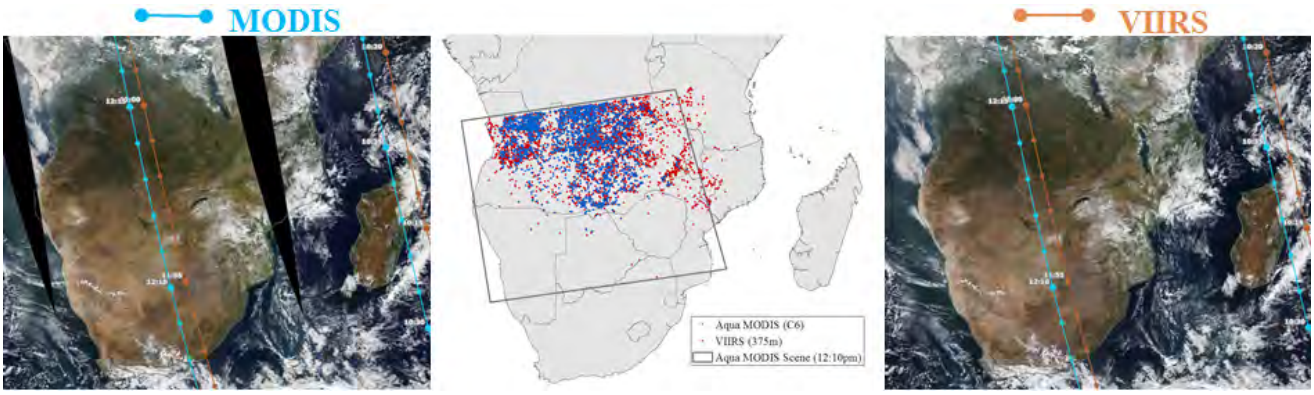


Another example (right) from September 18, 2016 shows similar results.

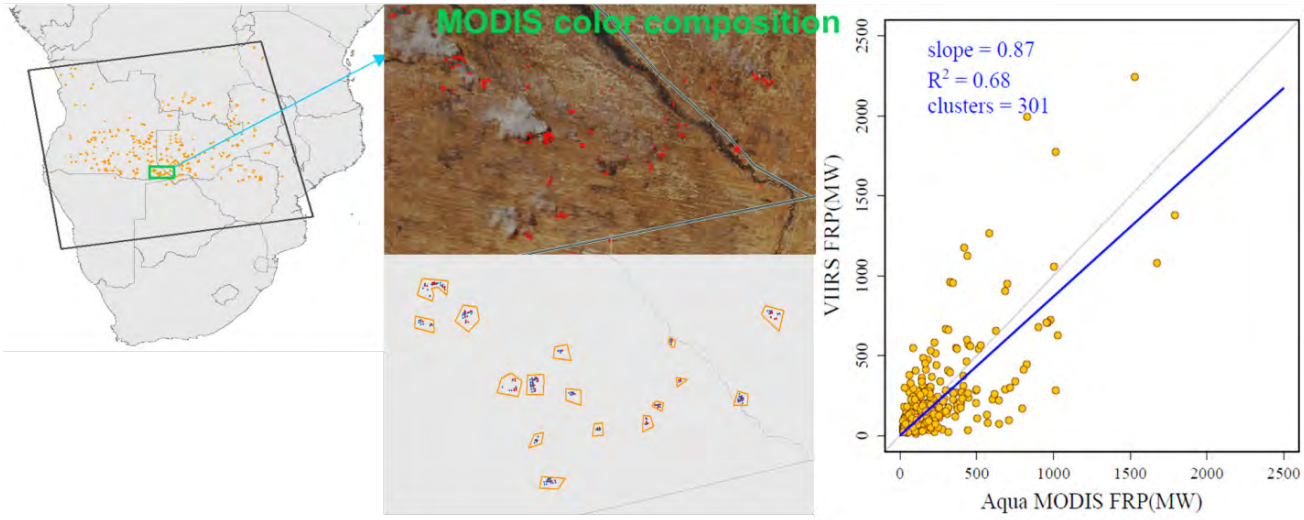
A possible reason for this could be that VIIRS wider swath allows fires not detected by MODIS which has orbital gaps in low latitudes. Another reason could be due to granule overlap, whereby the same fire is detected twice from two different orbits leading to the VIIRS observing the same fire twice.

To illustrate, the following figures (below) show I-band retrievals of VIIRS at 375 meters matched against MODIS retrievals from the Aqua satellite from passes over Southern Africa on June 3, 2016. VIIRS detects fires in the region not covered by MODIS.





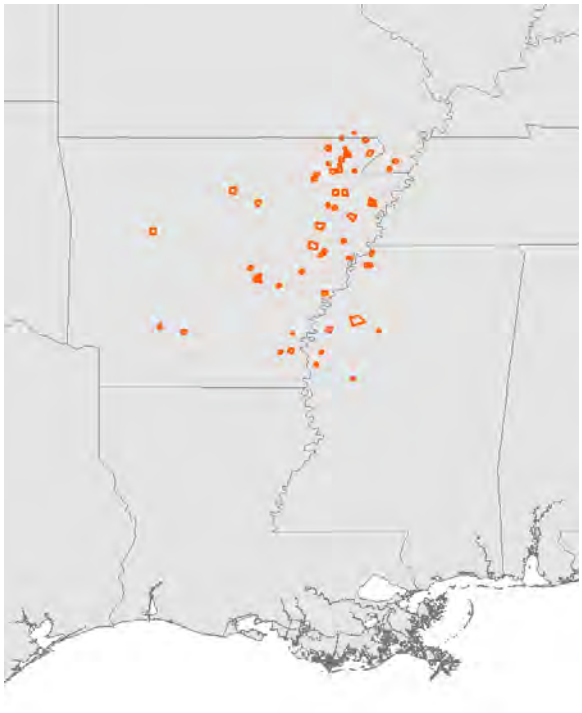
VIIRS CASE STUDIES

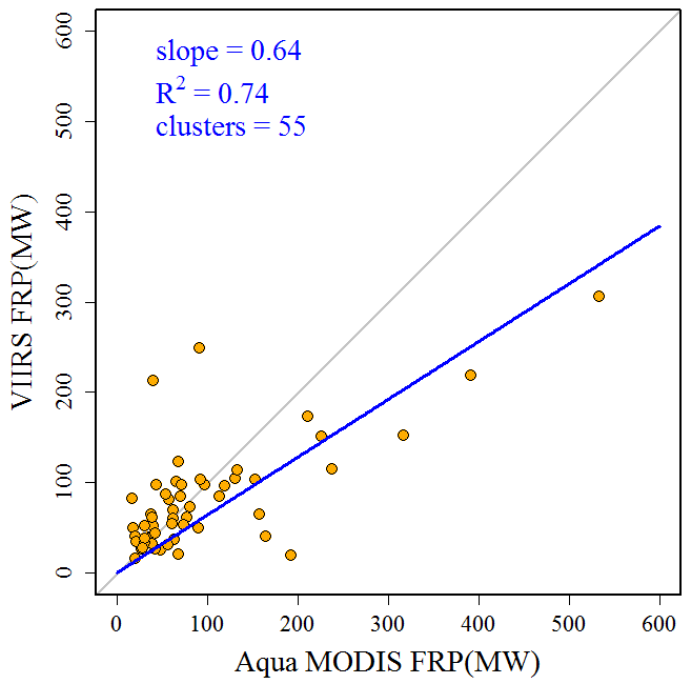


The case study above shows fire events observed on August 22, 2016 as VIIRS and MODIS passed over Africa. The fires from MODIS and VIIRS are matched in individual fire events. Each fire event is considered as a cluster. In this case, 301 fire events were selected. The middle panel depicts active fire pixels in fire events. The red pixels represent VIIRS, while the blue pixels represent MODIS. As seen in the MODIS image, some

fires hardly emitted smoke—an indication of small fires—which is consistent with the small FRPs generated from the VIIRS and MODIS observations.

In another case, satellite overpasses from both VIIRS and MODIS over the US on January 28, 2017 generated very low FRPs, indicating that these were not large forest fires.





EVALUATION OF REGIONAL AND GLOBAL MODELS WITH SATELLITE PRODUCT ASSIMILATION

Satellite observations from instruments such as VIIRS are utilized by algorithms to generate inputs for regional models such as Community Multiscale Air Quality (CMAQ) and global models such as NOAA Global Aerosol Forecast Aerosol Component Version 2 (NGAC-V2) that predict aerosols. NGAC V2 simulations were run at 1 x 1 degree resolution. GBBEPx was assimilated and NGAC simulations were run for September 2016. The results below show the model runs validated against various AERONET stations.

	RMSE		Bias		R^2	
	V2	v1	V2	v1	V2	v1
Fort McMurray	**0.2932**	0.5371	**0.02**	-0.1125	**0.41**	0.076
Alta Floresta	**1.098**	1.24	**-0.251**	-0.292	**0.08**	-0.122*
Lake Argyle	**1.118**	1.181	**-0.1748**	-0.202	**-0.0098***	-0.065*

Smoke dominated AERONET stations.

	RMSE		Bias		R^2	
	V2	v1	V2	v1	V2	v1
Beijing	**0.704**	1.656	**-0.143**	-0.606	**0.334**	0.012
Lille	**0.2862**	0.5522	**0.052**	-0.1411	**0.177**	0.106
GSFC	**0.339**	0.633	**-0.06**	-0.152	**0.074**	0.148
ARM SGP	**1.385**	1.551	**-0.124**	-0.219	**0.047**	0.035

Mixed aerosol dominated AERONET stations.

SUMMARY

For biomass burning scenarios, satellite capabilities have proven to be essential for a model to be able to accurately predict aerosols. Data from both geostationary and polar-orbiting satellites have been blended together in the GBBEPx product and work is nearing completion for Suomi NPP VIIRS data to be added into the operational processing. The assimilation of GBBEPx biomass burning emissions into the NGAC-V2 model, has improved its performance by 30%. This success provides exciting opportunities for this model to be used in new applications such as determining its impact on Sea Surface Temperature retrievals, improvements to UltraViolet (UV) Index forecasts, and evaluating regional air quality predictions when long range transport of smoke aerosols impacts regional air quality. With the launch of NOAA-20 in November 2017, researchers and modelers look forward to a wealth of polar orbiting data for years to come.

References

Reid et.al., IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, Vol. 2, No. 3, September 2009

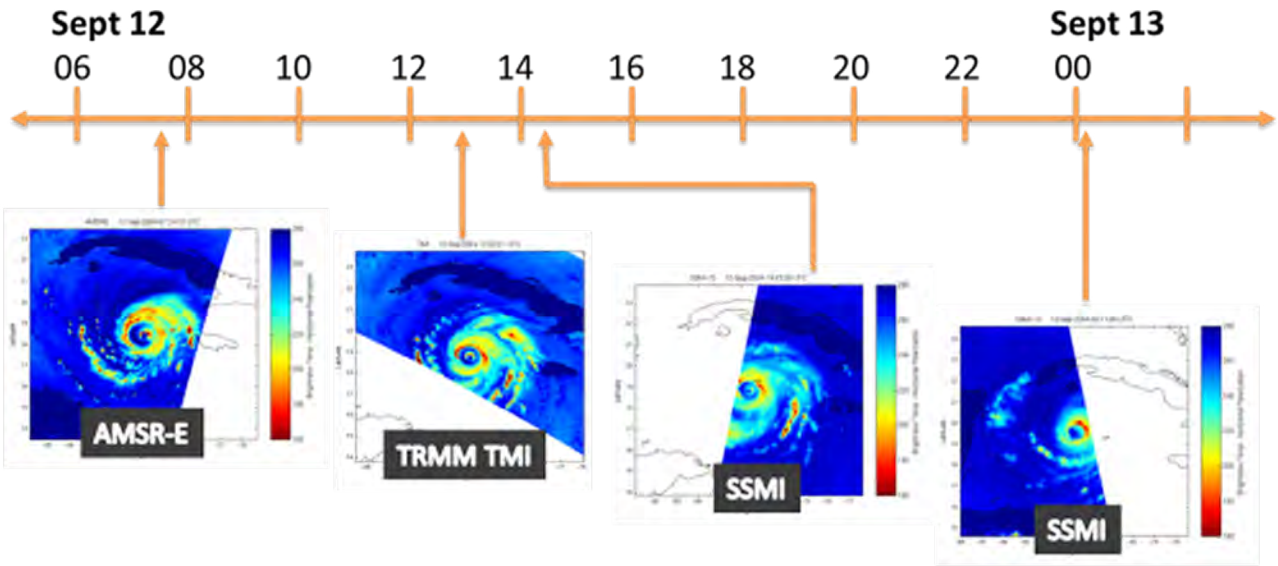
World Health Organization, Ambient (Outdoor) Air Quality And Health Fact Sheet, Updated September 2016, http://www.who.int/mediacentre/factsheets/fs313/en/

Zhang, X., S. Kondragunta, and B. Quayle (2011), Estimation of biomass burned areas using multiple-satellite-observed active fires, IEEE Trans. Geosci. Remote Sens., 49, 4469–4482, doi:10.1109/TGRS.2011.2149535.

Zhang, X., S. Kondragunta, J. Ram, C. Schmidt, and H.-C. Huang (2012), Near-real-time global biomass burning emissions product from geostationary satellite constellation, J. Geophys. Res., 117, D14201, doi:10.1029/2012JD017459.

PROVIDING SITUATIONAL AWARENESS THROUGH MORPHED INTEGRATED MICROWAVE IMAGERY FROM POLAR-ORBITING SATELLITES

The information in this article is based, in part, on the April 24, 2017 JPSS science seminar presented by Tony Wimmers, Cooperative Institute for Meteorological Satellite Studies, Space Science and Engineering Center, University of Wisconsin-Madison. With contributions from Chris Velden, Jordan Gerth, Andy Heidinger and Scott Bachmeier.



Movement of Hurricane Ivan from Sept 12 to 13 shown through individual swaths from several instruments including the Advanced Microwave Scanning Radiometer for EOS (AMSR-E), the Tropical Rainfall Measuring Mission Microwave Imager (TRMM-TMI) and the Special Scanning Microwave Imager (SSMI).

Traditional global composites of data do not represent the state of the atmosphere at a single time. For example, individual swaths (shown above) may give an indication of where a weather event such as a tropical cyclone is situated, but the time gaps make it difficult to piece the sequence of images together and construct a full story. While forecasters may be able to infer the progression of an event, they can still miss other important details in the temporal resolution of the data. Dynamic animations, on the other hand, allow a forecaster to visually ingest many important features associated with an event such as a frontal passage, the progression of an atmospheric river or the feeder bands of a tropical cyclone. This can help enhance an end user's forecast as well as their situational awareness.

This article describes the Morphed Integrated Microwave Imagery at CIMSS—Total Precipitable Water (MIMIC-TPW) which takes advantage of the constellation of five polar-orbiting satellites to make observations for every part of the globe roughly every six hours. With water vapor for example, transport is the primary reason for changes in distribution between satellite scans, and it can be estimated quite well using numerical model winds. To provide a better sense of why and how MIMIC-TPW produces highly fluid and intuitive depictions of atmospheric variables such as water vapor, the article will begin with a brief background. In addition, the article will remark on some factors forecasters need to consider when interpreting this new form of derived product, and the larger implications for applying these methods to atmospheric imagery.

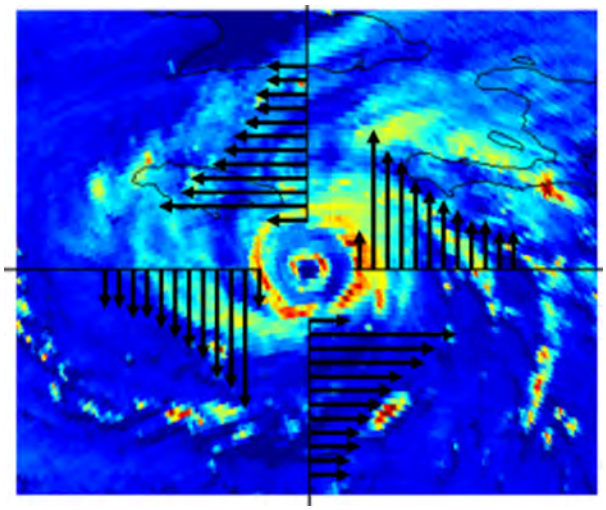
POLAR-ORBITING SATELLITES: CHALLENGES AND OPPORTUNITIES

Polar orbiting satellites monitor the entire Earth, tracking global weather and providing atmospheric data and images of environmental features. Their data, which is provided to the forecasting and science community as either global, daily composites, or as single local overpasses, is critical for weather analysis and forecasting. Because of their low altitude overpasses, these satellites are able to capture detailed vertical profiles of temperature and moisture in the atmosphere. But unlike geostationary satellites, they cannot provide continuous observations over one spot. With satellite orbits of roughly 100 minutes, they can only provide a few instantaneous measurements at the same position per day. On average, polar-orbiting satellite sensors can view any point on the Earth at least twice per day (twelve hours apart) in most regions

of the globe, except at higher latitudes where the revisit time is shorter. The time difference and data gaps between overpass swaths tends to shortchange the wealth of information in these observations, and hide the potential for more rapid updates which are available. Undeterred by these conventional limits, scientists have found a way to interpolate and extrapolate global data in real time from multiple polar-orbiting satellites and create visualizations that animate changes in the atmosphere. Their family of algorithms morphs that data in such a way that it is able to overcome the associated time gaps and increase its frequency allowing for it to be applied in ways not possible before. The Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin first tested this concept in their study of Tropical Cyclones. This research was supported by the Naval Research Lab. Researchers at CIMSS focused on microwave imagery in the ice-scattering range (85–92 GHz), which can be interpreted similar to a ground-based radar animation. The product CIMSS created was called the Morphed Integrated Microwave Imagery at the Cooperative Institute for Meteorological Satellite Studies of Tropical Cyclones (MIMIC-TC)

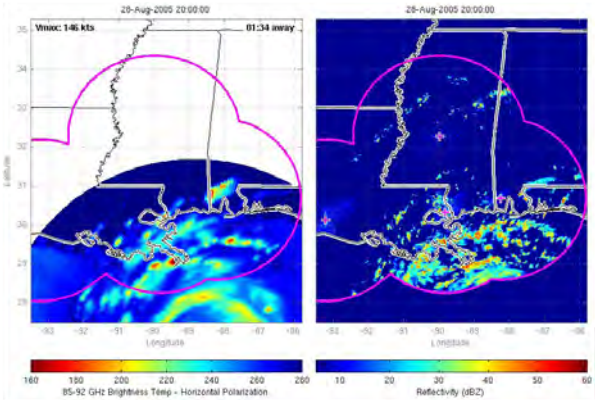
MIMIC-TC AT WORK

As referenced in the picture (right), the MMIC-TC product is a synthetic blend of tropical cyclone imagery from five low-Earth orbiting satellite instruments: the DMSP-13/14/15 SSM/I (85 GHz channel), the TRMM TMI (89 GHz channel, now using the GPM GMI) and the Aqua AMSR-E (85 GHz (A) channel, now using the GCOM-W1 AMSR2). The algorithm strikes a balance between these different kinds of motion and imposes an advection scheme on the microwave signal that is a function of radius and reported maximum wind speed. The algorithm works by blending purely interpolated images into one another, and also by rotating the interpolated images throughout the blending process. Two select cases, Hurricane Ivan in September 2004, and Hurricane Katrina on 26 Aug 2005 are presented here to show some early using MIMIC-TC.



10 Sept, 1829 UTC
Methodology: Identify center, apply advection proportional to reported maximum winds

As CIMSS continued to work on the MIMIC-TC capability their success became obvious as they tracked various tropical cyclones and compared them with radar reflectivity. The images below show Hurricane Katrina as it neared landfall on 26 Aug 2005. Subsequent images showed the arrival of the outer rain bands, the double eyewall and Katrina's eyewall evolution.



Left: MIMIC Brightness Temperature
Right: NEXRAD Composite Base Reflectivity

These tools reinforced that satellite-based passive microwave imagery of TCs is an invaluable resource for assessing the organization and evolution of convective structures in TCs when often no other comparable observations exist. MIMIC-TC continues to allow forecasters and analysts to use microwave imagery to follow trends in a tropical cyclone's structure more efficiently and effectively, which can result in higher-confidence short-term intensity forecasts.

MIMIC became the cover story of the August 2007 issue of the Bulletin of the American Meteorological Society, spreading its story to the worldwide weather community.

The success of MIMIC-TC led CIMSS to consider how else this capability could be used. The Total Precipitable Water Product (TPW) has become a valuable input to forecasters tracking heavy precipitation events. The TPW product became a prime candidate for MIMIC. After the launch of Suomi NPP the JPSS Program provided funds to bring its ATMS data into this product.

MORPHED INTEGRATED MICROWAVE IMAGERY AT CIMSS—TOTAL PRECIPITABLE WATER

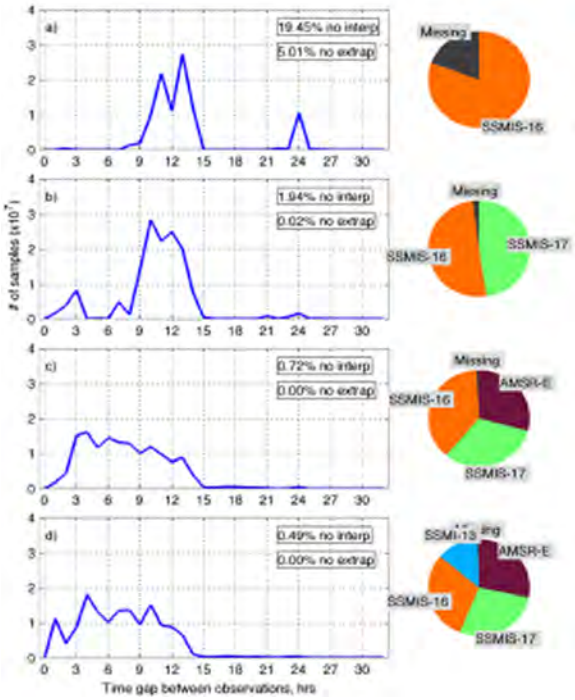
MIMIC-TPW was created by scientists at the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin-Madison to provide a near real-time visualization tool depicting global water vapor in the atmosphere. The original MIMIC-TPW algorithm (version 1) uses real-time data from the U.S. military Defense Meteorological Satellite Program (DMSP) class of microwave instruments: the Special Sensor Microwave Imager (SSM/I), and the Special Sensor Microwave Imager/Sounder (SSMI/S); and the Advanced Microwave Scanning Radiometer (AMSR) sensor onboard the NASA Aqua satellite. The product provides retrievals over oceans, but none over ice or land. A newer version of the MIMIC-TPW product (Version 2) takes advantage of microwave instruments from several polar-orbiting satellites including the Suomi-NPP satellite in the Joint Polar Satellite System (JPSS). Retrievals from next generation sounders such as the Advanced Technology Microwave Sounder (ATMS) are enabling retrievals over water, ice and land.

WHY TPW?

TPW is one of the ways used to express the amount of water vapor in the atmosphere. It is the “thickness” of the amount of liquid water corresponding to the total amount of water vapor in the atmospheric column. Water vapor is one of the most important drivers of the Earth’s atmospheric circulations, weather systems and climate patterns. As it condenses it forms clouds, rain or snow, which transfer heat, redirect solar radiation, and transport water around the globe. Water vapor has the most immediate and obvious impact as the basic fuel for severe weather, tropical cyclones and other precipitation related events. TPW is the go-to retrieved quantity for forecasting because it provides information on how much moisture is in the air and its impact on weather. TPW provides information on other features in the Earth’s atmosphere as well. For example, the dry pockets in TPW coming off areas like the Sahara desert are known to hold high levels of fine aerosols, which forecasters use to predict air quality and cloud formation.

There are several methods of measuring the amount of water vapor in the atmosphere. These include remotely sensed measurements derived from microwave and infrared frequency satellite observations. Microwave sounders on polar-orbiting satellites are able to “see” through clouds, and therefore provide complete global retrievals, which visible and infrared soundings cannot do. As MIMIC-TPW relies exclusively on microwave observations, it is able to overcome the time gaps and increase the frequency of data when multiple polar-orbiting satellites are available (as shown in the figure on the next page).

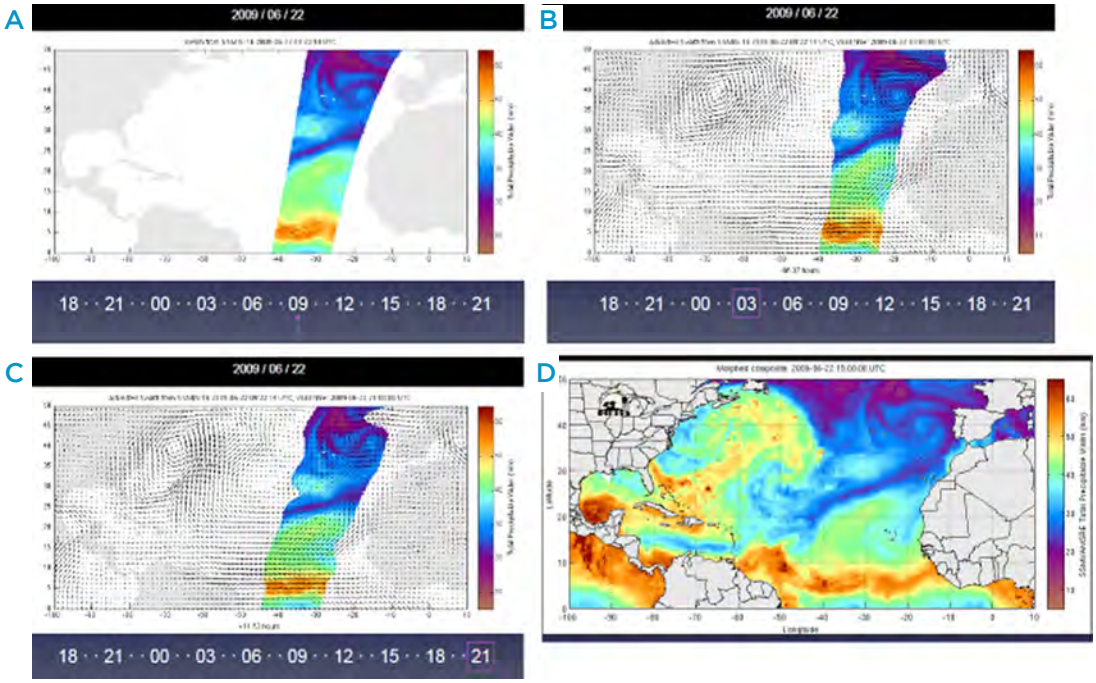
TPW follows the horizontal movement of a background wind field without substantially changing its properties for about 9–18 hours. This spacing allows optimal sampling for morphing, as it makes TPW an ideal candidate for data compositing using an added adjustment for advection with the wind. The algorithm uses numerical weather prediction model winds to "advect" the water vapor between satellite scans. This approach, referred to as "blended advection" or "morphological compositing", results in a more accurate, highly fluid, and more intuitively sound depiction of water vapor in the atmosphere. It works by using a vertically weighted average of wind values from the National Centers for Environmental Prediction (NCEP) Global Forecast System (GFS). The wind data enables the algorithm to move the TPW swaths backward or forward in time. It may come as a bit of a surprise at first that the water vapor lines up so well between one "advected" dataset and the next corresponding satellite scan. When put together, the final global hourly composite, looks natural and consistent, which allows forecasters to visualize moisture content in the atmosphere as it evolves.



From Top: One satellite; Two satellites; Three satellites; Four satellites

ANIMATION MATTERS

The figure that follows contains several advected scans to demonstrate this process. The original scan (a), which was acquired at close to 09:00 UTC displays the raw data prior to advection. Scans b and c show this same data, but shifted in time using low level GFS winds. Low-level winds are used because almost all moisture in the atmosphere is near the surface. Thus the observations are moved by weighted winds at 1000, 850 and 700 mb. The final product (d) is a simple composite of many advected TPW scans over a selected domain. A completed animation of TPW provides a clearer picture of moisture changes in the atmosphere.



The advection process (B and C) for a single TPW swath (A) from the F-16 SSMI/S on 22 June 2009 at 09:22 UTC, while (D) shows a morphed composite of TPW over the north Atlantic Basin.

Unlike with geostationary satellite images, animations of TPW cannot be assembled simply from the first images created in real-time. This collection of images would have incomplete coverage and would lack continuity. Instead, MIMIC-TPW continuously updates the most recent 18 hours of imagery with the effects of new data in order to maintain the accuracy and fluidity of the transitions between each hour of images.

Although the TPW product works in "real time", it utilizes data from the past, that is, the forecast wind fields as well as analysis winds. Over time the "older" advections are overwritten by more data over the next 12 hours as analysis winds come in to replace forecast winds. An archive ready product is valid at times far enough in the past to be uninfluenced by real-time information. By this stage, it has undergone a number of iterations to be considered "finished". Similarly, a near real-time product uses data that may have occurred in 6 hours or less after the valid time and is close to "finished", but continues with minor adjustments as new data is incorporated. Finally, with a real-time product, the entire composite is created from data advected forward from the past. For any given hour, a swath may be revised 20–40 times until it is considered archive-ready. Every revision is necessary to maintain a fluid transition.

MORE WORK NEEDS TO BE DONE

The work on MIMIC continues to bring great benefit to forecasters. The MIMIC-TPW is now available over water and land, and is being incorporated into NWS AWIPS II. The advection scheme is not perfect, because it is applied over a tall vertical layer of water vapor. This scheme also works well in some areas where topography is not a factor, but in areas along the west coast the one-level advection approach often fails to represent the impact of weather and topographic conditions. Thus, other ways to treat the advection are under consideration. Also, new sources of data have unique biases and artifacts. There is a lot of work remaining to get the most out of each available data source while preserving the temporal continuity of the product that forecasters have come to value so much. Work also continues on blending ATMS into the MIMIC-TPW just in time for the launch of JPSS-1.

SUMMARY

Satellite observations have enabled us to capture global scenes of the Earth's dynamic environment. Their high temporal and spatial resolution, continuity, and global coverage have made it easier to detect and quantify changes in the Earth's environment. Although the temporal resolution of polar-orbiting satellites is limited compared to geostationary satellites, products such as MIMIC-TC and MIMIC-TPW continue to be invaluable to forecasters. These products' ability to leverage observations from microwave sounders on polar-orbiting satellites are producing seamless and high temporal resolution visualizations to assist severe weather forecasting, verifying NWP models and enabling more rapid and precise environmental monitoring. With each successful operational application, these products will become a vital tool to an increasing user base and open the door for this morphing approach to be used in other satellite products.

References

Wimmers, A. J. and C. S. Velden, Seamless advective blending of total precipitable water retrievals from polar orbiting satellites, J. Appl. Meteor., 50, 1024–1036, 2011.

Wimmers, A., and C. S. Velden, 2007: MIMIC: A new approach to visualizing satellite microwave imagery of tropical cyclones. Bull. Amer. Meteor. Soc., 88, 1187–1196.

CICS-MD PROVING GROUND AND TRAINING CENTER: HELPING BRIDGE THE GAP BETWEEN PRODUCT DEVELOPERS AND USERS

The information in this article is based, in part, on the May 30, 2017 JPSS science seminar presented by Scott Rudlosky, PhD., NOAA/NESDIS/STAR, Cooperative Institute for Climate and Satellites, University of Maryland–College Park.

Satellite derived products are an important part of the toolkit used in the operational forecast applications of end-user communities such as the National Weather Service (NWS). NOAA's testbeds and proving grounds facilitate the orderly transition of research capabilities to operational implementation through development testing in testbeds, and pre-deployment testing and operational readiness/suitability evaluation in operational proving grounds. These are fertile environments to facilitate the demonstration of satellite derived data, algorithms and products in forecasts operations with the primary focus being to enhance their applications by user communities.

The Joint Polar Satellite System (JPSS) Program recognized that despite the wide array of products being launched, as well as their demonstration of significant outcomes in various applications, they needed to encourage more direct interaction between product developers and end-user communities. It is clear that end-user communities, such as the NWS, play a critical role in providing feedback on the utility and quality of data products, which helps shape the outcome of the product as well as its application. To address this challenge the JPSS Proving Ground and Risk Reduction (PGRR) Program began to leverages upon the capabilities of NOAA Cooperative Institutes (CIs) and various testbeds and proving grounds to tap into their wealth of experience and expertise. NOAA CIs are autonomous academic and non-profit research institutions that work in partnership with NOAA in support of its Mission Goals and Strategic Plan. They are a huge part of the PGRR establishment. Currently, NOAA supports 16 CIs consisting of 42 universities and research institutions across 23 states and the District of Columbia. A strong partnership with the University of Maryland and the Earth System Science Interdisciplinary Center laid the groundwork for the creation of the Cooperative Institute for Climate & Satellites—Maryland (CICS-MD).

THE COOPERATIVE INSTITUTE FOR CLIMATE AND SATELLITES-MARYLAND (CICS-MD)

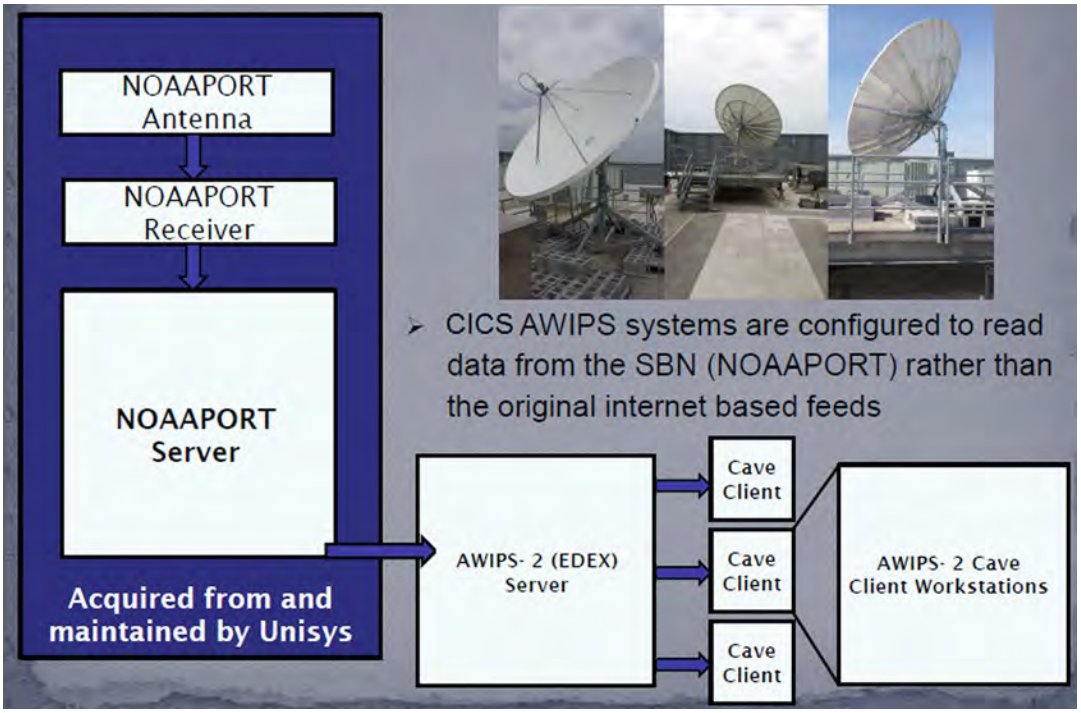
The CICS mission is to perform collaborative research aimed at enhancing NOAA's ability to use satellite observations and Earth System models to advance the national climate mission, including monitoring,

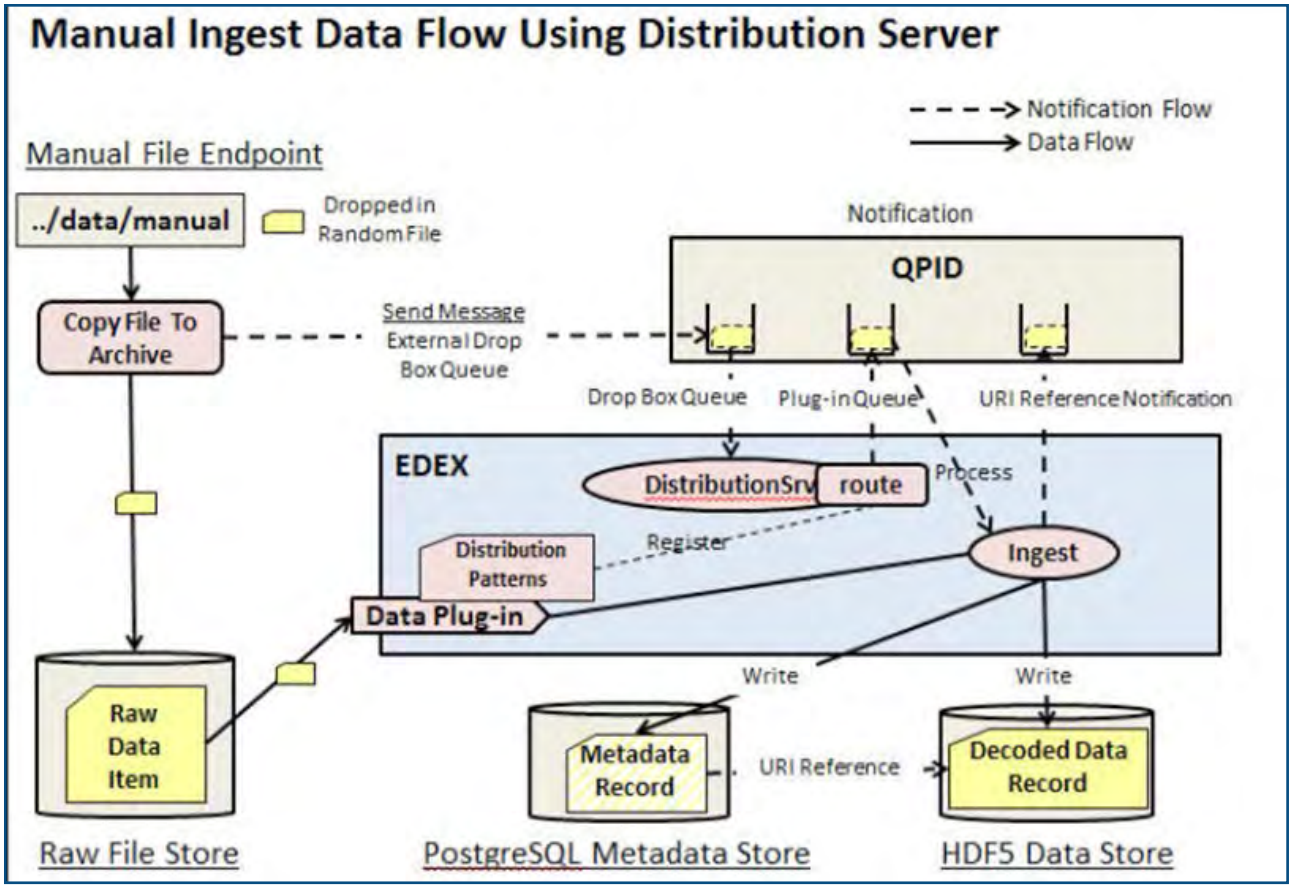
understanding, predicting and communicating information on climate variability and change. Nestled in the Discovery District (formerly known as M-Square), CICS-MD sits just a few steps from the NOAA Center for Weather and Climate Prediction (NCWCP). CICS-MD performs collaborative research aimed at enhancing NOAA's ability to use satellite observations and Earth System models to advance the national climate mission, including monitoring, understanding, predicting and communicating information on climate variability and change. As the newest entrant into the proving ground scene CICS-MD has built infrastructure that enables it to simulate operational environments. In addition, CICS-MD is able to develop products including imagery derived from Suomi NPP/JPSS/GOES-16 data that can be fully exploited to provide maximum benefits to operational users and researchers downstream—mainly the NWS, but other users such as the Federal Aviation Administration (FAA), and the United States Forest Service (USFS) as well. Since the NCWCP opened, CICS-MD has leveraged this proximity as well as its expertise with exploiting satellite information to improve weather and climate predictions. Much like its counterparts in the JPSS PGRR, CICS-MD is a significant contributor of the satellite derived algorithms used in NOAA operational applications.

The CICS-MD Proving Ground and Training Center (PGTC), an operational framework supported by the JPSS and the Geostationary Operational Environmental Satellite-16 (GOES-16) Program was established to help resolve this disconnect between product developers and end users through training, product evaluation, and solicitation of user feedback. Part of the PGTC plan includes product and decision aid demonstrations at NOAA Testbeds, NCEP Centers, WFOs, and the NWS PG Training Center. A range of approaches that will be used to measure the benefits to forecasters include evaluating the impact of new product infusion and technology in operational forecasting environments.

CICS-MD PGTC INFRASTRUCTURE

The CICS-MD PGTC infrastructure provides support to NOAA programs and requirements, most of which depend on round-the-clock performance. Access to NOAAPORT—the Satellite Broadcast Network (SBN) used to distribute environmental and hazards-related data to WFOs and national centers, as well as to external users—has brought the CICS-MD PGTC much closer to an operational environment than previously existed with internet-based feeds.





The NOAAPORT antenna, receiver, and server provide access to the full NWS SBN feed in real-time. Another high-power server obtains these data via LDM, and processes them for visualization in the AWIPS environment. This server feeds up to a dozen data-rendering clients, also known as Common AWIPS Visualization Environment (CAVE) workstations that serve as the forecasters' tool (presently four workstations in place).

A full grasp of this complex infrastructure requires a fair amount of expertise on the components, technology, and capabilities, and how the functional units work, individually and with one another. One of these functional units is the AWIPS, a direct connection between Cooperative Institutes and end users (forecasters). AWIPS is a complex network of systems that has two primary components which can standalone. One is a data-rendering client, or CAVE and the other is a backend data server, or Environmental Data EXchange (EDEX). AWIPS ingests and analyzes environmental data, creates useful visualizations and distributes time-sensitive weather statements such as watches and warnings. It allows CICS-MD scientists to visualize satellite data products in the same way end users such as the NWS forecasters would in an operational environment. It also helps students develop a feel for what variables are important in NWS operations as well as their significance.

The CICS-MD approach to visualizations in AWIPS has been done in coordination with a team from the NWS Total Operational Weather Readiness—Satellites (TOWR-S) Project. The TOWR-S project is designed to implement products from NOAA's next-generation satellites, including JPSS and GOES-16 to aid the NWS forecast and warning mission. Included in the approach are shared insights into the early deployment of products, and direct user connection, which provide avenues for product demonstration. All these activities allow for iterative development and testing of satellite data display and mission-integration activities. As NOAA's next generation satellites bring on the scene a quantum leap in technological capabilities, adjusting to the paradigm shift in operational satellite meteorology requires much infrastructure coordination and forecaster training to ensure user readiness.

INNOVATIVE WORK SPACE

The development plans for the CICS-MD PGTC include upgrades to the facilities that provide high performance computing resources such as the NWS Advanced Weather Interactive Processing System (AWIPS). Originally set up in a cube farm, the new space has been converted to an open-space seating floorplan designed to enhance access to a collaborative computing environment for more comprehensive scientific computing services and data. This new room provides space for STAR and CICS-MD scientists to visualize their products as viewed during operations by NWS forecasters.

More open spacing to accommodate more multi-panel workstations and large screen monitors.

SATELLITE BASED OBSERVATIONS—REAL TIME APPLICATIONS FOR ENVIRONMENTAL EVENTS

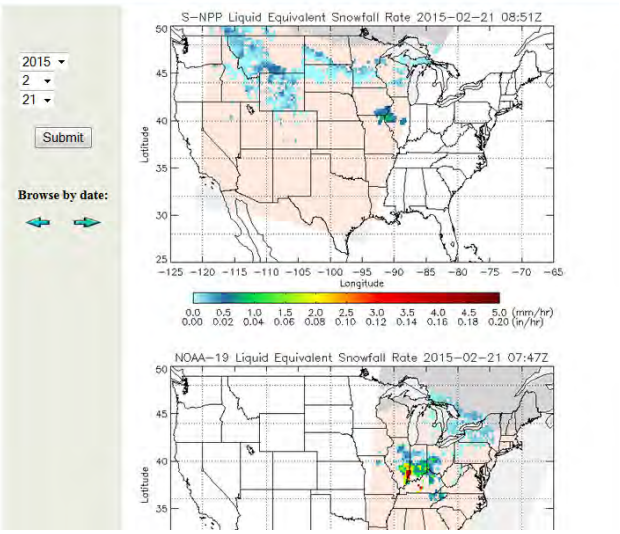
Satellite based observations have proven extremely useful in a wide variety of weather applications, including, improved information for high impact environmental events. Recently CICS-MD integrated three JPSS supported products into AWIPS: the NESDIS Snowfall Rate, Aerosols/Smoke/Dust, and Active Fire. The following examples illustrate some of the procedures used to get these products into AWIPS, and their use in operations.

NESDIS Snowfall Rate

The first in line of many accomplishments for the CICS-MD PGTC was the evaluation of the NESDIS/STAR snowfall rate (SFR) product in the AWIPS system.

Due to their sensitivity to the scattering effect of snow particles at certain high frequencies, passive microwave measurements are used to retrieve snowfall properties. Sensors such as the Advanced Technology Microwave Sounder (ATMS) aboard Suomi NPP have helped generate snowfall properties. ATMS is the follow-on to the legacy sensors Advanced Microwave Sounding Unit (AMSU) and Microwave Humidity Sounder (MHS).

The product which made its unofficial debut as a verification tool in the 2016 Winter Weather Experiment has been used to fill in gaps in areas where conventional snowfall



Near Real-Time SFR Webpage at CICS/UMD

data are not available. This product has performed well in mountains and remote regions where radar and weather stations are sparse or where terrain blocks the radar signal, or the radar signal overshoots the low-cloud tops of snow producing cloud. The product has also helped provide quantitative snowfall information to complement snowfall observations or estimations from other sources such as radar estimates or snow depth reports from volunteer observers.

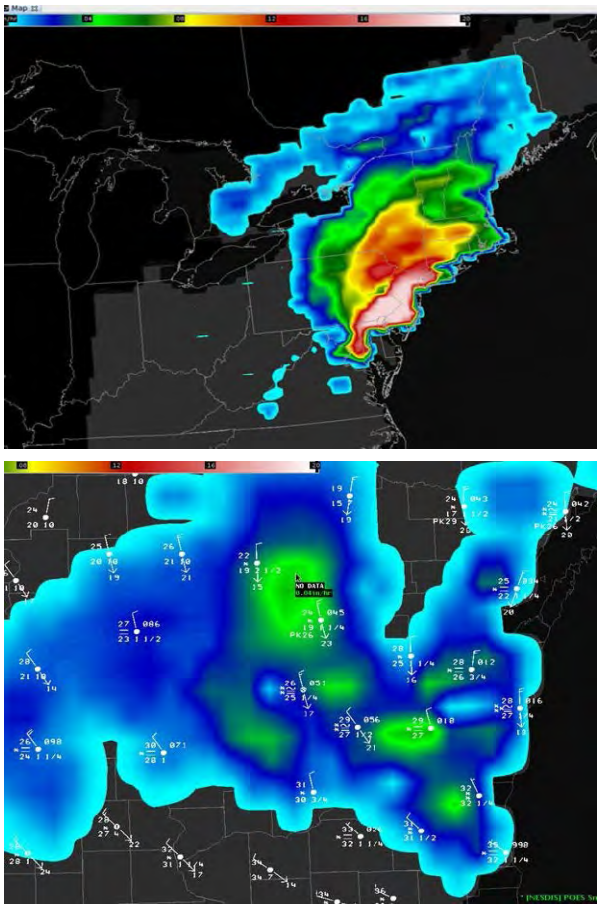
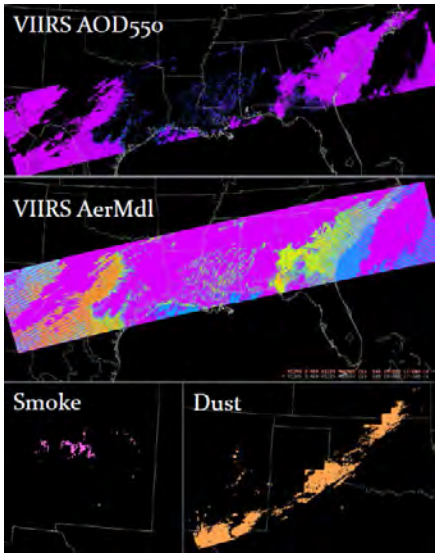


Image displays the SFR product along with surface observations during a blizzard on 14 March 2017.

The development of the NESDIS SFR product, funded by the JPSS PGRR program, resulted in an improvement over the original SFR algorithm, as the ATMS SFR includes a cold temperature component for snowfall detection. The SFR was the focus of a previous assessment done in collaboration with NASA SPoRT to gauge the usefulness of the product and determine issues that would require future development. Actions taken based on that evaluation resulted in lowering the 2-meter temperature lower limit from 22°F to 7°F, drastically increasing the probability of detection of snowfall in colder weather. The NESDIS SFR has been converted to an AWIPS-readable format, and is available for display on the CICS-MD AWIPS systems. Some steps leading to this achievement included setting up real-time data feed, creating the IDL code needed to re-project/format the data, and modifying EDEX/CAVE to recognize/process files. The ability to overlay STAR satellite products in the operational NWS system will provide tremendous insights to STAR scientists and will help to ensure the relevance and utility of newly developed products.

IMPLEMENTING SAMPLE S-NPP AEROSOL AND ACTIVE FIRE PRODUCTS IN AWIPS

CICS-MD worked with a team from the TOWR-S project to obtain and implement tools needed to visualize data in AWIPS. Meetings with the AWIPS development team proved very helpful in identifying the official path to operations for these changes. Present versions rely on a fairly basic point set plug-in which generates fairly simple representation/display of the smoke and dust mask. The PG team is working with the aerosol science team to enhance the plug-in tool to enhance the display of the products by overlaying with other products. Most important changes will be to overlay dust and smoke masks with true color RGB and aerosol optical depth products so forecasters can visualize the extent of smoke or dust and compare it to the smoke/dust seen in the RGB image. Additionally, the forecasters can combine smoke/dust mask with aerosol optical depth to understand how thick the smoke/dust that can help them qualify their warnings of

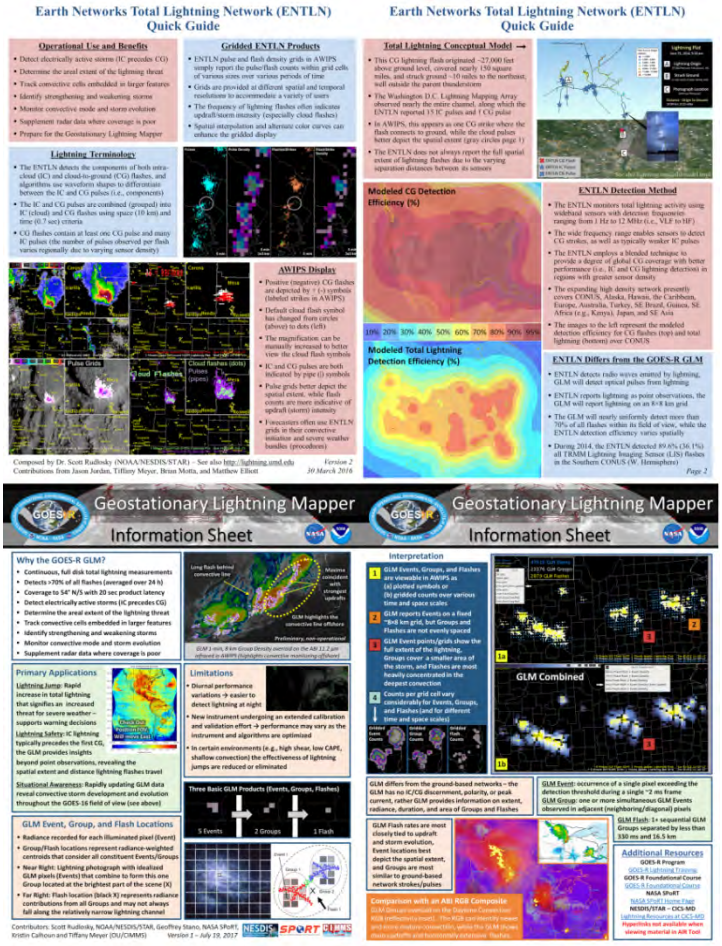


harmful air quality. The TOWR-S team was also helpful in getting the VIIRS Active Fire Product into the CICS AWIPS. The visualization of the product had been developed by the Experimental Products Development Team. Both the Aerosol and Active Fire Products are now available for additional testing and evaluation as needed by NWS and JPSS personnel.

USER TRAINING

Implementing science and technology into new algorithms is important, but it's of little use to forecasters if they do not understand or recognize how to use it. To complement existing, foundational knowledge and resources, operational users are provided training in a variety of forms.

One form of training is through the use of quick guides (examples shown right), which are easy-to-use, short reference tools that provide a brief introduction to the more important aspects regarding a product/tool. They will be made available across the user community through the NWS Training Division. Eventually the goal is that these training guides will be part of "point-and-click" product training on AWIPS where a user can right-click on a product and a training guide would be immediately available. Future plans for the CICS PGTC include obtaining and implementing software for creating forecaster training modules.



VISUALIZATION CAPABILITIES

Almost as important as having a product available in AWIPS is allowing the forecaster to tailor the visualization of products to maximize their benefits. This visualization may also be tailored to suit individual tastes as what may work for one user may not work for another. The CICS-MD test environment allows individual users to explore an almost endless stream of data combinations from various sources. For example, polar data can be laid over geostationary data. Radar data can be combined with satellite imagery, and so forth. Developers will have an environment where new visualization can be tested and fine-tuned. Different types of visualization can be evaluated and adjusted based on the needs of the final product user. At CICS this is done on operational AWIPS systems but without disrupting the flow of product and support in an operational center.

CURRENT CONSTRAINTS, LOOKING AHEAD

CICS-MD continues to work with potential users to define how they can use current CICS capabilities and what might be needed for a particular evaluation. CICS is just now beginning to implement and test AWIPS plug ins on an office-level scale, and work to have them included in baseline software. CICS may find that it

needs additional resources or new procedures to maximize its ability to provide a useful test environment. In the future, CICS-MD looks to gather and incorporate feedback from demonstrations, expand interactions with product developers and users, and develop and deploy new training materials. Building on this, CICS-MD also plans to determine how best to broaden its user interaction and identify a sustainable path forward. Moreover, it will continue to leverage its close proximity to NESDIS to identify which products in STAR are ready for implementation and demonstration in AWIPS, implement the Community Satellite Processing Package (CSPP), and promote synergy with the GOES program.

CONCLUSION

Satellite derived algorithms and products are an important part of the toolkit used in operational forecast applications of end-user communities such as the NWS. Some products are developed in NOAA's proving grounds, which have fostered some of the most advanced capabilities in forecast operations. Although many products are generated in the PGRR and have produced significant outcomes in operations, some have been slow to implement. To help resolve this disconnect between product developers and end users, the MD branch of CICS is deploying its proving ground provider capabilities to complement similar work at the other CIs and help provide the best possible weather forecasting tools to the NWS.

The installation of the NOAAPORT SBN antenna, receiver, and server at CICS-MD has enabled CICS-MD to simulate operational environments. The hands-on environment of the PGTC enables students to construct their learning through engagement and active exploration of the NWS forecasts operations while still in school. Several new products have been implemented in AWIPS to explore the ways to optimize their display and usefulness. Scientists worked with a project team from the NWS to obtain and implement tools for displaying in AWIPS the snowfall rate, aerosol and active fire products derived from and detected by the Suomi NPP satellite.

CICS MD develops training materials in a variety of forms to accompany any newly developed products. These include training quick guides which serve as short reference tools, as well as instructional modules, which are incorporated into the NWS training routine.

As the CICS-MD PGTC continues to grow, the operational user community can expect to see more satellite derived imagery available for the public, as well as more opportunities to exploit the exciting new capabilities made possible by NOAA's polar-orbiting and geostationary satellites including JPSS and GOES-16.

NEXT GENERATION NIGHT VISION: SEEING FIRES, FLARES, BOATS AND LIGHTS FROM SPACE

The information in this article is based, in part, on the June 16, 2017 JPSS science seminar presented by Chris Elvidge, Earth Observation Group, NOAA's National Geophysical Data Center, Boulder, Colorado.

Lights at night: Cities and human settlements, boats, gas flares and fires

Nighttime light displays both indoors and outdoors are one of the hallmarks of human presence and activity on the surface of the earth. In day-to-day life nighttime lights are used in a variety of ways including illumination, display or decoration. Now observations—derived from the light that is radiated, scattered and reflected by land, atmospheric and ocean surfaces—from environmental satellites orbiting the Earth some 500 to 22,500 miles away, are helping construct many nighttime environmental products that are allowing scientists to tease out information from Earth's night lights. Data from nighttime lights derived from space-based observations have emerged as one of the primary remote sensing observables linked to urbanization, economic activity, and population. These data are inspiring research on population and settlement density, economic activity, electric power consumption and distribution, and poverty and development status, as well as for addressing other environmental issues, such as light pollution

The ability for satellite sensors to detect radiant emissions coming from various sources including cities, human settlements, industrial lights, gas flares, fires and boats is not new. It was pioneered with the US Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) in the 1960s to view clouds by moonlight. Later its use was expanded to include mapping locations of man made lighting on the Earth's surface. However, the data were preserved on filmstrips, which greatly limited their capability as well as application. Other OLS limitations were the 6-bit dynamic range, which results in the saturation of urban centers, and the lack of onboard calibration.

Also the DMSP was a military program and for many years its capabilities were restricted to military applications. In 1992, the security restrictions on DMSP data were loosened allowing researchers around the world to begin evaluating the value of the OLS Day-Night-Band (DNB) data. Beginning in 1996, the Earth Observation Group at the National Oceanographic and Atmospheric Administration/National Geophysical Data Center (NOAA/NGDC) began generating global annual nighttime lights composites using the DMSP-

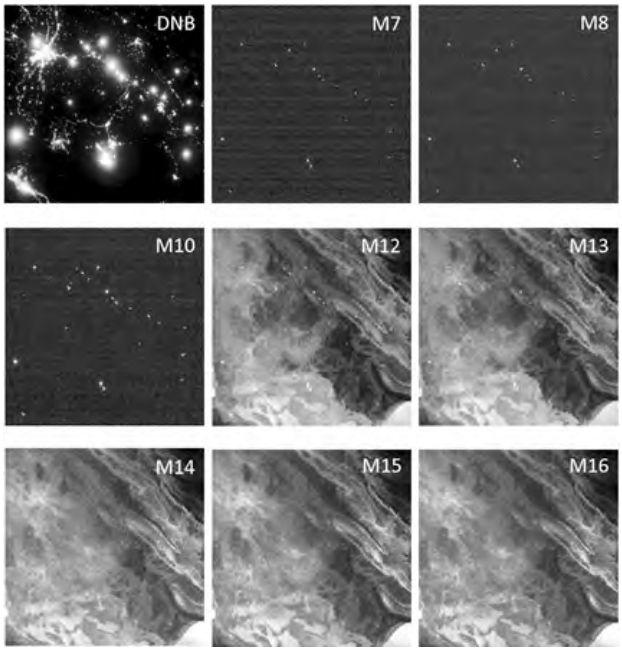
OLS data. These products have proved valuable to the scientific community, enabling the study of lighting patterns over time, and allowing researchers to study socio-economic parameters for which nighttime lights serve as a reasonable proxy. Yet the OLS limitations hindered more widespread use of its datasets.

Sullivan, W.T. III, 1989, A 10 km resolution image of the entire night-time Earth based on cloud-free satellite photographs in the 400–1100 nm band. International Journal of Remote Sensing, v. 10, p. 1–5

All that changed with the launch of the Suomi National Polar-orbiting Partnership (Suomi-NPP) spacecraft in 2011. On board Suomi-NPP was the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument a huge leap forward in satellite capabilities. The VIIRS Instrument had a DNB product built on the success of the OLS DNB. The lessons learned from OLS were invaluable to the VIIRS. Both the VIIRS and OLS DNB have a comparable broad spectral range of 0.5–0.9 µm centered at 0.7 µm and the have ability to collect low-light imagery at night. Compositing algorithms for the VIIRS DNB are adapted from heritage DMSP OLS algorithms, developed at NOAA NGDC with adjustments for sensor differences and data specific parameters. However the VIIRS DNB was a huge upgrade to the OLS DNB capability. VIIRS produces global data at 742m spatial resolution, a 14-bit dynamic range, and is a calibrated radiometer. The user community quickly began to leverage this technical leap for a wide range of activities.

OBSERVING THE EARTH AT NIGHT

VIIRS works by scanning in 22 different wavelength bands. For each pixel, it uses a low-, medium- or high-gain mode to accurately depict the light from each source. Low-light signals are amplified and bright lights are kept from being over-saturated. The DNB is sensitive enough to detect the nocturnal glow produced by Earth's atmosphere. It detects lights in a range of wavelengths from green to near-infrared and uses filtering techniques to observe dim signals such as city lights, gas flares, auroras, wildfires and reflected moonlight. Besides the DNB, VIIRS has several channels including M7 at 0.865 µm, M8 at 1.24 µm, M10 at 1.61 µm, that are designed for daytime imaging but are still able to collect a style of low light imaging data. Soon, the M11 channel at 2.25 µm will be added to this list. These daytime channels enable



VIIRS low light imaging at night: DNB detects electric lighting, fires and flares. M7, 8 and 10 detect combustion sources.

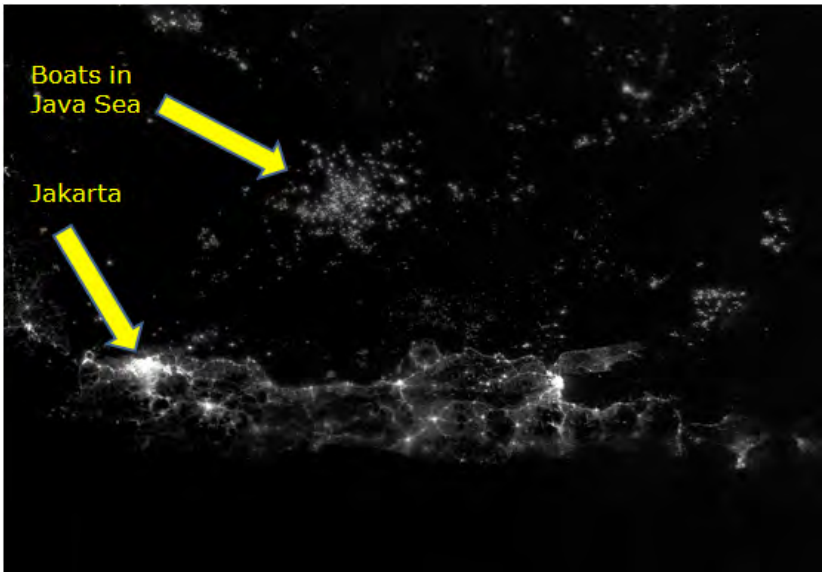
the detection of radiant emissions that are obscured by reflected sunlight as seen below in the image showing gas flares in Basra Iraq. The DNB however, is unique in that it continues to collect this low light data at night.

VIIRS PRODUCT LINES FROM LIGHTS AND COMBUSTION SOURCES WORLDWIDE

The NOAA National Centers for Environmental Information (NCEI) (formerly the NGDC) Earth Observation Group (EOG) specializes in nighttime observations of lights and combustion sources worldwide. The group has developed three global product lines based on VIIRS low light imaging data: 1) VIIRS boat detections (VBD), VIIRS nightfire (VNF) and VIIRS nighttime lights (VNL). VBD and VNF are produced in near real time, with a nominal four hour temporal latency. VNL production requires extensive filtering to exclude sunlit, moonlit, and cloudy observations, making annual products most appropriate. The data products are available at: https://ngdc.noaa.gov/eog/.

BOAT DETECTION

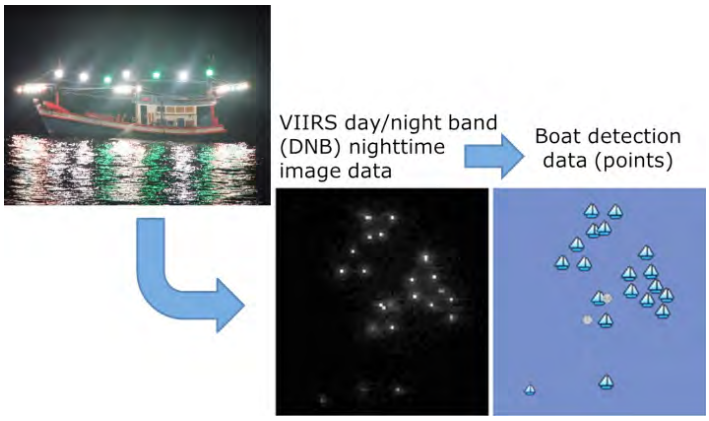
At night commercial boats rely on very bright light to attract fish to their nets. In numerous areas of the globe, fishing vessels equipped with huge halogen lights sail out into coastal waters after sunset. Many countries where fishing is a large portion of their economy establish fishing regulations on the type of catch, where they can be caught, and the seasons they can be caught in. Lacking the benefit of satellite images of lights at night, these countries found it challenging to enforce these regulations. It was discovered that the type of high powered halogen lights from fishing vessels could be detected and tracked from space using the Suomi NPP VIIRS signals in the near-infrared and short-wave infrared spectrum. The VIIRS' light intensification can detect faint radiant emissions, which enables the mapping of lights sources even in the most remote areas. What is now called the VBD product became an exciting capability for these countries to consider using.



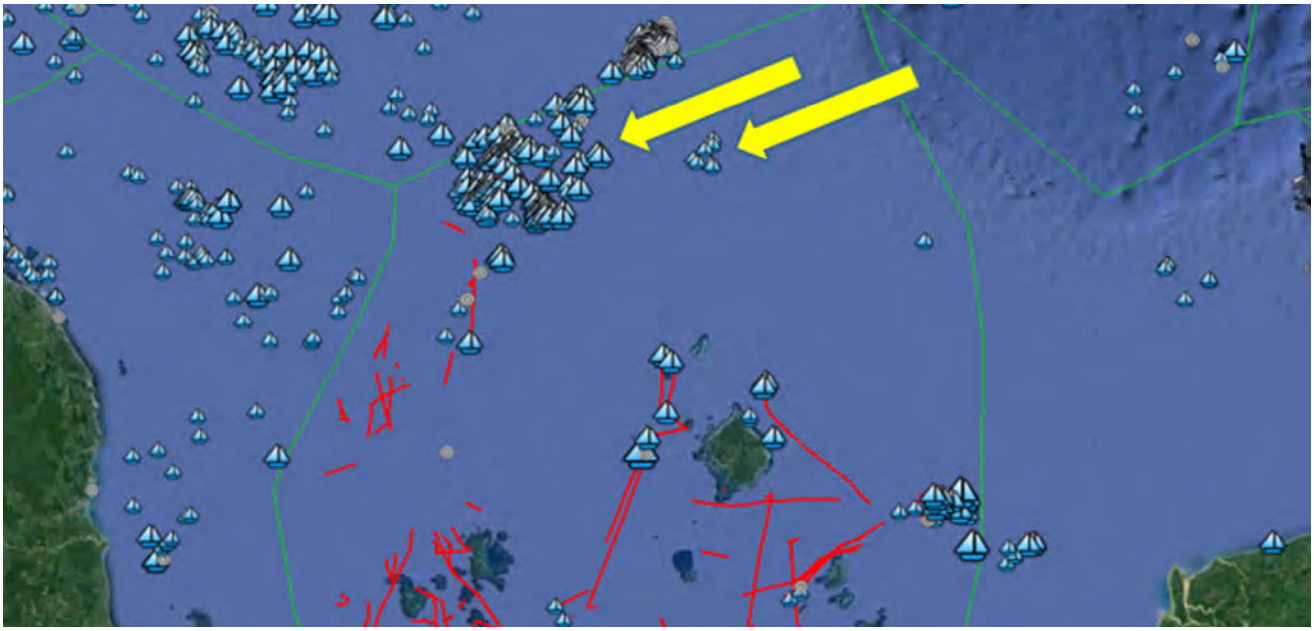
The DNB image above shows clusters of lights from boats in the Java Sea.
The largest cluster is highlighted by the top yellow arrow.

The VBD is a fully automated system that detects and reports the date, time, location and radiance of boat detections. The algorithm uses the VIIRS visible and infrared nighttime satellite images to detect bright spots in the ocean and to discriminate them from gas flares, moonlit cloud tops and lightning. On low moon nights, VBD can detect electric lighting with less than 1KW electric power within 0.5 km2 VIIRS day-night band pixel http://www.mdpi.com/2072-4292/7/3/3020. On high moon nights, VBD can see boats between the moonlit clouds and the lunar glint. It has been deployed by fishery agencies for offshore detections of lights. The product was first made available to user communities in Indonesia but was expanded to include the Philippines, Southeast Asia, and the Pacific and in May, 2017 it was released globally. It is available at a four hour temporal latency.

Initially the product was requested by fisheries agencies from several countries including Japan, Peru, and Argentina. The data was made available via subscription to an FTP site. However, initially the only data that could be retrieved using this method was that from the OLS that was still available from the DMSP spacecraft still on orbit. The data volume from VIIRS was too large to be readily available. In 2014 an algorithm was created to enable users to download only those pixels that had boats.



The contrast enhanced DNB image subset on the left showing a cluster of boats. The corresponding boat detections are shown on the right.



October 1, 2016 boats detected by VIIRS but lacking VMS are suspect.

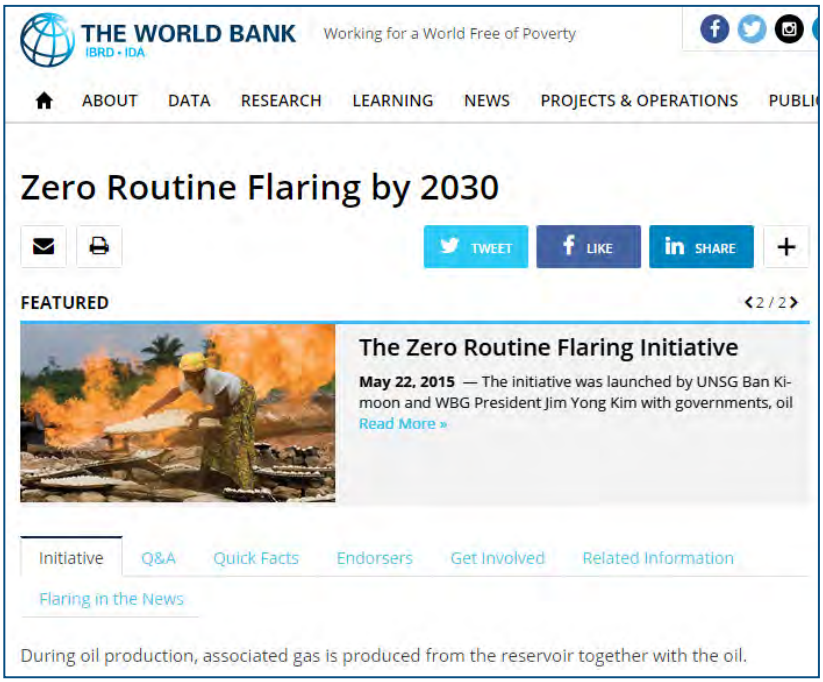
To make the VBD product even more useful software was created that would alert countries of the presence of boats in their areas of interest. This might be in marine protected areas (MPAs), restricted coastal waters, or areas that had seasonal fishery closures. For example, over a six month period in 2016 the Government of the Philippines used the VBD to apprehend 14 fishing vessels fishing illegally in their BFAR Region 5. Countries are using this product to identify vessels that do not have or are not operating an electronic signature or VMS (vessel monitoring system). The boats detected by VIIRS might otherwise not have been able to be traced by these normal means which can be a sure indication that they plan to fish illegally.

VIIRS NIGHTFIRE (VNF)

The VNF is a multispectral fire product that detects fires, flares and other IR emitters. It provides invaluable data for detection and characterization of natural and technological combustion sources on the surface of the Earth, such as forest fires, gas flares, steel mills or active volcanoes. VNF makes use of near-infrared and shortwave infrared data to detect combustion sources as night as the radiant emissions can be observed without solar contamination. The presence of sub-pixel hot infrared (IR) emission sources can be readily

detected at night in 1.6 micron near-infrared M10 channel. Their temperature and radiant heat intensity can be estimated by fitting of the Planck black-body spectral curve to the observed radiances of VIIRS infrared M-channels out to 4 μm. VIIRS instrument is sensitive to the IR sources over a wide range of temperatures. This method can discriminate low temperature sources such as volcanoes and forest fires from the high temperature gas flares with 300m average location error. It is used for annual surveys of gas flare locations and flared gas volumes. Like VBD, VNF is available at a four hour temporal latency. It is the only global fire product that reports out temperatures, source areas and radiant heat.

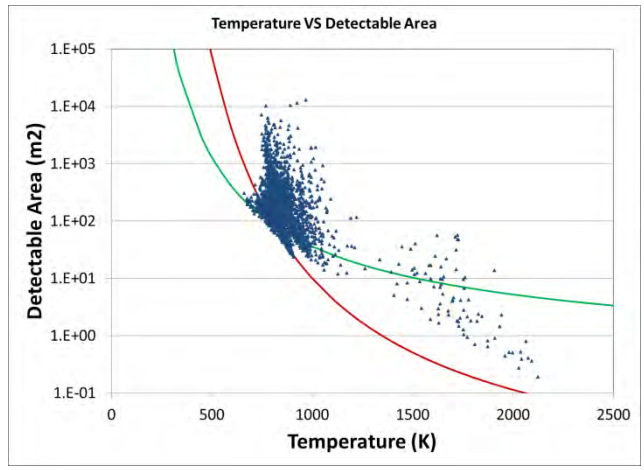
VNF temperatures and source sizes may be useful in modeling fire induced land cover change. They can also be a useful indicator of encroachment into protected and high biodiversity value areas. Other applications include mapping and tracking gas flaring worldwide.



Gas flaring is a widely used practice to dispose of natural gas that cannot be utilized or brought to market due to lack of infrastructure. As oil is considered to be the primary product, there is little economic incentive to put the gas to use or sell it. Flaring is the standard mode of disposal in poor countries as well as for offshore companies located in remote regions. Even more important, flaring of gas contributes to climate change and impacts thew environment through emission of CO2, black carbon and other pollutants. It also wastes a valuable energy resource that could be used to advance the sustainable development of producing countries. Satellite observations provide the capability for detecting flares and estimating flared gas volumes. VNF is ideally suited for detecting and estimating flare volumes because the M10 band covers the peak radiant emissions for these flares.

The World Bank Agency has established a database of facilities around the world where gas flaring is taking place. Since gas flares are a major source of pollution, the World Bank has establish a "Zero Routine Flaring by 2030" Initiative. This initiative brings together governments, oil companies, and development institutions who recognize the flaring situation described above is unsustainable from a resource management and environmental perspective, and who agree to cooperate to eliminate routine flaring no later than 2030. Using VNF data the World Bank documented 18,129 flares from 2012–2015. According to the data, Russia has the largest flare volume, while the USA has the largest number of flares. It is anticipated that the VIIRS flares data can be used to help monitor, report, and verify changes in flare location and intensity that can be tied to greenhouse gas emission reduction under the Paris Climate Agreement, and assist the UN & World Bank in tracking progress in meeting its "Zero routine flaring by 2030" Initiative goals.

VIIRS NIGHTTIME LIGHTS (VNL)



Detection Limits: At 1800 K flares as small as 0.25 m2 are detectable.

The VNL product indicates the locations and brightness of human settlements, from large cities down to small towns and many exurban housing clusters. Many bright linear road features propagate into the VNL product, but dimmer road features are frequently missed. The quality of the VIIRS night-time lights product banks on two principals. The first is that the quality of the data product can be improved by excluding data featuring signal from phenomena other than electric lighting. This includes sunlit, moonlit, and cloudy pixels. The other principal that enhances the quality of the product is the 'power of the mean.' That is to say, the stability of the average night-time lights radiance improves through the inclusion of larger numbers of observations. To make a research quality night-time lights product from VIIRS data requires a cascading series of filtering steps to strip out data contaminated by extraneous features prior to temporal averaging. This filtering is essential to producing a highly uniform standardized night-time lights product. First, sunlit, moonlit, and cloudy observations are filtered out to create a raw cloud-free composite. Initially biomass burning was filtered out using simultaneous VNF data. Biomass burning signals are detected at a lower temperature than gas flaring. Often these have a larger source size than gas flares. It was discovered that the low detection limits in the DNB allowed it to detect fires which were not showing up in the VNF product. As a result, an outlier removal process was implemented. This process filters out fires and most of the aurora contamination. The VIIRS nighttime lights product itself is filtered further to remove background noise and the remaining aurora features through manual editing. The VNL product is widely used in the sciences, social sciences, and development tracking communities.

The VNL product can be utilized in various ways including power grid stability analyses, power outage and power recovery detection due to natural disasters, measuring growth rates of infrastructure in towns, and as an input to spatial modeling of economic indices

SUMMARY

Data from space-based observations derived from nocturnal lighting and combustion sources across the globe play an important role in providing information on global social and economic activities, and the impact of natural disasters on populated regions. Products from satellites such as JPSS, have proven their value in providing critical data to decision makers around the globe. Whether it is tracking fishing vessel movement in protected areas or determining the impact of hurricanes on the power infrastructure, the JPSS' DNB tailored products are making the difference where no other data source is available. Each successful operational application encourages researchers to evaluate new ways for these products to be used. With the launch of JPSS-1 in November 2017, more DNB products will join those produced from Suomi NPP to provide decision makers the tools they need to respond to rapidly changing environmental conditions. The best is yet to come!

References

Bennie, J., T. Davies, J. Duffy, R. Inger, and K. Gaston (2014), Contrasting trends in light pollution across Europe based on satellite observed night time lights, Sci. Rep., 4, 3789, doi:10.1038/srep03789

Chen, X., and W. Nordhaus (2011), Using luminosity data as a proxy for economic statistics, PNAS, 108(21), 8589–8594, doi:10.1073/pnas.1017031108.

Chand, T., K. Badarinath, C. Elvidge, and B. Tuttle (2009), Spatial characterization of electrical power consumption patterns over India using temporal DMSP-OLS night-time satellite data, Int. J. Remote Sens., 30(3), 647–661, doi:10.1080/01431160802345685.

Ceola, S., F. Laio, and A. Montanari (2014), Satellite nighttime lights revealing increased human exposure to floods worldwide, Geophys. Res. Lett., 41, 7184–7190, doi:10.1002/2014GL061859

Elvidge, C., K. Baugh, E. Kihn, H. Kroehl, and E. Davis (1997), Mapping city lights with nighttime data from the DMSP operational linescan system, Photogramm. Eng. Remote Sens., 63(6), 727–734.

Elvidge, C., P. Sutton, T. Ghosh, B. Tuttle, K. Baugh, B. Bhaduri, and E. Bright (2009), A global poverty map derived from satellite data, Comput. Geosci., 35(8), 1652–1660, doi:10.1016/j.cageo.2009.01.009.

Elvidge, C.D.; Zhizhin, M.; Hsu, F.-C.; Baugh, K.E. VIIRS Nightfire: Satellite Pyrometry at Night. Remote Sens. 2013, 5, 4423–4449.

Elvidge, C.D.; Zhizhin, M.; Baugh, K.; Hsu, F.-C. Automatic Boat Identification System for VIIRS Low Light Imaging Data. Remote Sens. 2015, 7, 3020–3036.

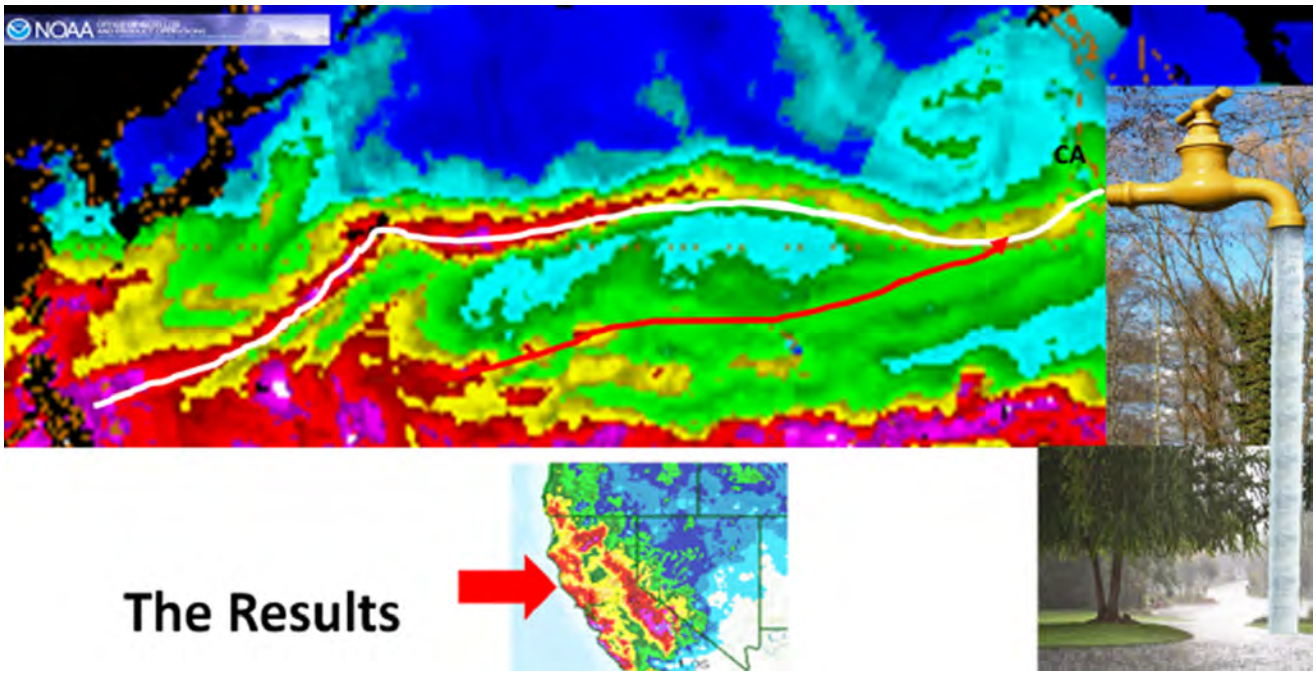
Elvidge, C.D, K. E. Baugh, M. Zhizhin, F.C. Hsu, and T. Ghosh. (2017) VIIRS night-time lights, International Journal of Remote Sensing, 38:21, 5860–5879, DOI: 10.1080/01431161.2017.1342050

Ghosh, H. T., R. Powell, C. D. Elvidge, K. E. Baugh, P. C. Sutton, and S. Anderson. 2010. "Shedding Light on the Global Distribution of Economic Activity." Open Geography Journal 3: 147–160. doi:10.2174/1874923201003010147.

Sullivan, W.T. III, 1989, A 10 km resolution image of the entire night-time Earth based on cloud-free satellite photographs in the 400–1100 nm band. International Journal of Remote Sensing, v. 10, p. 1–5

THE PAST, PRESENT AND FUTURE OF SATELLITE MOISTURE AND PRECIPITATION PRODUCTS AND APPLICATIONS

The information in this article is based, in part, on the July 31, 2017 JPSS science seminar presented by Sheldon Kusselson Retired NOAA/NESDIS/ Satellite Analysis Branch, Silver Spring, Maryland. Additional contributions from John Forsythe and Stan Kidder of CIRA/Colorado State University, Limin Zhao, Bob Kuligowski, and Huan Meng of NOAA/NESDIS and Tony Wimmers of CIMSS/University of Wisconsin.



24hr Rainfall ending 12 UTC 14 October 2009.

In the atmosphere, water exists in a gaseous form as vapor, in a liquid form as rain, and in a solid form as snow and ice. Most of the water vapor, or moisture in the atmosphere is contained within the first 10,000 feet above the earth's surface. Water vapor plays a key role in the Earth's atmospheric circulations, weather systems and climate patterns. It also transfers heat, redirects solar radiation, and transports water around the globe. Without it there would be no clouds, no precipitation and no weather on Earth as we know it.

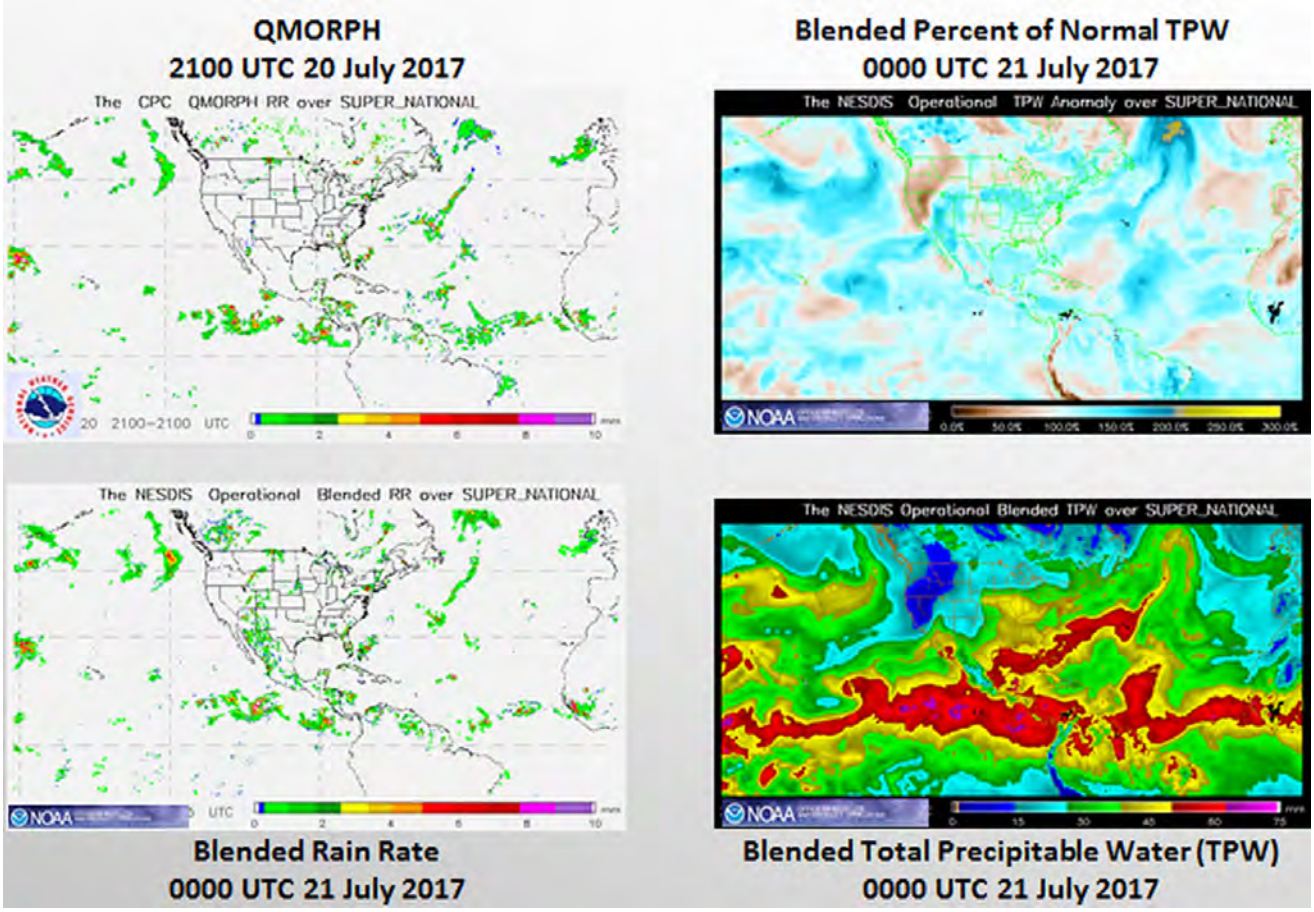
In unsuitable amounts and places, moisture can result in unfavorable environmental events, including threats to life and property. It is critical that forecasters are able to accurately forecast these extreme precipitation events. Take for example, the image above from the Fall of 2009 when a moisture plume or "atmospheric river of moisture" extended across the entire Pacific Ocean and brought excessive amounts of rain to northern California in early October. An usually strong storm this early in the fall would feed on this equally unusually long fetch of moisture to help bring close to 15 inches of rain to the Santa Lucia Mountains on California's central coast and over 10 inches in the Santa Cruz Mountains. Heavy rains also spread across much of northern and central California as well as the Santa Ynez mountains just south and east of Point Conception in southern California. The storm was accompanied by strong winds with gusts in excess of 50 mph noted along much of the coast and in the central valley of California. Given this was an out of season early Fall storm, deciduous trees still had most of their leaves resulting in many reports of tree damage; downed limbs as well as trees and branches blown over. There were also negative impacts on California agriculture, notably to the harvest of grapes for wine and the drying of the raisins. More than a week before the storm's arrival, forecasters were able to start to follow the hourly expansion and spread of the moisture across the Pacific with satellite microwave data/imagery from NOAA/NESDIS' Blended Total Precipitable Water Product. Several days in advance of the storm the combination of the satellite moisture data and numerical model forecasts gave forecasters increasing confidence to alert both agricultural growers and ordinary citizens of the upcoming storm so that they could take effective measures to prepare for it.

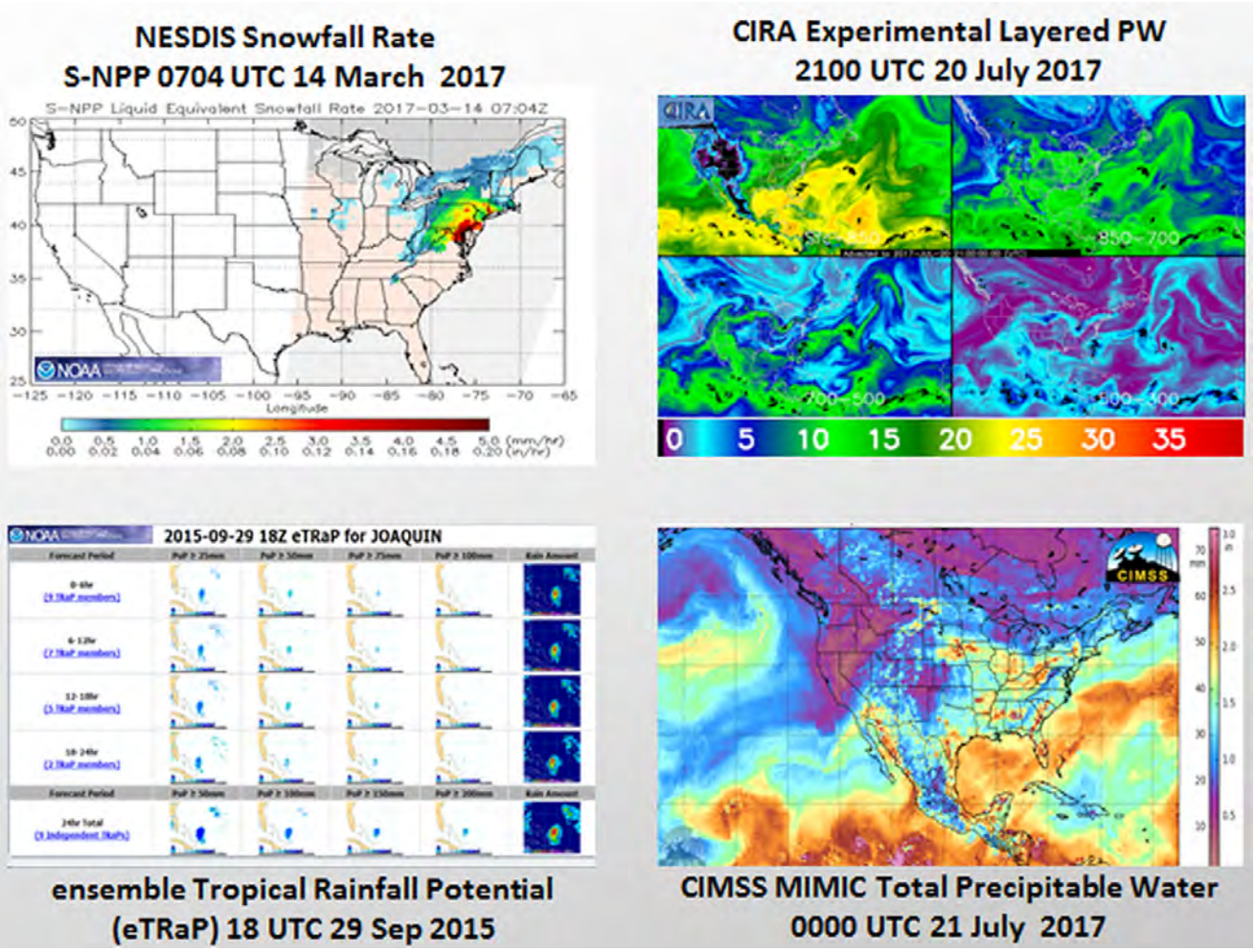
The National Environmental Satellite, Data, and Information Service (NESDIS) Satellite Analysis Branch (SAB) precipitation group assists the NOAA/NCEP National Weather Service (NWS) national center Weather Prediction National Center (WPC) in their efforts to prepare the public for these extreme

precipitation events. The SAB uses two primary sources of operational remote sensing data, i.e., ground-based and space-based observation systems. Ground based systems include rain gauges and weather radar. They can often be subject to coverage gaps over land, especially in mountains and remote sparsely inhabited locations, and sparse non–uniform observations in remote locations, like over oceans. This sparsity makes any type of analysis of precipitation over land, let alone over the ocean, very difficult.
By far the most abundant source of data on moisture in the atmosphere and precipitation that reaches the ground and ocean (meteorological variables) comes from Earth observation satellites. Many of the weather variables captured by Earth observation satellites have been transformed into operational products that are used in a wide range of applications ranging from nowcasting, numerical weather prediction (NWP), to agriculture, and hydrology. The SAB has many well-rounded satellite product tools in its lineup to help NWS river and weather forecasters meet their major mission requirements of saving lives and property.

NOAA/NESDIS SATELLITE ANALYSIS BRANCH AND ITS PRODUCTS

The NESDIS SAB supports local NWS Weather Forecast Offices (WFOs) and River Forecast Centers (RFCs) through their briefings to NOAA/NWS' WPC. SAB monitors developing and on-going precipitation events using all the satellite tools that are available and provides tailored analyses of short term precipitation trends and rainfall estimates to the NWS offices via the NWS' WPC. Briefings to NWS' WPC include satellite analysis and application information on excessive rainfall areas, precipitation trends over the next 24 hours.





Many of the products available from NESDIS (see above) are derived from microwave sensors onboard polar-orbiting satellites. The advantage of these products is that they were developed with the idea of both complementing and supplementing conventional observations as well as the more timely and frequently produced geostationary satellite imagery. Microwave sensors are able to see through non-precipitating clouds, thus their products, when used in tandem with the more frequently produced imagery from geostationary satellites guarantees a more complete analysis of atmospheric moisture over land and ocean, and forecast of precipitation. Satellite signatures and pattern recognition help satellite analysts and forecasters more quickly and accurately clue in to potential hazardous weather.

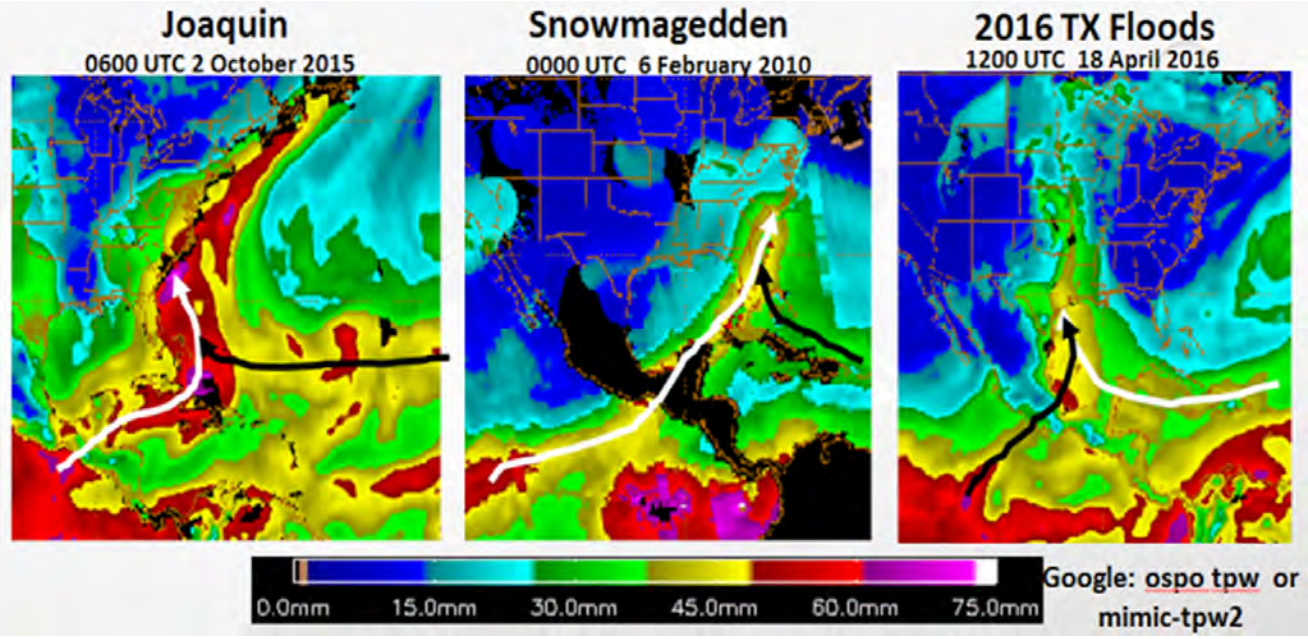
PRECIPITATION PRODUCT BACKGROUND

Satellite microwave sensor derived water vapor imagery was introduced into forecast operations in the late 1980's with the launch of the first Defense Meteorological Satellite Program (DMSP) Special Sensor Microwave Imager (SSM/I). The DMSP added a sounder to their program in the early to mid 2000's and now the sensor is called SSMI/S). The success of the early DMSP SSM/I led to NOAA launching their own Advanced Microwave Sounding Unit (AMSU) in 1998. These microwave sensors are able to estimate atmospheric temperature, moisture, and surface parameters and have paved the way for the creation of many of the products seen at the top of this page, including the Total Precipitable Water (TPW) products. Today, data from different satellite microwave sensors are blended to produce products like Blended TPW, Rain Rate, MIMIC TPW, QMORPH, eTRaP. In particular, the Blended TPW product has gained significant notoriety with forecasters as it eliminates the biases between the datasets; allows a forecaster to view all the

TPW in one global composite with very few if any data gaps; allows for more frequent updates with faster processing. The section that follows describes the TPW and other products that are providing forecasters, now and in the future with JPSS satellites, a unique, space-based perspective of features that might not be readily apparent from traditional IR or VIS satellite imagery or radar.

KEY PRECIPITATION PRODUCTS

Since most of the moisture in the atmosphere is below 10000 feet, TPW is useful for locating high amounts of low-level moisture—one of the most important ingredients necessary for generating and sustaining heavy precipitation. Furthermore, as it accurately depicts tropospheric water vapor and its movement, applications using it help support real time forecasts of heavy rainfall/flooding and severe weather.



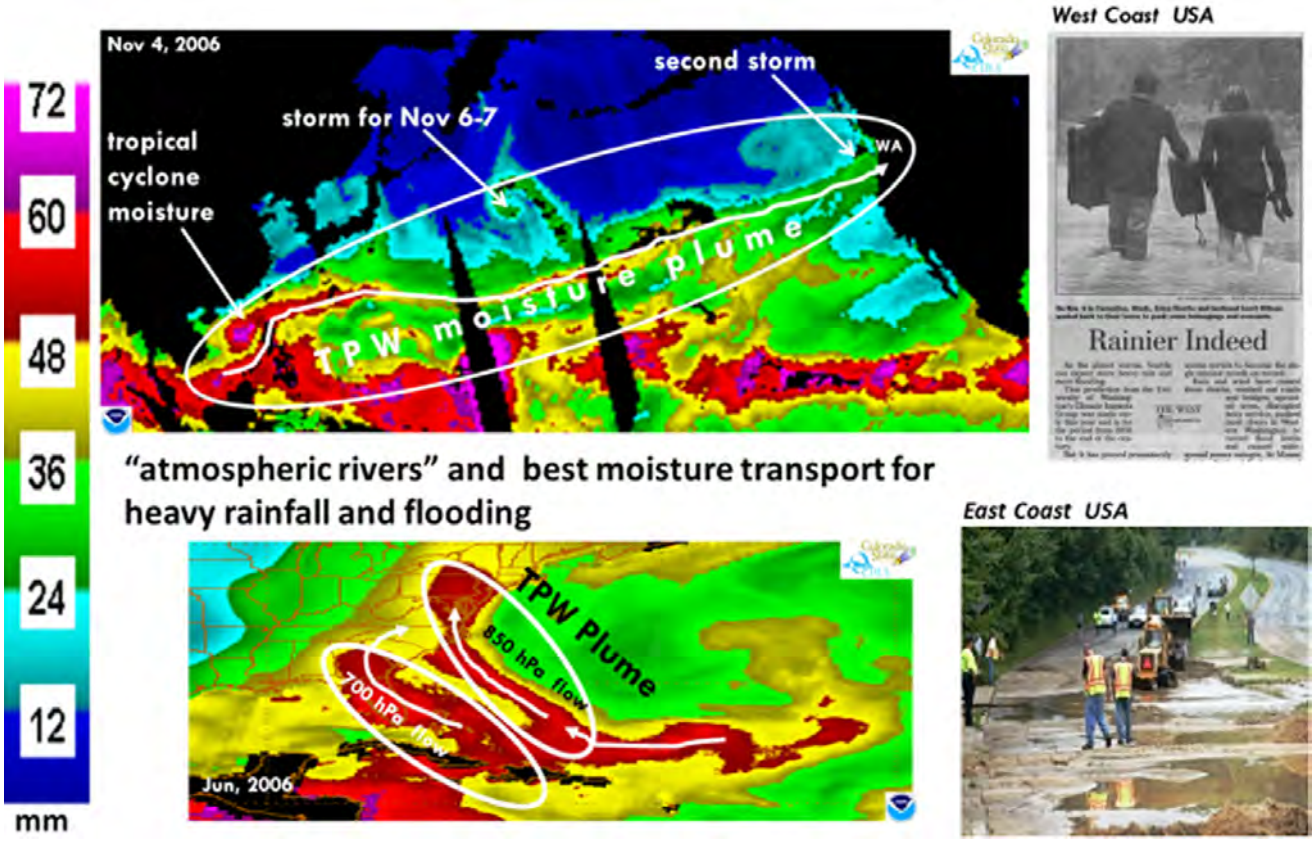
The most recognized satellite signature for TPW is the water vapor plume or "atmospheric river" (AR). ARs are relatively long (hundreds to thousands of miles), concentrated moisture rich areas in the atmosphere. They can be found in most any part of the globe and can be responsible for most of the horizontal transport of water vapor outside of the tropics that are associated with major storms. When the lead of front edge of ARs make landfall and interact with a storm, they often release this water vapor in the form of rain or snow. This product can help forecasters recognize key moisture signatures for heavy precipitation and potential flooding such as: the concentration of high moisture (plume) connected to the tropics or at least the subtropics; long fetch moisture transport in which low level winds are blowing parallel and through the highest moisture; additional secondary moisture plume converging into the main one for the threat of an even greater catastrophic weather event at the end of the plume of moisture. In addition, other TPW signatures can give forecasters an indication of severe weather potential.

BLENDED TOTAL PRECIPITABLE WATER (BTPW)

The Blended TPW product was developed in 2006 by scientists at the Colorado State University's Cooperative Institute for Research in the Atmosphere (CIRA) so forecasters and analysts would only have to look at one uniform globally composited TPW product instead of separate TPW products from various remote sensing entities. Now known as the NOAA/NESDIS Blended TPW (bTPW) product, it became

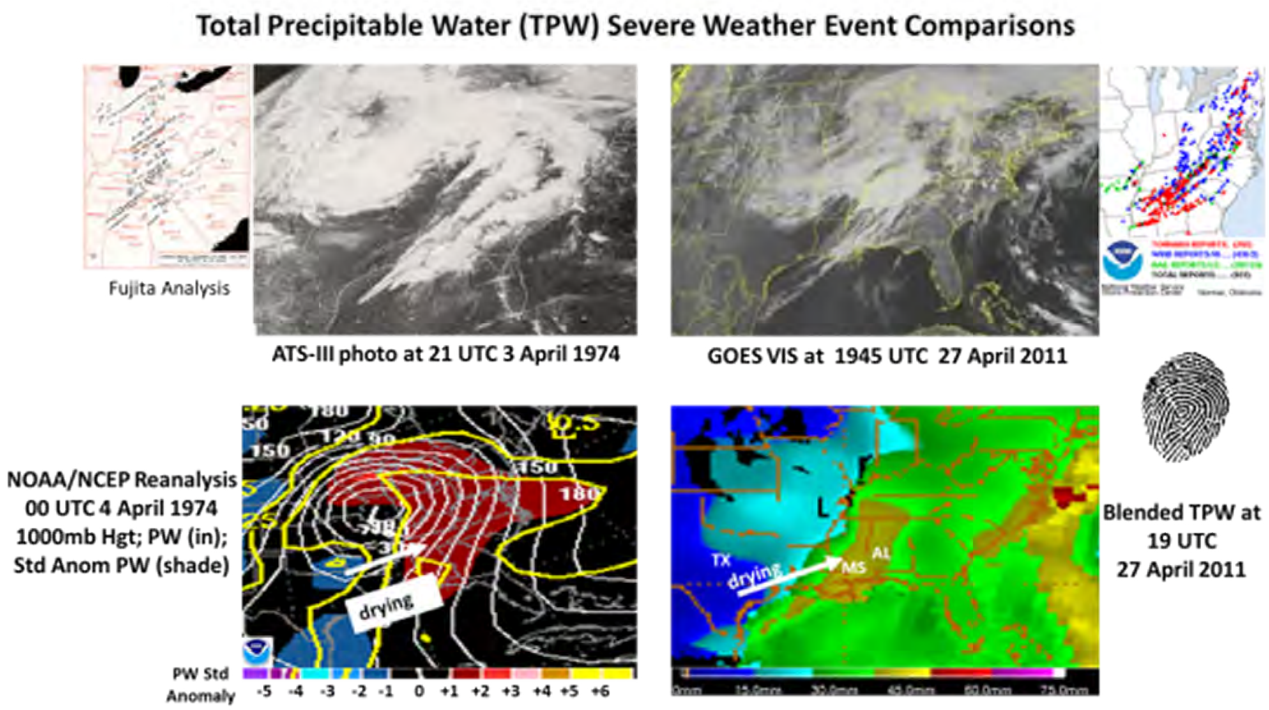
operational (supported 24 x 7 x 365) in 2009. The bTPW contains data from multiple remote sensing sources including microwave sensors on polar-orbiting satellites, retrievals from geostationary satellites and land-based Global Positional Satellites (GPS-MET). Over the continental United States (CONUS), the product uses remote sensing TPW data primarily from GPS-MET data. Over the observation poor regions of the world, such as the oceans, a blend of MIRS SSMI/S, AMSU and ATMS data are used. To finish the product overland outside of the CONUS, MIRS TPW is included.

The early use of and development of applications for Blended TPW (see the forthcoming heavy precipitation cases) really brought out its potential, and put it on a fast track to operations.



The early use of experimental Blended TPW when it was being developed in 2006 by the scientists at Colorado State University's Cooperative Institute for Research in the Atmosphere (CIRA) awakened forecasters eyes as to the tremendous potential for this satellite derived product—putting it on a fast track to operations by 2009. Above are just two of the then experimental CIRA Blended TPW images that allowed satellite analysts to recognize the potential for heavy rain and flooding days in advance and convey that information to NWS forecasters. The top image shows a well-recognized "atmospheric river" of moisture from the Pacific Northwest coast west-southwest across nearly the entire Pacific and originating with a tropical cyclone near the Philippines. The long, white curvy arrow on the image represents the low level winds blowing parallel and through the highest moisture from the tropical cyclone to Washington State. This represented a well-recognized satellite signature, developed in the 1990's, of heavy rain and flooding potential at the end of the river of moisture. The bottom image shows a slightly different signature of heavy rain and flooding potential on the Blended TPW image. Two long fetch moisture plumes, advecting and converging over the Mid-Atlantic states, resulted in river, stream and highway flooding around the Washington, DC area. The early use of Blended TPW in 2006 and desire by forecasters to see this product on a daily basis, spurred further development of this product to operational

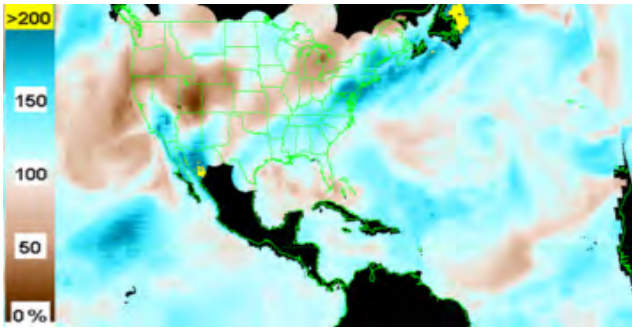
status in a near record three years. Now this product is poised to be further enhanced with microwave data from the ATMS sensor onboard NOAA-20.



And the bTPW product was not just for heavy precipitation and flooding. Applications using TPW data are a bit different for severe weather. For example, in the April months of 1974 and 2011, plumes carrying high amounts of moisture would clash with lower moisture coming in from the west to form a huge violent weather event, or a super outbreak of tornadoes. In the 21st century the benefit of more and better types of satellite data enabled a comparison of both high and low amounts of moisture in these hazardous events as well as the recognition of patterns that resulted in these catastrophic severe weather events. While the moisture patterns of these two huge, violent events were not exactly the same, they were close enough.

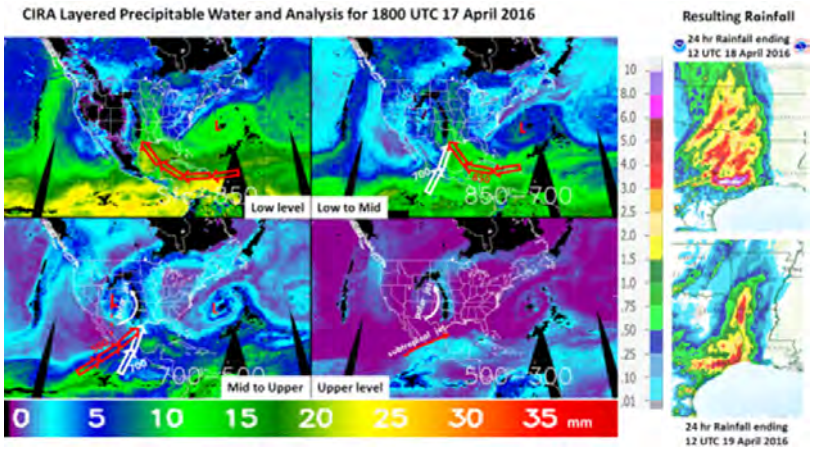
BLENDED TPW PERCENT OF NORMAL

The Blended TPW Percent of Normal product compares bTPW with a 1988–99 satellite climatology derived from NASA's Water Vapor Project (NVAP). As a complement to b TPW, Blended TPW Percent of Normal helps forecasters quickly see areas where active weather is happening now or going to occur and assess the potential severity of the hazardous weather in the near future.



Using the bTPW and Percent of Normal TPW products together and relying on established conceptual models can allow forecasters to more easily and quickly identify potential heavy rain/flooding and other hazardous severe weather situations. Thus, increasing their confidence in getting more timely and accurate hazardous weather forecasts issued to the public.

EXPERIMENTAL ADVECTED LAYERED PRECIPITABLE WATER (ALPW)



The satellite-derived Blended TPWproduct conveys no information on the vertical distribution of moisture, relevant to a variety of forecast concerns. Moreover, traditional point observations, such as radiosondes, leave gaps, while other layers of the atmosphere are missed by geostationary satellite sensors because of clouds. Vertical profile information is particularly lacking over the oceans to see the totality of moisture systems. To fill a niche, the experimental Advected Layered PW (ALPW), developed in 2012 by CIRA scientists, allows forecasters to see the vertical distribution of water vapor in near real-time at four distinct layers. Not resting on the laurels of bTPW, the Experimental CIRA ALPW allows forecasters to track individual layers of moisture ahead of and during developing hazardous weather. This helps forecasters quickly recognize heavy rain/flash flood and severe weather signatures so they can issue more timely and accurate watches and warnings to the public of coming hazardous weather. In this example from Texas in April 2016 and 6 hours before the heavy rains began, a pattern of long fetch moisture transport along with converging plumes of high moisture at several levels all pointed to SE Texas getting an excessive heavy rain and flooding event. Coincidentally, surface boundary and upper level forcing features, seen clearly with the ALPW imagery, would eventually help squeeze out the very high moisture that was piling up over that area. Being able to visualize moisture alignment in the same location at three layers, tells us much more. Now we know from the ALPW image below that there is a deep layer of moisture that can contribute to heavy rainfall and flooding. Over the next 24 hours the combination of moisture plumes converging at two or more layers and the location of a distinct boundary/front at different layers helped forecasters focus on where the heavy rain and flash flood would be. Thus providing timely and accurate warnings to the public of impending hazardous weather.

In this case heavy rain and flooding were the predominant hazard and the signatures were evident in this data at least 6 hours prior to the event.

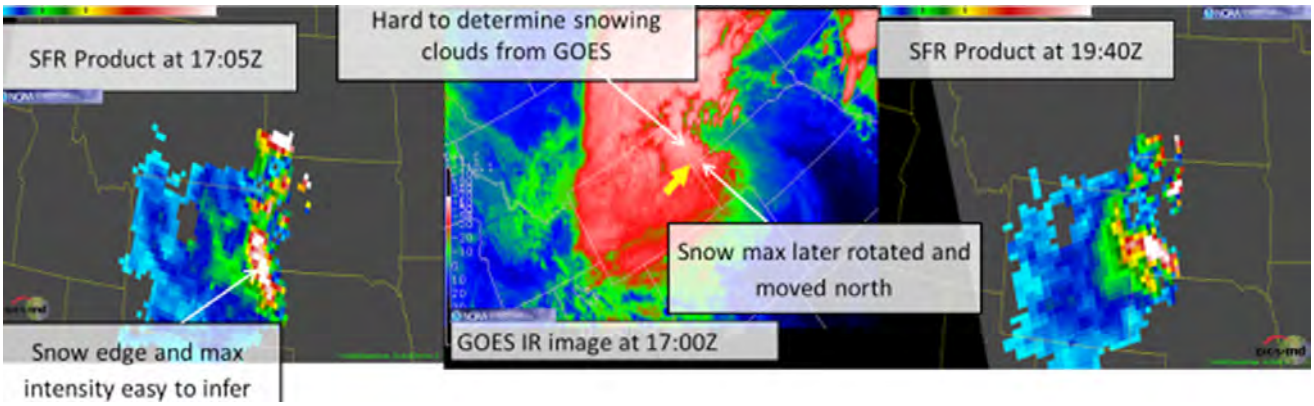
BLENDED RAIN RATE (BRR)

Microwave sensors onboard polar-orbiting satellites are the most accurate depicter of rain area and amount. The problem when using them for fast changing weather is that they are less frequent, timely and of lower resolution than rain estimates from other remote sensing, like radar. Plus forecasters only have time to look at one composite product that updates with new data passes than looking at many different satellite microwave rain rates. Nonetheless, microwave rain rates have been helping forecasters for almost 3 decades get a handle on what is going on mostly over the water. Thus to better assist forecasters, different microwave satellite data from polar orbiting satellites were blended into one consistent, uniform rain rate product called Blended Rain Rate (bRR). Estimates from the bRR are useful for identifying the areal extent and intensity of rain both over the data sparse ocean areas and over land areas where radar and observational rain gauge coverage is inadequate. The microwave rain rates are instantaneous and the resolution is 15km at nadir. Forecasters have to understand how to use them under those circumstances. The estimates over the water allow forecasters to follow the trends of offshore storm rainfall before it reaches

land. With 60% of the US population living in the 23 states bordered by either an ocean, sea or Gulf, bRR plays an important observational role for forecasters to follow the areal extent and intensity of rain trends beyond the reach of coastal radars and before reaching land.

SNOWFALL RATE (SFR) PRODUCT

The NOAA/NESDIS liquid equivalent, in-cloud Snowfall Rate (SFR) Product, which has benefited from continuous improvement since it became operational in 2012, is derived from passive microwave instruments aboard polar-orbiting satellites. The sensors include the Advanced Technology Microwave Sounder (ATMS) aboard Suomi-NPP and the Advanced Microwave Sounding Unit (AMSU)/Microwave Humidity Sounder (MHS) pair aboard a suite of two NOAA and two EUMETSAT polar-orbiting satellites. With a suite of five satellites, SFR can provide on average ten water equivalent snowfall rate estimates per day over land in mid-latitudes at a resolution of 16 km at nadir with more frequent estimates at higher latitudes, like for Canada and Alaska. Please also note that for the winter of 2017–2018, the SFR will be adding data from one NASA GPM and three DMSP SSMI/S sensor satellites. Since the winter of 2014–2015, SFR has been produced for the CONUS and Alaska using direct broadcast (DB) data provided by the University of Wisconsin-Madison and University of Alaska Fairbanks/GINA. This reduces SFR latency to less than 30 minutes and is ground-breaking for making the product more useful for weather forecasting. Further in the future, the SFR will include ATMS sensor data from NOAA-20.



No one satellite can do it all. Though GOES imagery is more timely and frequent, it many times is harder to determine which areas have or do not have snow as well as the intensity. This is because the GOES infrared sensor cannot penetrate the clouds like with the microwave. One of the biggest advantages of SFR is it brings out features that may not be readily apparent from traditional IR or VIS satellite imagery or radar. Thus it is often paired with GOES IR and VIS (only daytime) images to provide trend information on both the movement and the intensity of the snow between polar-orbiting satellite microwave passes. This allows forecasters to use the objective snow water equivalents from SFR with GOES subjective snow signatures to give an even better snow analysis.

CONCLUSION

For over 25 years NESDIS precipitation products derived from polar-orbiting satellites have helped operational forecasters prepare for the most demanding heavy precipitation outbreaks. Forecasters have looked to the SAB's expertise in satellite imagery and product interpretation to identify areas of heaviest precipitation and where the moisture for these events originate. The SAB's ability to effectively use standard precipitation products and assist in the application and development of new satellite products has been

critical to improving the analysis of rapidly changing weather environments and both the timeliness and accuracy of high impact weather forecasts.

Operational forecasters now have a variety of operational and research products and tools to interrogate hazardous weather systems for different environments.

There is always more work to be done, more satellites to include, especially with the activation of generation satellites such as GOES-16 and NOAA-20. There will be opportunities in the future for satellite analysts, researchers and forecasters to collaborate together in improving existing satellite products and applications. There will be many more opportunities for satellite researchers to propose and evaluate new products and applications as they become more familiar with the next generation GOES and JPSS capabilities. The future is bright indeed for the operational use of satellite moisture products.

USING FIRE RADIATIVE POWER DATA FROM THE VISIBLE INFRARED IMAGING RADIOMETER SUITE TO FORECAST SMOKE DISPERSION

The information in this article is based, in part, on the August 28, 2017 JPSS science seminar presented by Ravan Ahmadov, PhD, NOAA/Earth System Research Laboratory/Global Systems Division and the Cooperative Institute for Research in Environmental Sciences (CIRES), University of Colorado at Boulder, Boulder, Colorado.

Massive Detwiler Fire sends smoke all the way to Idaho while choking Yosemite and Lake Tahoe (July 2017).

The Detwiler Fire was just one of many fires that ignited across the United States in the 2017 fire season, which seemed longer than most as it really hadn't stopped since the fall of 2016. According to the Business Insider (www.businessinsider.com/wildfire-season-western-us-2017-9), by the middle of September more than 8 million acres had burned with more than 500 homes and other structures destroyed. In addition, the article states that the Forest Service had spent more than $1.75 billion fighting fires and the Interior Department had spent more than $391 million since the season began. Beyond structural damages, there were further risks associated with the smoke from these fires, particularly to vulnerable groups like children, the elderly, and people with respiratory and cardiac conditions. These risk groups can often be hundreds of miles away from the burn site.

As showcased in the snippets captured above from the *Business Insider*, these news stories are important because they bring to the forefront the dangers of fire. They not only highlight the dangers to the surrounding communities, but also the significant effects of transcontinental transport of smoke. Plume rise, the height that smoke particles can reach after they are ejected from wildland fires, ranges anywhere from tens to thousands of meters. As highlighted in the news article, if injected into higher elevations, these particles can be transported by prevailing winds a great distance from their source, which can create hazards to human health and the environment thousands of miles from a burn site.

First responders, forecasters, and researchers are continually looking for the best smoke models to use in preparing communities for hazards from these fires. To make smoke forecasting models more effective, satellites provide fire products in real time. The Visible Infrared Imaging Radiometer Suite (VIIRS) Fire Radiative Power (FRP) data from the Joint Polar Satellite System (JPSS) have proven to be an invaluable input to these models.

The VIIRS Active Fire (VIIRS-AF) product provides detections of thermal anomalies across the globe on a daily basis. For those anomalies that can be linked to fires, whether manmade or tied to natural causes, the VIIRS-AF product can provide information about fire location and intensity which can be used to help

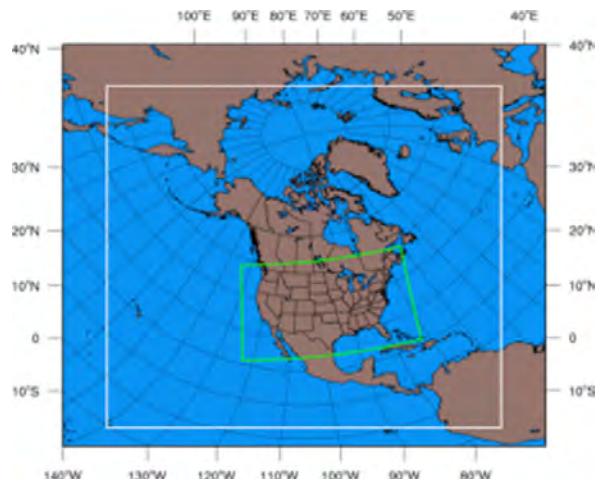
in operational response decisions. The product consists of 6-minute granules in an unprojected segment of the VIIRS orbital swath. Distributed from the NOAA CLASS data archive in NetCDF format, the data consists of numerous fields that characterize the fire detections including latitude and longitude, brightness temperature, and FRP, expressed in megawatts.

INGESTING SATELLITE FIRE RADIATIVE POWER INTO THE HIGH-RESOLUTION RAPID REFRESH (HRRR) SMOKE MODEL

While there are a number of operational and quasi-operational smoke forecast models in the United States and abroad, very few use the satellite FRP data to estimate wildfire emissions and plume rise. Some atmospheric models do not include fire plume rise parameterization. Moreover, many of these models are run at relatively coarser spatial resolutions. Fire and smoke model development and validation is an important area of research in the Joint Polar Satellite System (JPSS) Proving Ground and Risk Reduction Program's Fire and Smoke Initiative. The initiative includes an effort to assimilate real-time fire detection and characterization data, or FRP, derived from VIIRS into forecast models used at NOAA such as the National Weather Service (NWS) High-Resolution Rapid Refresh (HRRR) model.

HRRR-SMOKE MODEL BACKGROUND

The Rapid Refresh model (RAP) provides boundary conditions of meteorological fields for the HRRR model (shown right). The RAP is the continental-scale NOAA hourly-updated assimilation/modeling system operational at NCEP and run in experimental mode at NOAA/ESRL. The RAP model is at 13km horizontal grid spacing and the HRRR is at 3km grid spacing.

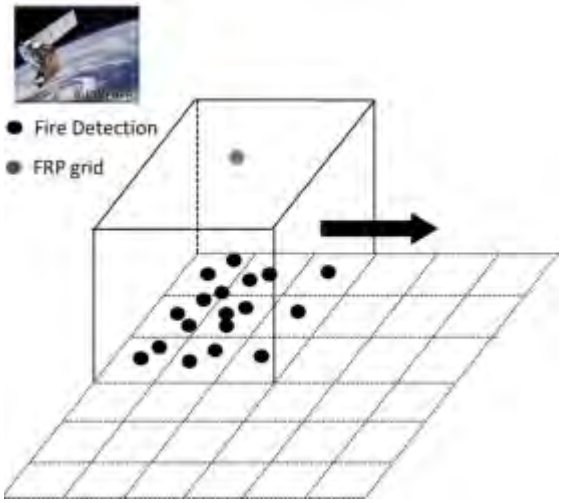


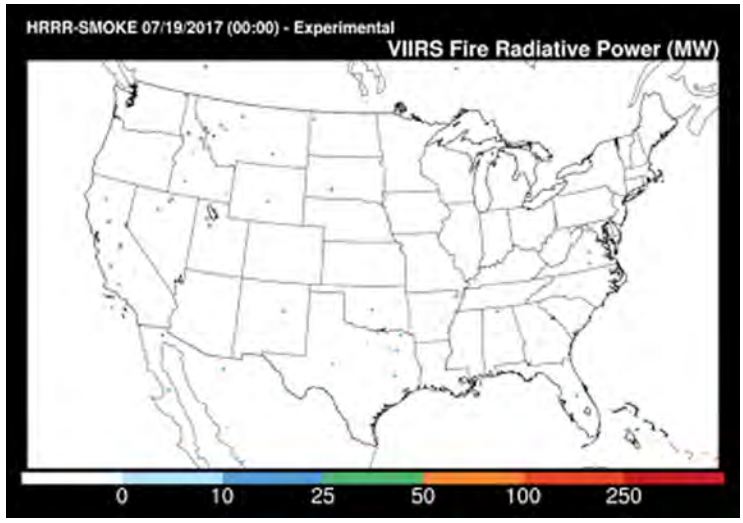
Operational weather forecast models at NWS:
RAP (white), 13km resolution
HRRR model CONUS domain (green), 3 km resolution
(https://rapidrefresh.noaa.gov/)

The HRRR model includes an aerosol aware microphysics scheme, which uses only climatological aerosols. It is based on the Weather Research and Forecasting (WRF) model. The HRRR Model is able to simulate mesoscale flows and smoke dispersion over complex terrain. It is a coupled meteorology and chemistry model. The HRRR-Smoke is an experimental online meteorology-smoke model based on the HRRR model with added smoke tracer emitted as fine particulate matter by biomass burning emissions (including simulation of plume rise by the model). It simulates plume rise and smoke concentrations in real-time with a 6-hourly update cycle over two high resolution (3km) domains covering CONUS and Alaska.

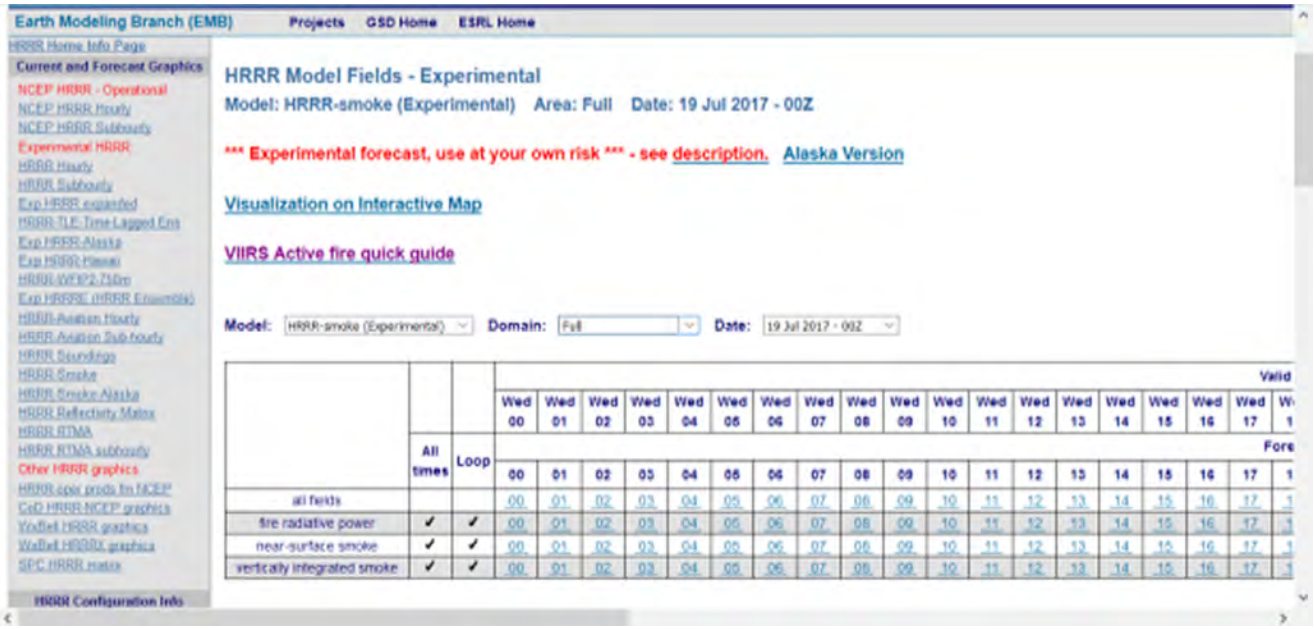
The coupled structure of the model allows for meteorology and smoke to be studied within the same modeling framework. This allows for a rapid update of the data assimilation cycle for meteorology. It runs four times a day (00, 06, 12 and 18 UTC) to produce smoke forecasts for the next 36 hours. To represent meteorological conditions as realistically as possible, multiple real-time datasets serve as inputs for the meteorological data assimilation. These include surface observations, radiosondes, GFS model output, and satellite data. For post processing functions, the system has been designed to generate binary, or GRIB2 files in a special format that allows for different Weather Forecast Offices (WFOs) to visualize the product in their native display systems such as the Advanced Weather Interactive Processing System (AWIPS).

VIIRS FRP DATA ASSIMILATED INTO THE HRRR-SMOKE MODEL



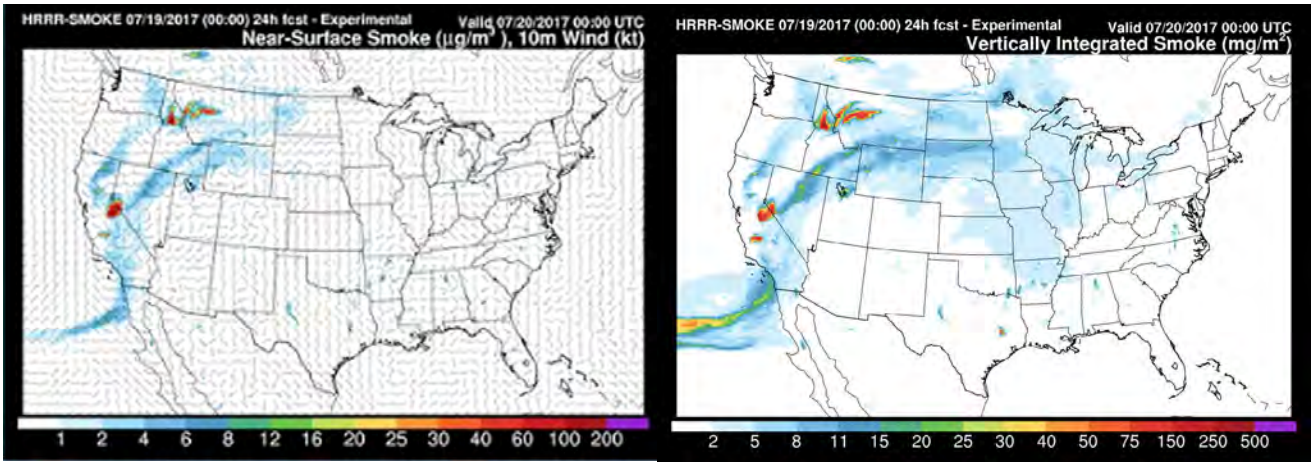


The VIIRS FRP values are collected and then aggregated to the model grid's 3x3 km grid cells. Above right is satellite fire detection mapped over 3x3km HRRR CONUS grid pixels for July 19, 2017. The model assumes that the fires will continue to occur in the same location over the smoke forecast period, and uses the VIIRS FRP data within its prep_chem tool to calculate fire emissions and other parameters. The HRRR-Smoke output is post processed for users and visualized on the HRRR-Smoke webpage (below).



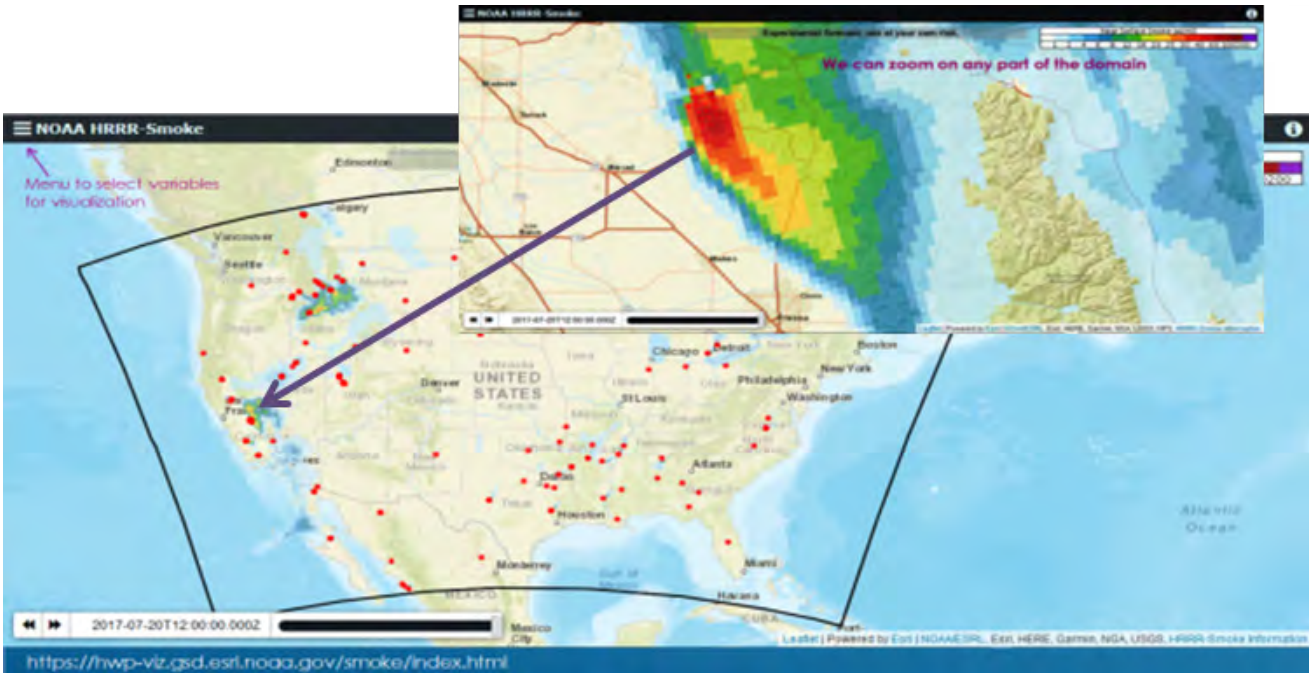
In the plot shown on the next page, the left panel displays near surface smoke plots which simulated fire emitted fine particulate matter (PM2.5 or fire smoke) concentrations at the first model level, which is approximately 8m above ground and wind barbs are also provided so the user can get a feel for how the smoke moves in response to the changing wind fields. The vertically integrated smoke plots shows simulated total PM2.5 mass within vertical columns over each model grid cell. It displays the effect of fire smoke in the boundary layer as well as aloft. In addition to the satellite FRP and smoke concentrations (near-surface and vertically integrated), the web interface allows users to browse forecasts of wind,

precipitation and air temperature. The plot below shows a forecast of vertically integrated smoke for July 19, 2017, 8 p.m. EDT over the CONUS. This forecast is based on a 24-hour model simulation initialized at 8 p.m. EDT, July 18, 2017.



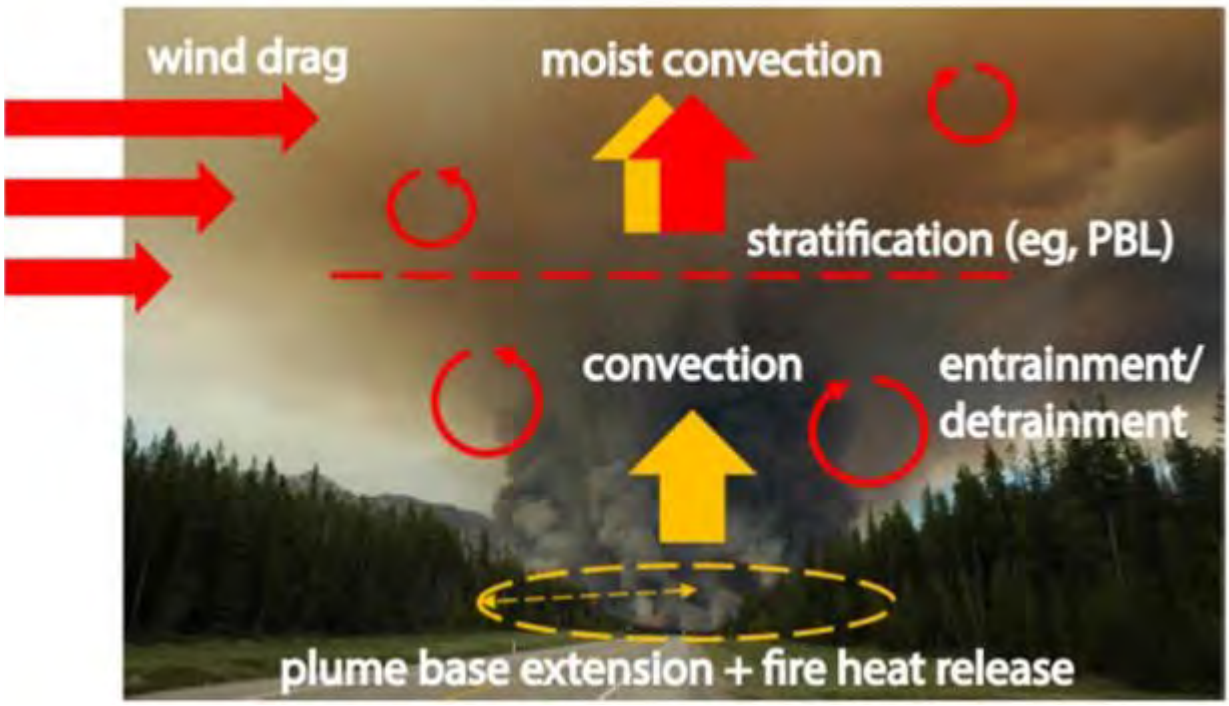
RESPONDING TO USER FEEDBACK

The Fire and Smoke Initiative Working Group was established to advance support for fire weather and smoke forecasting. It has been a superb forum to evaluate the operational value of the HRRR-Smoke model products to NWS. For instance, a new visualization platform was developed to address a request from NWS Incident Meteorologists (IMETs) for an interface that could show smoke over manmade and geographical features such as roads, rivers and cities. The original HRRR version used regional boundaries to show the smoke products. This new version is a CONUS-wide visualization that can be zoomed in to look at the smoke products at a much finer scale over high-resolution geographical map. These new features, which can display smoke over a highway, for instance, can help decision makers determine exact areas being affected, or decide if detours are necessary, for example. The red dots in the larger map below show the fire locations based on the VIIRS FRP data. The IMETs and operational forecasters have provided invaluable feedback and insight to the HRRR developers who in turn have made changes in response to this feedback.



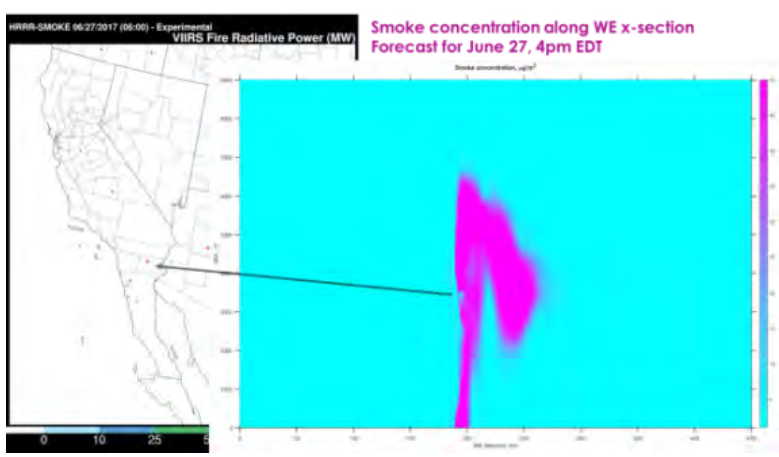
FIRE PLUME RISE DYNAMICS

One of the key elements of fire smoke modeling is how the model handles the "fire plume." It is a very complex phenomenon and very challenging to simulate. There are many physical processes—such as the amount of heat being emitted by a given fire and atmospheric stability, which affect the plume rise and eventually smoke transport. Heat flux is needed to calculate plume rise. The HRRR-smoke model is based upon the WRF-Chem model; in the older version of WRF-Chem, heat flux was determined by a look-up table of heat flux numbers tied to an assumed constant fire over a given land classification, such as grassland, boreal forest, tropical forest, etc. The new approach ties the satellite-derived FRP to a heat flux within a given grid cell.

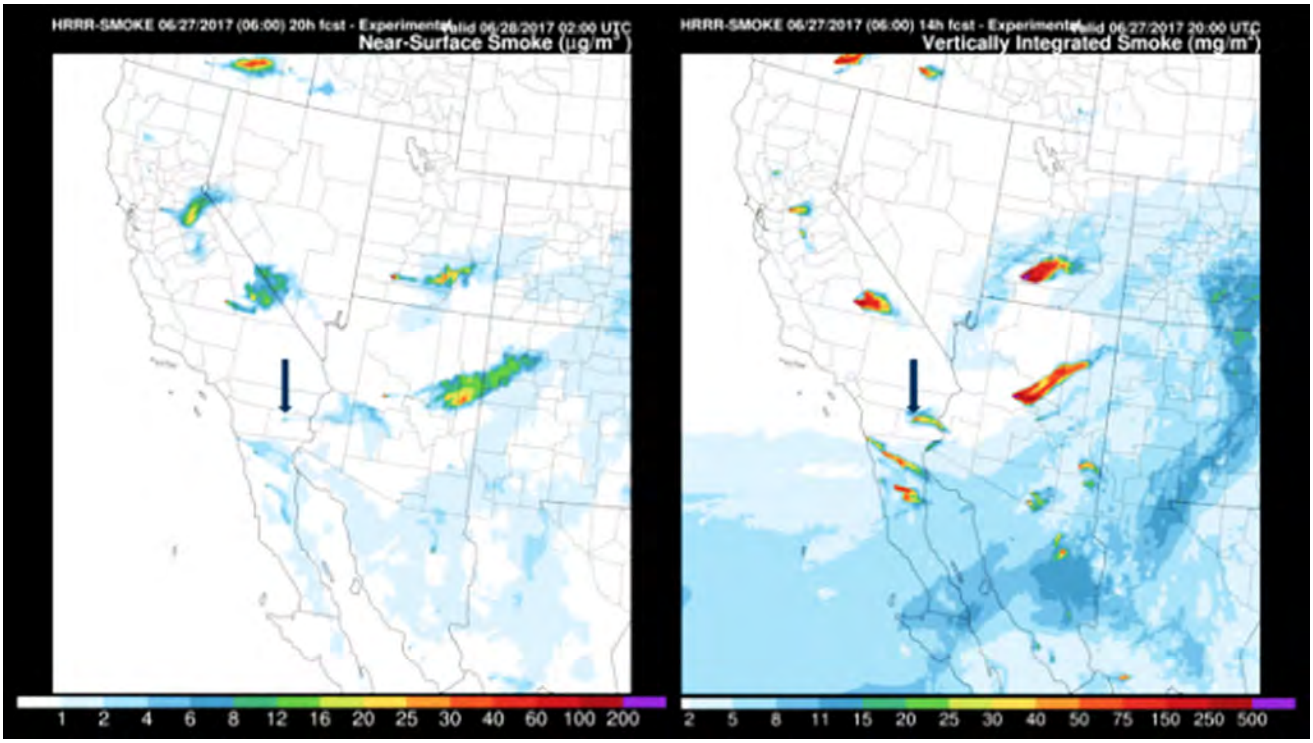


Schematic view of processes which drive plume rise in various environments. Red and yellow colors stand for atmospheric or fire-induced mechanisms respectively. Image credit Paugam et al., ACP, 2016.

The HRRR-Smoke model's use of plume dynamics in certain fires allows the smoke to rise much higher vertically, allowing it to be "transported" by the model's upper level winds. The figure on the following page is a cross section showing smoke concentration plotted along the West-East direction for fires in southern California on June 27, 2017. This cross section plot reveals two plumes; one rises to about 7km above ground level and the other is concentrated around 4km above the surface. Both plumes are above the boundary layer. Smoke emitted above the boundary layer can travel great distances; eventually this smoke will be deposited on the ground and all its inherent social impacts such as low visibility, health problems, ash deposit, etc., will be realized. The HRRR-Smoke model aims to provide the public some measure of warning of incoming smoke to allow them to take actions to mitigate its impact.

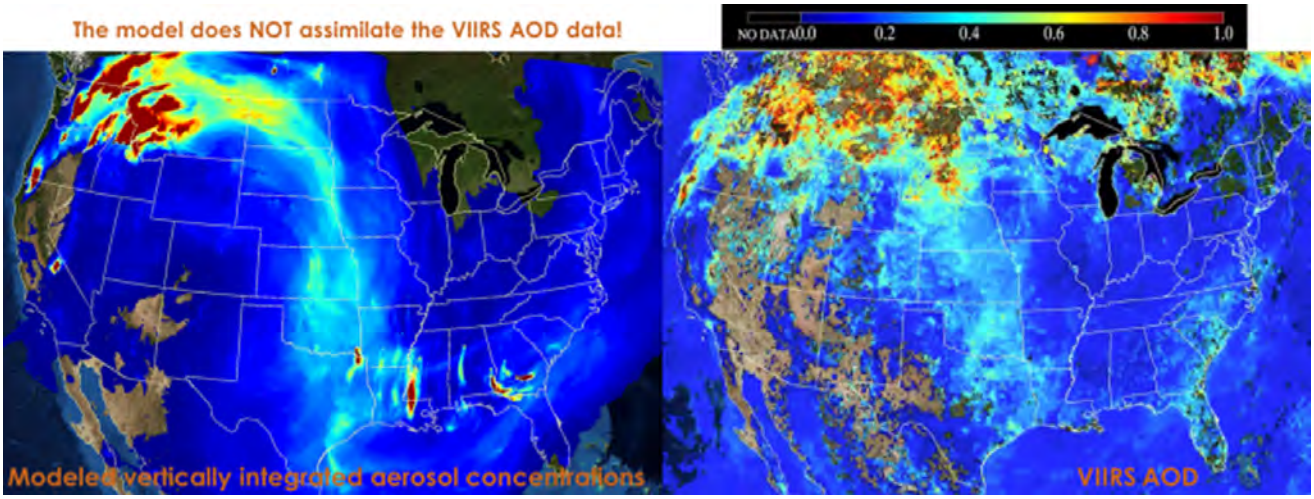


This same CA fire (black arrow) is shown below to demonstrate the impact of plume rise on a 24-hour forecast for June 28. The left panel shows near-surface smoke; not much smoke from these fires is present near the surface. The right panel, which is vertically integrated smoke, shows that the smoke is generally aloft, and only travels a relatively short distance eastward. The more intense Goodwin Fire (black circle) has extensive smoke near the ground and a strong vertically integrated smoke signal.

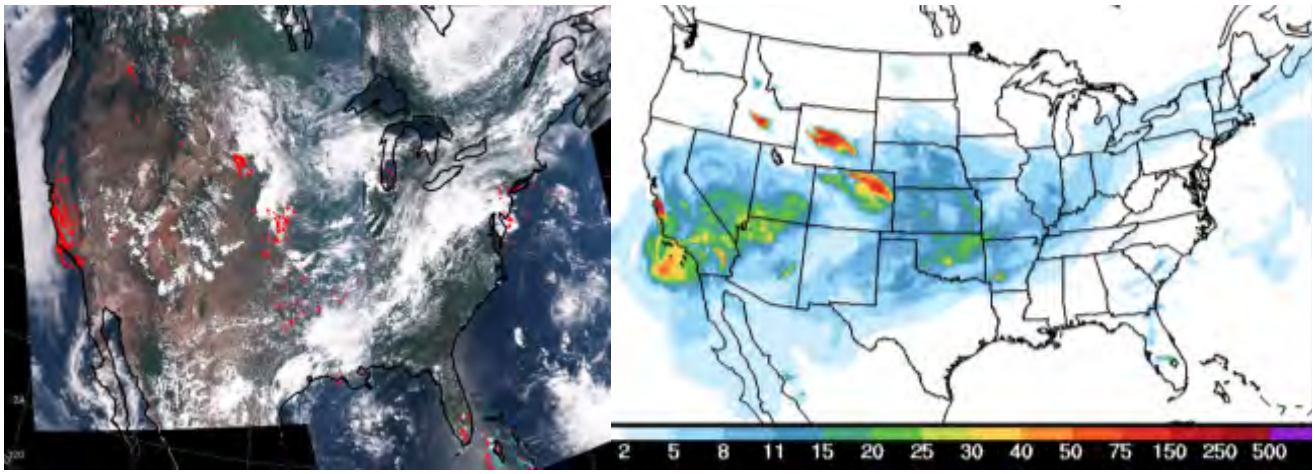


HRRR-SMOKE MODEL VALIDATION

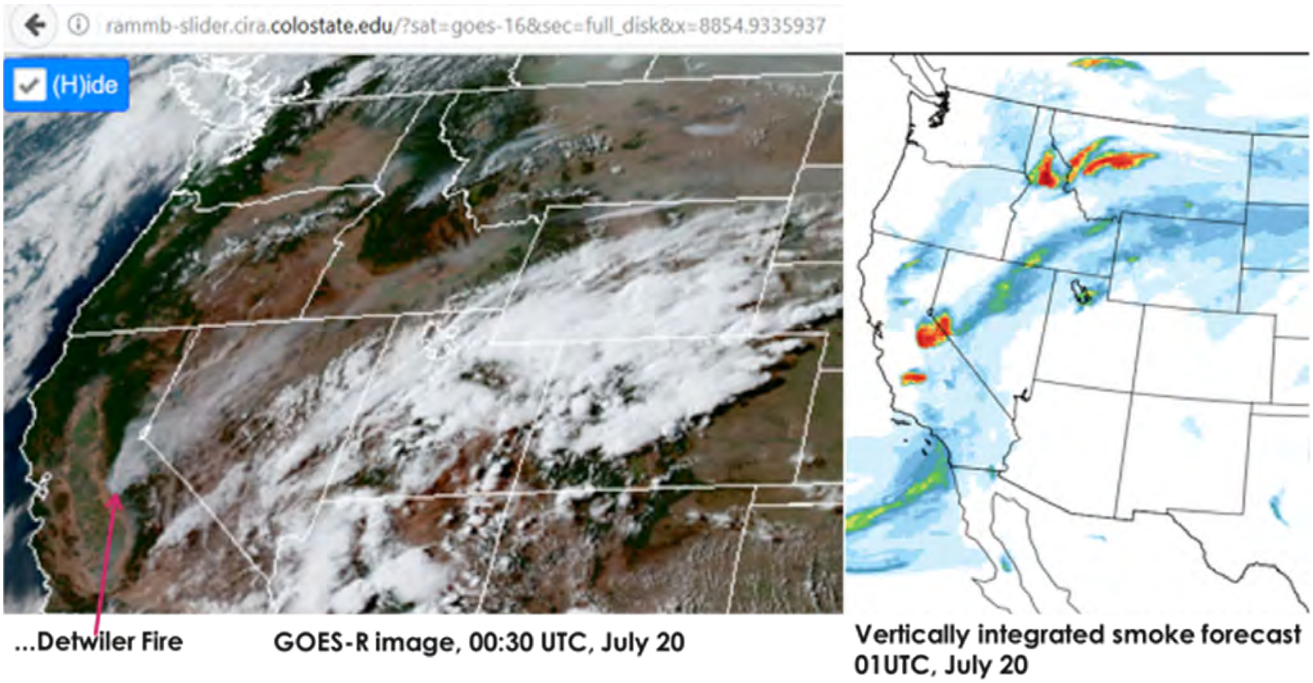
Validating a product is important because it measures the quality, value, and the ability of the product or service to meet user needs. In the example below, a user can see that the VIIRS AOD product (right) provided a good qualitative validation of the HRRR Smoke Model (left). August 2015 had many large fires in the Pacific Northwest. Both the model and VIIRS AOD shows the extensive smoke along the US-Canadian border and the smoke transport (because of the plume rise) into the eastern parts of Texas.



A year later, the VIIRS AOD data generated by NOAA/NESDIS started including a smoke mask. The red dots shown in the left panel (AOD with smoke mask) indicate smoke. A similar spatial pattern is visible in the HRRR-Smoke forecast especially over California, Colorado, and Wyoming.



HRRR-Smoke forecasts were also validated qualitatively using visible GOES-16 imagery and ground sources as shown in the case below of the Detwiler Fire, which according to Cal Fire, burned nearly 82,000 acres in Mariposa County, California. The satellite validates the Detwiler's smoke movement to Idaho. It also shows the northern Idaho wildfires quite well.



HRRR-SMOKE UPDATES

Based on user feedback, the HRRR-Smoke model now ingests FRP from the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument on board the NASA TERRA and AQUA satellites in addition to VIIRS. HRRR-Smoke is also using the high-resolution MODIS land-use map to derive the biomass burning emissions. Finally, various approaches (e.g. the Fire Energetics and Emissions Research emission coefficients) are being tested in HRRR-Smoke to estimate the biomass burning emissions.

SIMULATING SMOKE FEEDBACK ON METEOROLOGY IN HRRR-SMOKE

HRRR-Smoke allows us treating the effect of smoke feedback on shortwave radiation in the model. Forecasters have long known that a thick column of smoke can have a significant impact on the local temperature, much like cloud cover will "cool" things down. Researchers seek to determine how the solar irradiance that is modified due to smoke would impact the weather forecast. Initial indications are that representing smoke feedback upon meteorology can dramatically improve forecasts of low-level temperature and PBL mixing.

CONCLUSION

Predictions of fire behavior, weather, and smoke transport and dispersion are very complex as conditions can and do change rapidly. While there are many smoke forecast models available for use in operations and for research, very few use the satellite FRP data to estimate wildfire emissions and plume rise and are simulated in high spatial resolution. The real-time HRRR-Smoke modeling system provides experimental smoke forecast products, which is used by IMETs, forecasters, researchers and the public. The coupled experimental model is also showing promise in improving weather forecasting by accounting for smoke impact on meteorology. Future work will include efforts to add visibility as a product to the experimental forecast output; transition the HRRR-Smoke model to operations at NCEP; assimilate FRP in the RAP model (covering the entire North America) to provide boundary conditions for smoke to HRRR-Smoke, and evaluate how GOES-R FRP also could be ingested into the HRRR-Smoke model.

Acknowledgment: The HRRR-Smoke model is developed and simulated by researchers at the NOAA/ESRL Global Systems Division and Cooperative Institute of Research in Environmental Sciences (CIRES) of CU Boulder and Cooperative Institute for Research in the Atmosphere (CIRA) of CSU. This work is conducted in collaboration with researchers from NOAA/NESDIS, NCAR and NASA.

Sources

Loria, K., "Nearly 2 million acres of land are burning across the US in one of the worst fire seasons we've ever seen", Business Insider, Sep. 14, 2017. Accessed at: http://www.businessinsider.com/wildfire-season-western-us-2017-9

SUOMI NPP AND BEYOND: ENHANCING THE UNITED STATES NAVAL RESEARCH LABORATORY'S NUMERICAL WEATHER PREDICTION (NWP) MODEL AND DATA ASSIMILATION SYSTEMS

The information in this article is based, in part, on the September 27, 2017 JPSS science seminar presented by Benjamin Ruston, Naval Research Laboratory, Monterey CA. It contains work by Dr. Ruston, Sergey Frolov, Song Yang, Steve Swadley, Naval Research Laboratory, Monterey, CA; and Mayra Oyola, ASEE Postdoctoral Fellow.

The Naval Research Laboratory's Marine Meteorology Division (NRL-MRY) in Monterey CA (hereafter, NRL Monterey) has been a NOAA Joint Polar Satellite System (JPSS) Program partner for decades. NRL Monterey is collocated with Fleet Numerical Meteorology and Oceanography Center (FNMOC) to support development and upgrades of their operational numerical atmospheric forecast systems and related user products. NRL Monterey also conducts research and development programs designed to improve the basic understanding of the atmospheric processes and the atmosphere's interaction with the ocean, land and cryosphere. Collocation and collaboration with FNMOC allows NRL Monterey access to the Navy's supercomputer and workstation resources. The NRL Monterey mission and its capabilities made it a natural fit when they proposed to assist the JPSS Program in exploring the enhancement of operational usage of data from the Advanced Technology Microwave Sounder (ATMS) and Cross-track Infrared Sounder (CrIS) instruments within the NRL Numerical Weather Prediction (NWP) model and data assimilation systems. The NRL work directly influences the operational missions of FNMOC and the Naval Oceanographic Office (NAVO).

THE NAVAL RESEARCH LABORATORY MARINE METEOROLOGY DIVISION (NRL MONTEREY) BACKGROUND

Since 2004, the NRL in Monterey has been providing the global community with environmental products derived from a constellation of low earth orbiting (LEO) and geostationary (GEO) satellites. For the operational weather service community the laboratory's research efforts in predictability, data assimilation methodologies, ensembles, and other related applications have added new and innovative science and toward improved capabilities for satellite data assimilation.

The FNMOC drives warfighting effectiveness and fleet safety of Naval, Joint and Coalition forces by operating and disseminating assured global and regional numerical environmental prediction and applied decision making. To provide tailored products to its users FNMOC placed the Navy Global Environmental Model (NAVGEM) at the center of its production cycle. The NAVGEM system became FNMOC's operational model in 2013. With the launch of the joint NOAA/NASA Suomi National Polar-orbiting Partnership (Suomi NPP) satellite, NRL Monterey worked with the JPSS Program to test the assimilation of Suomi NPP CrIS and ATMS data into its NAVGEM Model.

Products from the NAVGEM Model are also critical to the NAVO in its mission to provide oceanographic products and services to all elements of the Department of Defense. Starting with NAVGEM, NAVO adds data from other sources to allow it to tailor oceanographic, hydrographic, bathymetric, geophysical and acoustic products to meet its user requirements. The operational applications of these products are critical to the NAVO's vision to assure the Navy's oceanographic knowledge superiority and risk reduction by providing the forecast battlespace through smart collection, focused analysis, and responsive delivery.

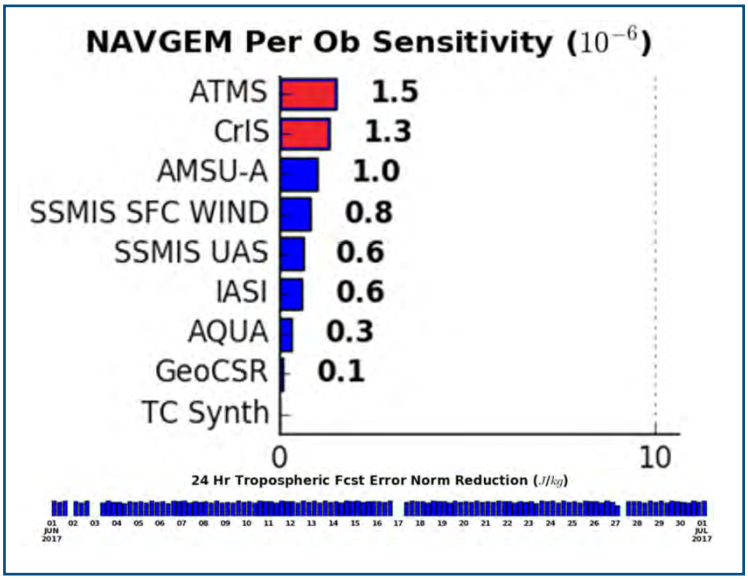
Forecast models have helped drastically improve forecasting skill, accuracy and verification. Consequently, NRL-Monterey has continued to leverage the most advanced satellite data available in the US Navy's forecast models, given the importance of this data to its users and their missions. Teaming with the JPSS Program was therefore a high priority. Success came quickly. ATMS was operationally assimilated at FNMOC with NAVGEM v1.2 in Nov 2013. CrIS was successfully assimilated in Nov 2015 with NAVGEM v1.3.1. Since then with each change in ATMS and CrIS data or a new release of NAVGEM the impact of JPSS satellite data growing in support of Navy operations. But this assimilation work can be very challenging. To understand why, one needs to be familiar with the NRL-MRY methodology for the assimilation of JPSS data.

THE NRL METHODOLOGY FOR THE ASSIMILATION OF JPSS DATA

NRL has been using its NWP model and data assimilation systems (DAS) to explore the enhanced use of data produced by the Suomi NPP and prepare for the Joint Polar Satellite System (JPSS) follow-on constellation. These systems, run operationally by the US Navy at FNMOC, have the capability for ATMS and CrIS in clear-sky areas over land, ocean, and sea-ice surfaces and have existing infrastructure to study the impact on the temperature and humidity analyses and forecasts for the NAVGEM. Since the Community Radiative Transfer Model (CRTM) and the data sources for ATMS and CrIS are identical to those used by the NOAA Global Forecasting System (GFS), NRL maintains an open dialogue with its NOAA and NASA partners who are responsible for Infrared and Microwave sounder radiance assimilation including the JPSS Proving Ground and Risk Reduction (PGRR) Program. Areas of focus for enhancing assimilation methodology include correlated observation error, enhanced use in cloudy scenes, and improved use of surface sensitive channels.

The technology developed begins with Scientific Data Records (SDRs) from ATMS and CrIS. NRL receives the CrIS SDR including Full Spectral Resolution (FSR) which contains full unapodized spectrum (currently 1317 unapodized radiances, 1305 channels after apodization). The ATMS data requires application of both calibration and spatial noise reduction strategies to achieve the rigorous signal-to-noise requirement necessary for NWP applications. With the full unapodized spectrum researchers have the flexibility to run tests in the future. For example, scientists may choose to conduct the apodization differently, or test the full unapodized radiance assimilation.

It is critical to be able to identify what areas needed to be assessed when determining the effectiveness of assimilating certain data into forecast models. The NRL Monterey has a long history of evaluating the sensitivity of the NAVGEM model to various types of satellite observations. When ATMS and CrIS became available they used their evaluation approach to determine the relative value of these instruments and found that ATMS was outperforming AMSU-A and CrIS was outperforming IASI (right) on a per observation basis.



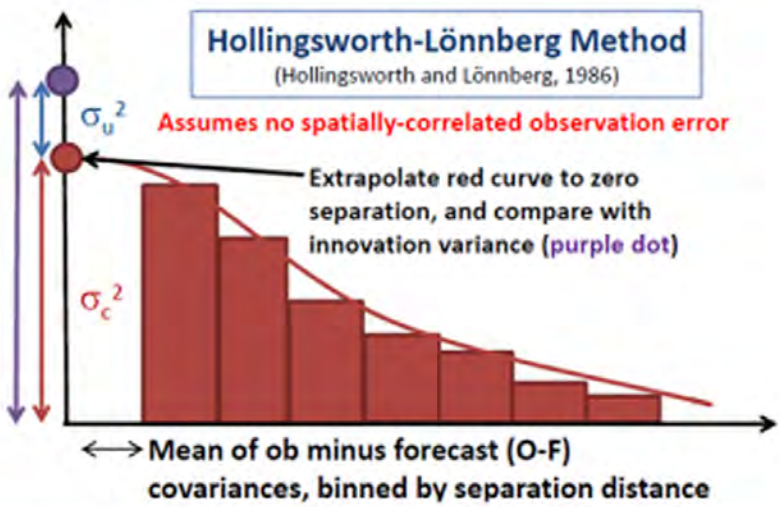
The per observation sensitivity to reduction of a 24-hour NAVGEM forecast error norm for satellite sensors in June 2017.

The following areas were considered in reaching these conclusions.

CORRELATED ERROR

Remote sensing observations often have correlated errors, but the correlations are typically ignored in data assimilation for numerical weather prediction. Not taking into account error correlations on specific satellite instruments can result in the data being underweighted and may cause vertical aliasing of signal in the solving step of the DA procedure. Recent studies have shown that using observation error correlations in data assimilation will improve the analysis.

Several methods, all with different assumptions (below) have helped formulate estimates of the background and/or observation error covariance matrices. The Hollingsworth-Lonnberg Method assumes that the forecast errors will be correlated but the observation errors will not. You can then separate the forecast errors from the observation errors. The Desroziers et al. (2005) method assumes that the observation and forecast errors are known but then can extract a correlation matrix for the observations.



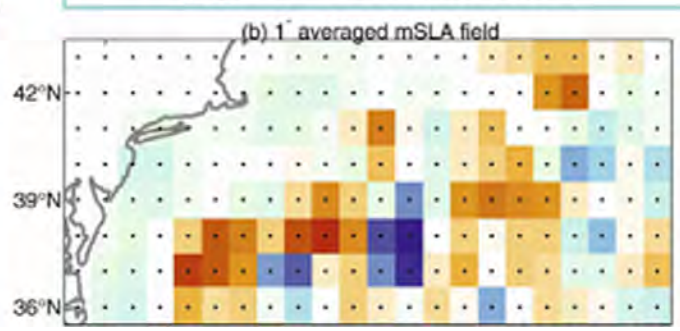
Desroziers et al. Method
(Desroziers *et al.* 2005)

$$\left\langle \left(\vec{O}-\vec{F}\right)\left(\vec{O}-\vec{A}\right)^T \right\rangle = \mathbf{R}$$

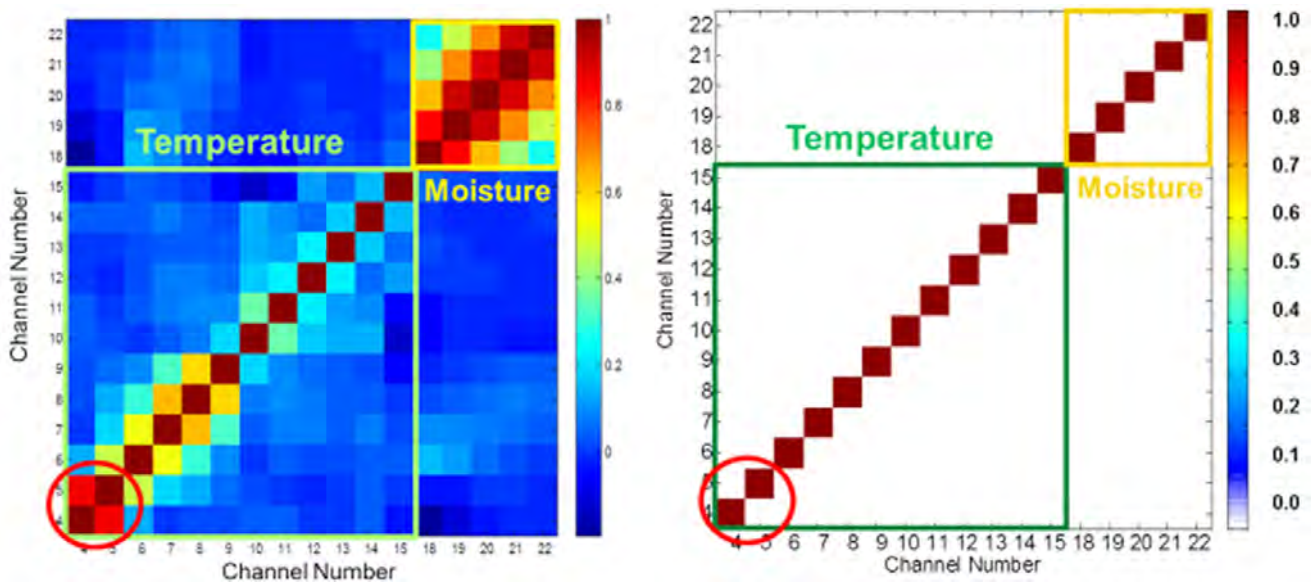
$$\left\langle \left(\vec{A}-\vec{F}\right)\left(\vec{O}-\vec{F}\right)^T \right\rangle = \mathbf{HBH}^T$$

$$\left\langle \left(\vec{O}-\vec{F}\right)\left(\vec{O}-\vec{F}\right)^T \right\rangle = \mathbf{R}+\mathbf{HBH}^T$$

Observation Based Methods
(e.g. Oke and Sakov 2007)



How does NRL-MRY apply these approaches to JPSS data? On the next page is the traditional approach which shows that in the ATMS Channels there is no correlation between the channels. Using Desroziers' method an error correlation matrix can be derived from a posterior statistics. In the figure on the left (next page), you can see that the moisture channels are highly correlated and surface channels (channel 4 and 5) also exhibit high correlations. Using this approach you can generate correlation matrices for any satellite sensor. This allows you to test correlated error with any sensor or type of observations.



Left: Desroziers' method estimate of inter-channel portion of observation error correlation matrix for ATMS; Right: Current observation error correlation matrix used for ATMS, and for ALL observations.

SURFACE SENSITIVE RADIANCES

The assimilation of radiances from infrared sounding spectrometers such as IASI and CrIS over the sea has been well established. However these observations over land have been challenging due to uncertainties in the infrared emissivity and skin temperature of the land. NRL has undertaken an effort to provide realistic land surface temperature and land surface emissivity to increase the likelihood that NWP models will be able to assimilate data from surface-sensitive channels. The first task in this effort was to extend the control variables in the DA system to include the ability to one for a surface skin temperature. This involved generating the associated jacobians with between the radiances of interest and the new surface skin temperature variable, which allows the DA solver to apply signal to the surface skin temperature and not alias this signal into the atmosphere. The next piece was to create a realistic covariance between this new surface skin variable and the atmosphere above and the surface below. The final piece was apply the increment created for the surface skin in the new analysis.

JACOBIANS

In the first experiment (jac), jacobians are generated allowing signal to flow to a surface skin temperature acting as a sink variable, this results in a small positive impact on the forecast, a +4 score.

ENSEMBLE

The second (+ens) experiment uses the jacobians and surface skin temperature sink variable, but now with a coupled covariance matrix between the surface skin temperature variable and the atmosphere.

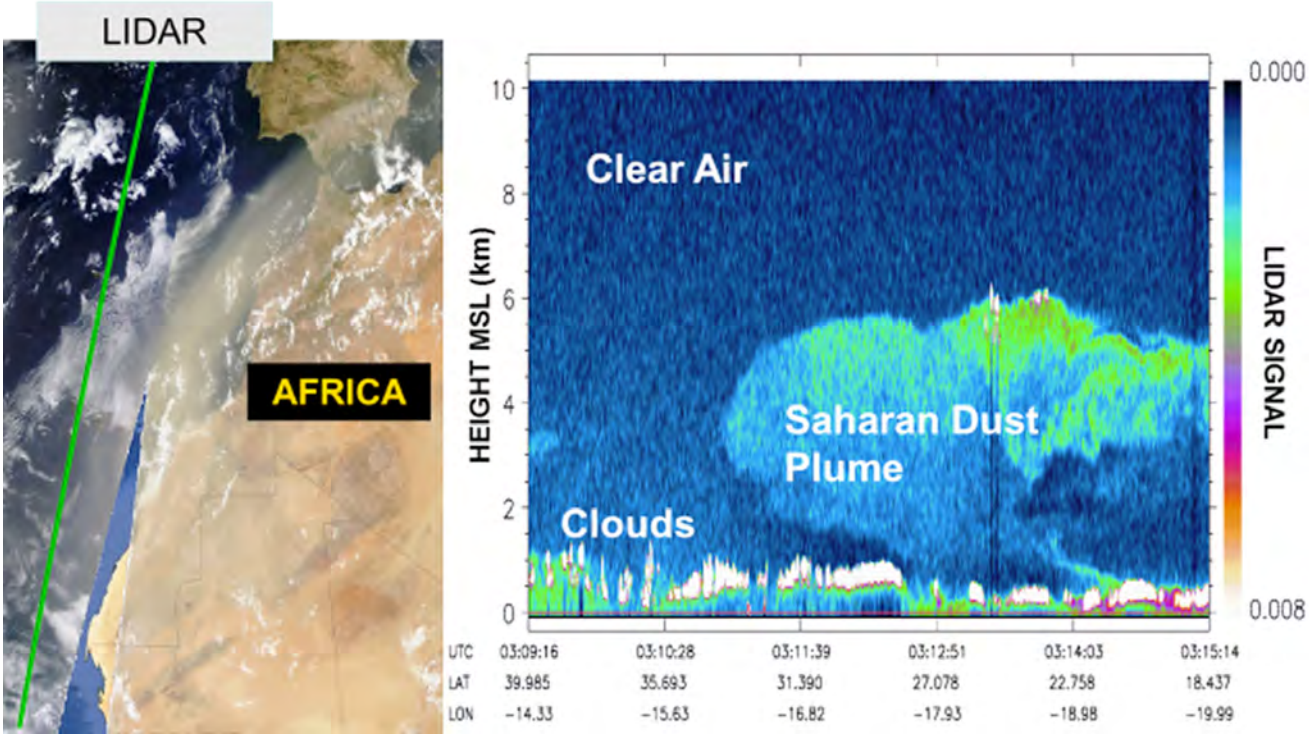
FORECAST

The third experiment (+fcst), now activates the surface skin temperature so rather than acting as a sink variable the increment is applied to the surface temperature initial condition for the forecast model. This showed a very promising +12 score, and continues to be evaluated for promotion to operations.

					jac	+ens	+fcst
ECMWF Analysis	200.0	NH	96	Wind			+1
ECMWF Analysis	200.0	Tropics	96	Wind			+1
ECMWF Analysis	200.0	SH	96	Wind	+1	-2	
ECMWF Analysis	500.0	NH	120	GH			+2
ECMWF Analysis	500.0	NH	120	GH			-2
ECMWF Analysis	500.0	SH	120	GH			+1
ECMWF Analysis	500.0	SH	120	GH			+1
ECMWF Analysis	850.0	NH	96	Wind			
ECMWF Analysis	850.0	SH	96	Wind			+1
ECMWF Analysis	850.0	Tropics	96	Wind		+1	
ECMWF Analysis	1000.0	NH	120	GH		-1	
ECMWF Analysis	1000.0	SH	120	GH			
Fixed Buoy	None	NH	96	Wind Speed			
Fixed Buoy	None	Tropics	96	Wind Speed	+2	+2	+2
Manual Sfc Land	None	NH	96	Air Temperature			
Manual Sfc Land	None	SH	96	Air Temperature	+1	+1	+1
Radiosondes	100.0	Global	96	GH			
Radiosondes	250.0	Global	96	Air Temperature			
Radiosondes	250.0	Global	96	Wind			+1
Radiosondes	500.0	Global	96	GH			+1
Radiosondes	700.0	Global	96	Relative Humidity			+1
Radiosondes	850.0	Global	96	Air Temperature			
Radiosondes	850.0	Global	96	Air Temperature			
Radiosondes	850.0	Global	96	Wind			+1
Total					+4	+1	+12

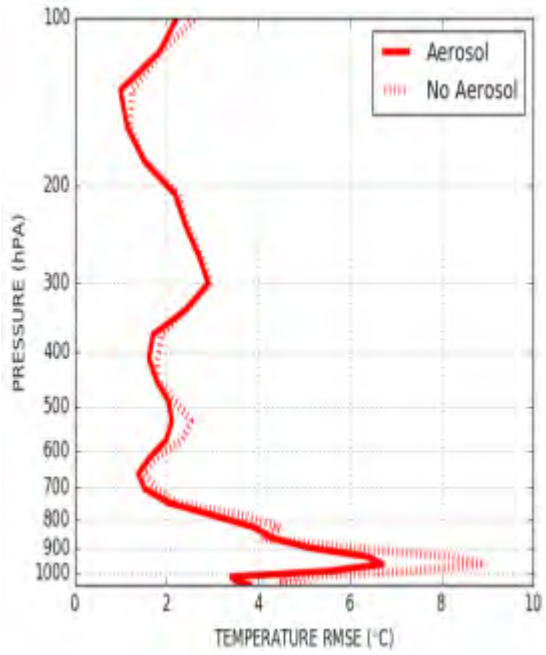
AEROSOLS (DUST)

Dust events affect IR radiances and the ability for a model to assimilate data from areas with dust. The image below shows the Calipso Spaceborne Lidar passing through a dust plume off the coast of Africa. The profile on the right shows where the dust plume is located. Currently the NRL's quality control system screens out data from areas with high levels of aerosols and the data is never assimilated into the models. Studies have shown that dust can impact brightness temperatures in an area by 5 to 6 Kelvin. The use of the operational aerosol forecast such as, the Navy Aerosol Analysis and Prediction System (NAAPS) to account for this dust as well as the impact on temperatures, will improve the dataset and ultimately lead to more radiance data being assimilated into the models. This will allow for improved aerosol forecasting as well as enhanced global scale research capabilities for the study of aerosol-meteorology interaction.



Meteosat image showing dust plumes coming off the western coast of Africa. Green line shows the lidar track. The lidar profile is shown on the right.

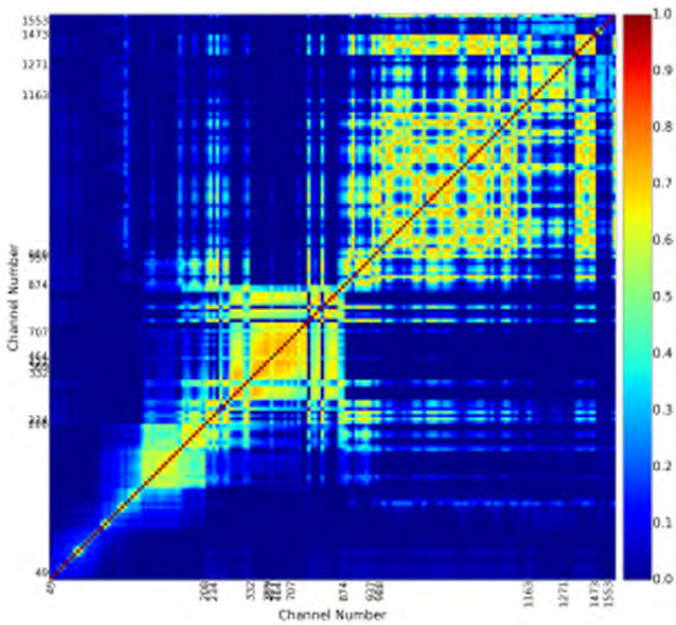
AEROSOL CASE STUDY: TENERIFE ISLAND, AFRICA



This test case was done over the Island of Tenerife—the largest of Spain's Canary Islands. The Island hosts surface meteorological equipment and supports radiosonde launches. Aerosol profiles were constructed from the Calipso Lidar overpasses and collocated with radiosonde measurements. The scientists started with an investigation using a one-dimensional variational data assimilation (1D-Var) system this performed a retrieval beginning with a climatological profile and CrIS radiances simulated from radiosonde. The simulation was done twice, once including LIDAR derived aerosol profiles, and once where aerosols are excluded. After cloud and quality control 200 test cases were included, it was found that inclusion of the aerosol on average realized a 20 percent increase in accuracy for the retrieved profile in both temperatures and humidity. Though a full recovery of the radiosonde profile was not achieved, the vast improvement with the use of aerosols indicates a large potential to improve NWP analysis by including aerosol impact.

THE ASSIMILATION OF CRIS DATA IN ITS FULL SPECTRAL RESOLUTION MODE

With over 2000 infrared channels, the CrIS instrument produces three-dimensional profiles of temperature and moisture. These profiles improve the accuracy of weather forecasting models. One of the first steps in



the process of incorporating the CrIS FSR data into a DA system and associated model involves channel selection. Further, the quality control must be adapted to make sure that it is working effectively for the assimilated channels. These steps have been complete and ensure that the NRL code is ready to process both the lower resolution and FSR CrIS data. The CrIS sensor after apodization has 1305 spectral channels for original resolution and 2211 channels for FSR with the extra channels occurring in the mid-wave and short-wave bands. In a perfect world, the NRL code would use the full channels all the time. But when working in the context of limited computer memory processing, in this case, the processor has to perform a range of functions from reading the data to parsing it to the solver in five minutes, therefore only a subset of the channels which deliver the highest information content are used. Thus, from these 1305 or 2211 channels a subset has been selected (399 and 431 respectively) to be delivered for NWP assimilation. In addition, having the full channel set allows for development of additional quality control using the full channel set which can subsequently be included with the subset information and passed on to JPSS partners for feedback. To date two coefficient files for the CrIS FSR data have been obtained for the CRTM, both for the full complement of 2211 channels as well as the 431 subset. To begin the channel re-selection, we began with a "nearest neighbor" water vapor channel set from operational CrIS (exp 1) and using all the water vapor channels in the CrIS FSR 431 subset. There was a very encouraging increase in impact using more water vapor channels from the CrIS FSR data.

Next, the error estimation and correlation matrix needed for be generated for the CrIS FSR data. The error estimate was done by combining Desroziers' method with statistics from the observation fit to simulated observation from the cycling experiment. The correlation matrix was obtained via Desroziers' method and a subsequent symmetrization and conditioning resulting in a final condition number of 128. NRL-MRY continues to cycling new experiments with ~180 CrIS channels in temperature and water vapor including these new estimates of correlated error.

USER INTERACTIONS

A big step in ensuring the accuracy of the work being done with model assimilation is to interact with users and other national and international modeling centers. NRL-MRY participates in NWP data assimilation workshops and conferences presenting the results and obtaining feedback. Data and methods from the studies presented in this report, and the operational global NWP analysis and forecasts are publicly available for use by others to use for their own testing and use in proposals. The peer reviews, such as those through the JPSS, have been invaluable in identifying what needs to be done to handle unanticipated data issues and have led to new ideas that provide benefit across the entire modeling community. Perhaps the best measure of success is the use of these improved models by Navy personnel and their feedback as they apply these capabilities across their broad spectrum of mission requirements.

SUMMARY

Satellite data remains the largest source and most impactful of all data assimilated into the NAVGEM model and data assimilation system. The ability to quickly obtain and test the assimilation of new satellite data allows NRL Monterey to continue to improve its models assisting every one of its users in meeting their missions. NRL Monterey models have implemented a successful approach in these efforts by first establishing a working prototype for to ensure end-to-end products are delivered. A sequential spiral development is actively undertaken to focus on rapid implementation and as better methods are developed there is greater ease in implementation and fewer NWP system changes are needed. This strategy is employed in every aspect from the error correlation of specific satellite sensors to the determination of the impact of aerosols on radiance received over land. NRL Monterey has proven it can be responsive to program changes such as when the JPSS Program began transmitting CrIS data at full resolution. These actions performed under the JPSS Proving Ground program will continue to drive a simplification of NWP system changes and facilitate more rapid expansion in the use of satellite data from JPSS by the NRL Monterey user community.

Sources

Campbell, W. F., E. A. Satterfield, B. Ruston, and N.L. Baker, 2017: Accounting for Correlated Observation Error in a Dual-Formulation 4D Variational Data Assimilation System. Mon. Wea. Rev., 145, 1019-1032.

Hogan, T. F., M. Liu, J.A. Ridout, M.S. Peng, T.R. Whitcomb, B.C. Ruston, C.A. Reynolds, S.D. Eckermann, J.R. Moskaitis, N.L. Baker, J.P. McCormack, K.C. Viner, J.G. McLay, M.K. Flatau, L. Xu, C. Chen, and S.W. Chang, 2014. The Navy Global Environmental Model. Oceanography 27(3):116–125, http://dx.doi.org/10.5670/oceanog.2014.73.

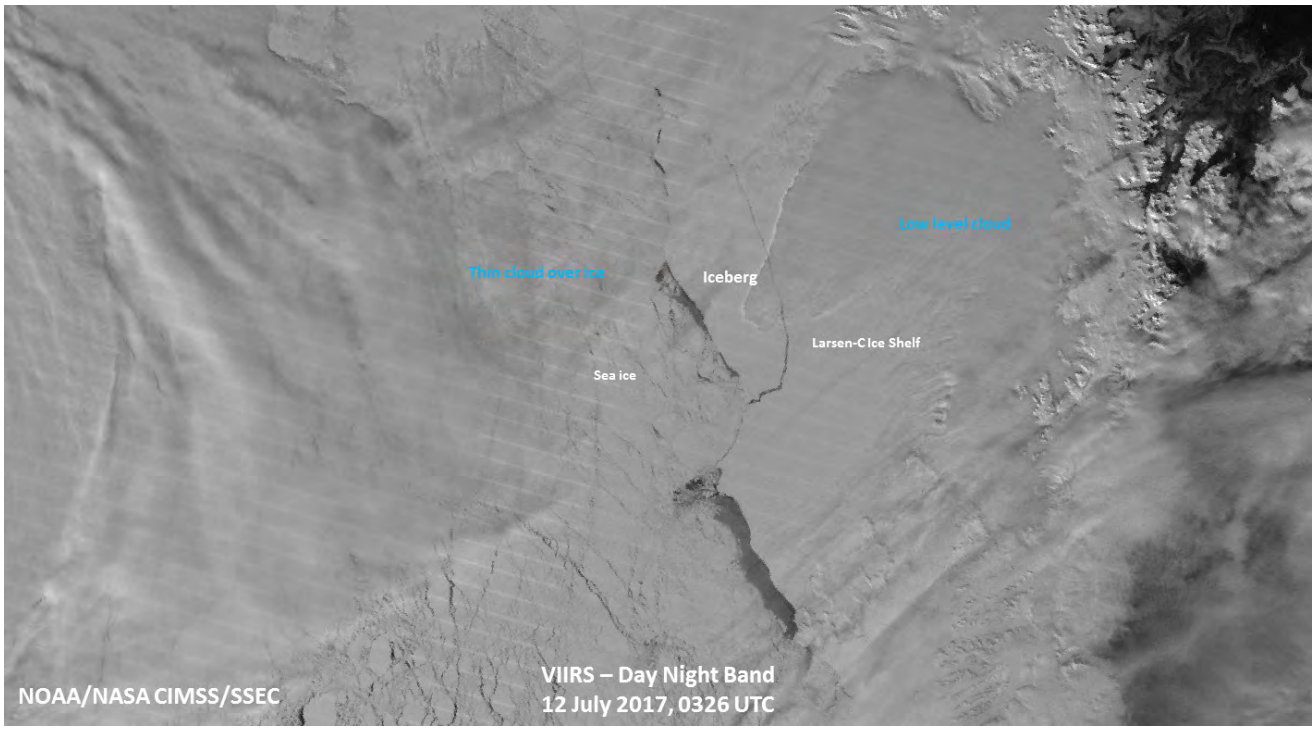
Zhang, J., J. S. Reid, D. L. Westphal, N. L. Baker, and E. J. Hyer (2008), A system for operational aerosol optical depth data assimilation over global oceans, J. Geophys. Res., 113, D10208, doi:10.1029/2007JD009065.

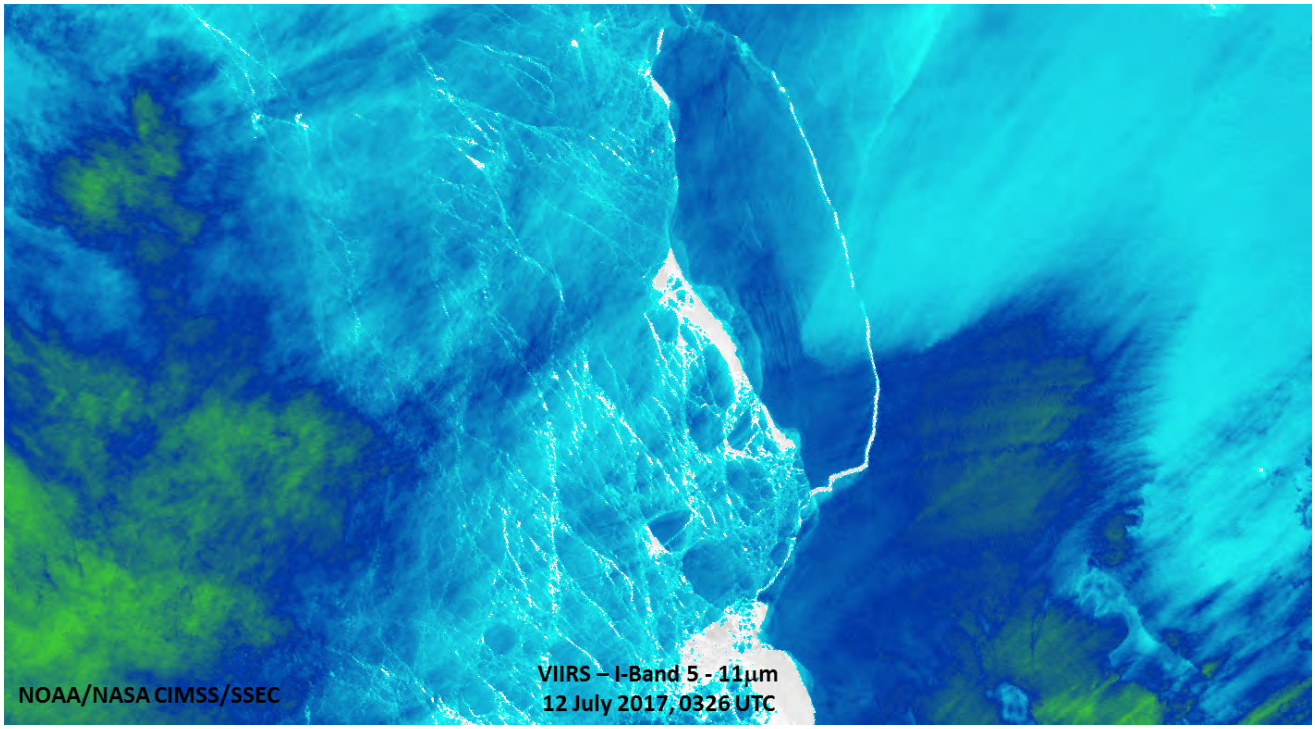
WEB FEATURES

WEB FEATURE: JULY 14, 2017

LARSEN C ICE SHELF CALVES LARGE ICEBERG

The Larsen C ice shelf calved a large iceberg estimated to have a volume twice that of Lake Erie sometime between July 10 and the morning of July 12, 2017. The Visible Infrared Imaging Radiometer Suite aboard the NOAA/NASA Suomi NPP satellite captured images of the shelf using multiple bands, including the Day/Night Band (top) and the I-05 longwave infrared band (bottom).





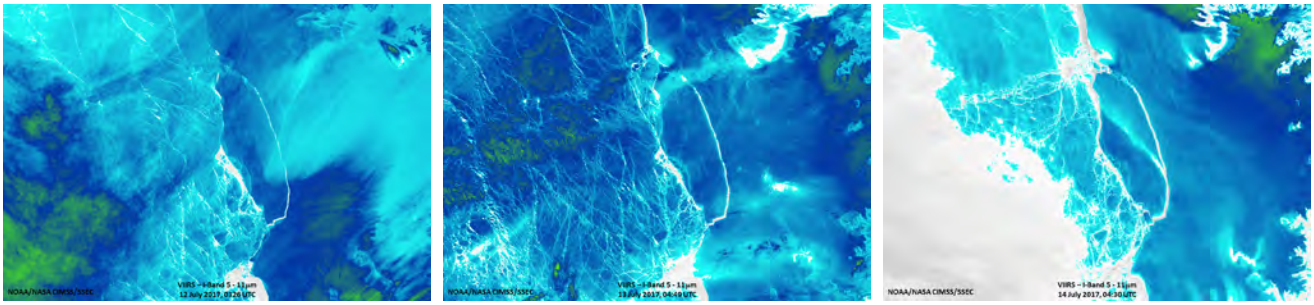
Scientists from Project Midas, a UK-based Antarctic research project, estimate that the iceberg is approximately 2,240 square miles (5,800 square kilometers), weighs more than 1 trillion tons and has a volume that is twice that of Lake Erie. The scientists have been monitoring a break in the Larsen C ice shelf for years and have been reporting growth of the rift for years.

Ice shelves fringe 75 percent of the Antarctic ice sheet and the Larsen C ice shelf, located on the east side of the Antarctic Peninsula, is the fourth largest ice shelf ringing Earth's southernmost continent. The first available images of Larsen C are airborne photographs from the 1960s and an image from a U.S. satellite taken in 1963. The rift that has produced the new iceberg was already identifiable in those pictures, along with a dozen other fractures. The crack remained dormant for decades, but in 2014, it started to grow rapidly.

VIIRS's Day/Night Band (DNB) is sensitive enough to detect the low levels of visible light at night. In doing so, the DNB allows the satellite to "see" at night using the reflection of moonlight and ambient nightglow—a mix of light coming from auroras, starlight, zodiacal light (sunlight scattered across the solar system by dust particles in space), anthropogenic light and a variety of other sources. This is significant because most visible-wavelength sensors don't work at night since the sources of light on the Earth's surface are too weak to be detected. Prior to the launch of Suomi NPP, only the DMSP satellites, which carried Operational Linescan System instruments, were able to capture visible imagery at night.

On the contrary, the I-05 longwave infrared band is, typically used as sort of an "all-purpose" channel for cloud detection, both during the day and at night. The band can provide an estimate of cloud height, provide information on surface temperature patterns, and can be used to detect so-called overshooting cloud tops in severe weather and areas of convection (for example, where a cluster of thunderstorms is around a tropical system). In addition, data from this band can be used in conjunction with data from other channels to determine sea ice concentration.

Monitoring sea ice is an important function of JPSS, both in the Arctic and Antarctic regions. The upcoming JPSS-1 satellite will support these and other critical observations to ensure a safer and educated nation.



This series of images shows the expanding crack between the shelf and the ice berg

WEB FEATURE: SEPTEMBER 15, 2017

NOAA SATELLITES AND AIRCRAFT MONITOR CATASTROPHIC FLOODS FROM HURRICANE HARVEY & IRMA

NOAA's GOES-16 and NOAA-NASA Suomi NPP are monitoring the flooding from Hurricane Harvey & Irma. Images from the two satellites are merged to create a detailed and comprehensive flood zone map which covers vast areas. These maps help FEMA and first responders determine where to focus their efforts.

The turquoise color corresponds to areas of severe flooding.

NOAA's GOES-16 and NOAA-NASA Suomi NPP provide FEMA with the first comprehensive view of flood zones.

When a catastrophic storm hits, the resulting floods can be deadly and cost billions of dollars in economic losses. In the US, floods are responsible for more loss of life and property than any other severe weather event.

By August 30th, the greater Houston area had received between 30–40 inches of rainfall from Hurricane Harvey, and the recovery effort in Texas and Louisiana is expected to cost over $100 billion. Record flooding from Hurricane Irma was recorded in Jacksonville, Florida where 356 people were rescued (see image on next page).

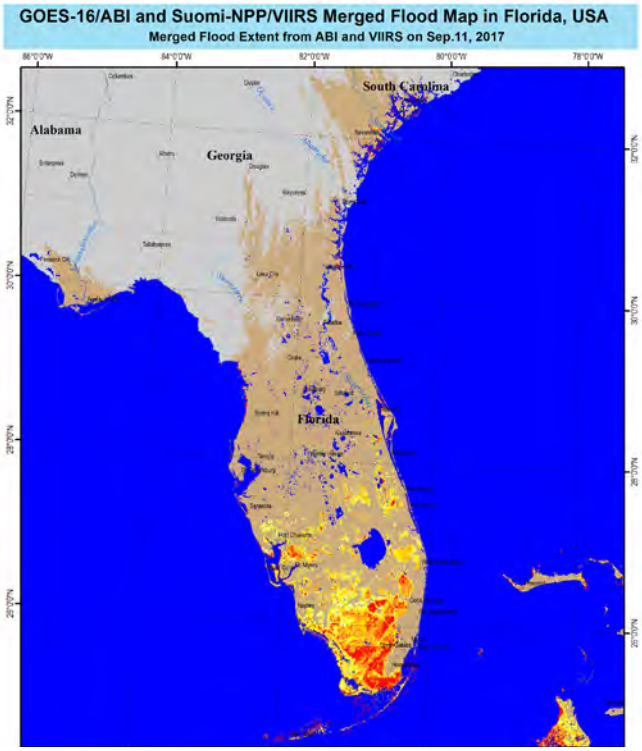
NOAA's flood maps are changing how we measure the evolution and dynamics of flooding by providing high resolution detail over vast areas. This information allows teams on the ground to plan for evacuations and determine where to focus their recovery efforts.

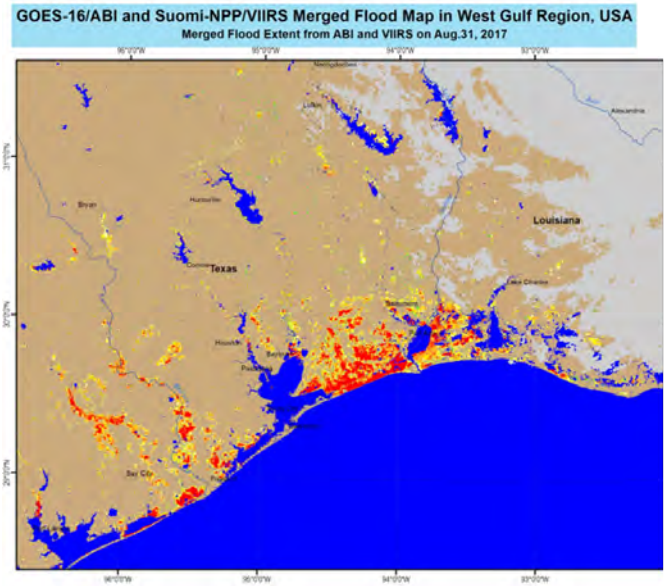
These experimental flood maps, developed by scientists at George Mason University with NOAA support, use data from the NOAA-NASA Suomi NPP satellite's VIIRS instrument and NOAA GOES-16 Advanced Baseline Imager. The maps allow officials to quickly determine where to employ limited resources during a

Texas National Guard soldiers arrive in Houston to aid residents in heavily flooded areas from the storms of Hurricane Harvey, Aug. 27, 2017. Texas Army National Guard photo by 1st Lt. Zachary Wes.

flood. They also allow for insight into where water is receding. This highly valuable information is given to community officials to help them determine, in combination with other critical resources, when it is safe for people to return to their homes. The maps were provided to FEMA during the catastrophic flooding of Hurricane Harvey & Irma.

Below (left) is the map highlighting the impact of Hurriane Irma in the State of Florida as of September 11, 2017. Colors correspond to fraction of land covered by water—ranging from green–less than 30% to red–more than 90%.





This map (above) highlights the large areas of land flooded by Hurricane Harvey in the Gulf Region as of August 31, 2017.

AERIAL IMAGERY

Satellite maps are used to identify where local survey teams need to focus their efforts. After a significant storm like Harvey and Irma, NOAA will also deploy aircraft to collect aerial images of flooding.

These photographs are shared with FEMA and provide a detailed local look at the flood water destruction.

LCDR Rebecca Waddington piloted NOAA aircraft to help NOAA's National Geodetic Survey collect this post-Hurricane Irma image of Marathon, a 13-island community in the heart of the Florida Keys. After Irma devastated Marathon, FEMA requested aerial images to help emergency teams fully assess damage, an almost incomprehensible feat from ground level. National Geodetic Survey has now collected over 10,000 aerial images as an early step in the path to recovery for Florida communities.

Staff from NOAA's Office of Marine and Aviation Operations and NOAA's National Geodetic Survey capture these images using specialized remote-sensing cameras aboard NOAA aircraft (primarily NOAA's King Air and Twin Otter aircraft) flying above the area at an altitude between 1,640 and 4,921 feet. Learn more about these images[1] or access them online[2].

Many offices at NOAA play a role in helping Americans stay safe, and recover, from extreme weather events such as Hurricanes Harvey and Irma. For more about NOAA, go to www.noaa.gov.

Footnotes

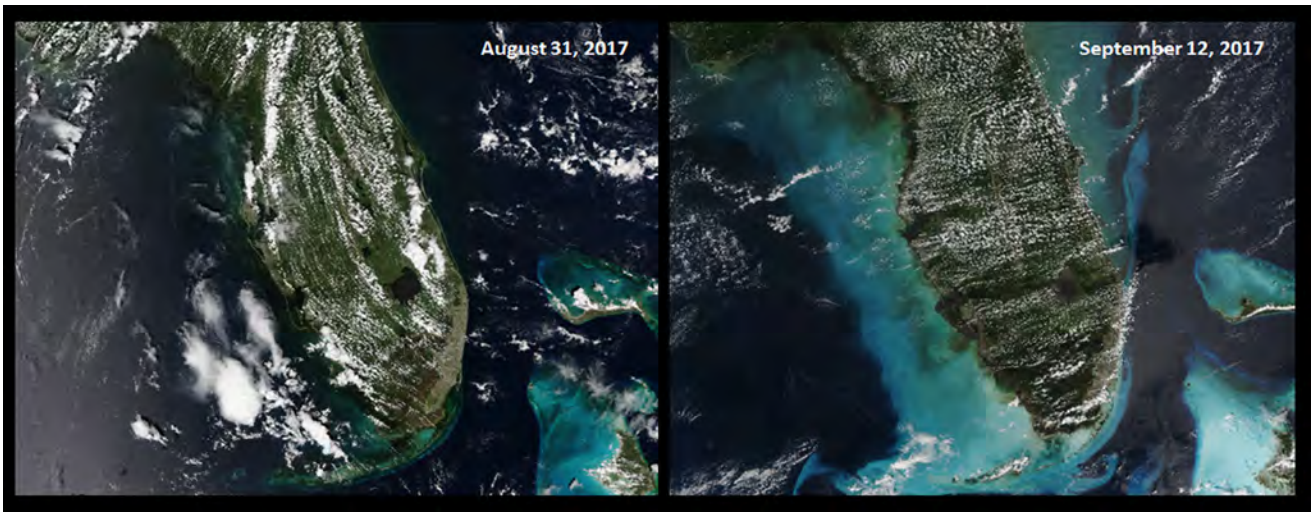
[1] https://storms.ngs.noaa.gov/storms/irma/index.html#6/28.139/-81.547

[2] http://www.noaa.gov/news/assessing-irma-s-destruction-from-air-aerial-images-available

WEB FEATURE: SEPTEMBER 15, 2017

VIIRS SEES IRMA-CHURNED SEDIMENTS AROUND FLORIDA, BAHAMAS

Hurricane Irma didn't just impact land. As seen in these before-and-after true-color images captured by the VIIRS instrument on the NOAA/NASA Suomi NPP satellite, the storm altered the distribution of sand around the coast of Florida. The light blue color shows sediment suspended in the water, kicked up by the intensity of the storm.



The Visible Infrared Imaging Radiometer Suite (VIIRS) aboard the NOAA-NASA Suomi NPP satellite captured these two images of Florida before (l) and after (r) Hurricane Irma made landfall in the Sunshine State. Notice anything different between them?

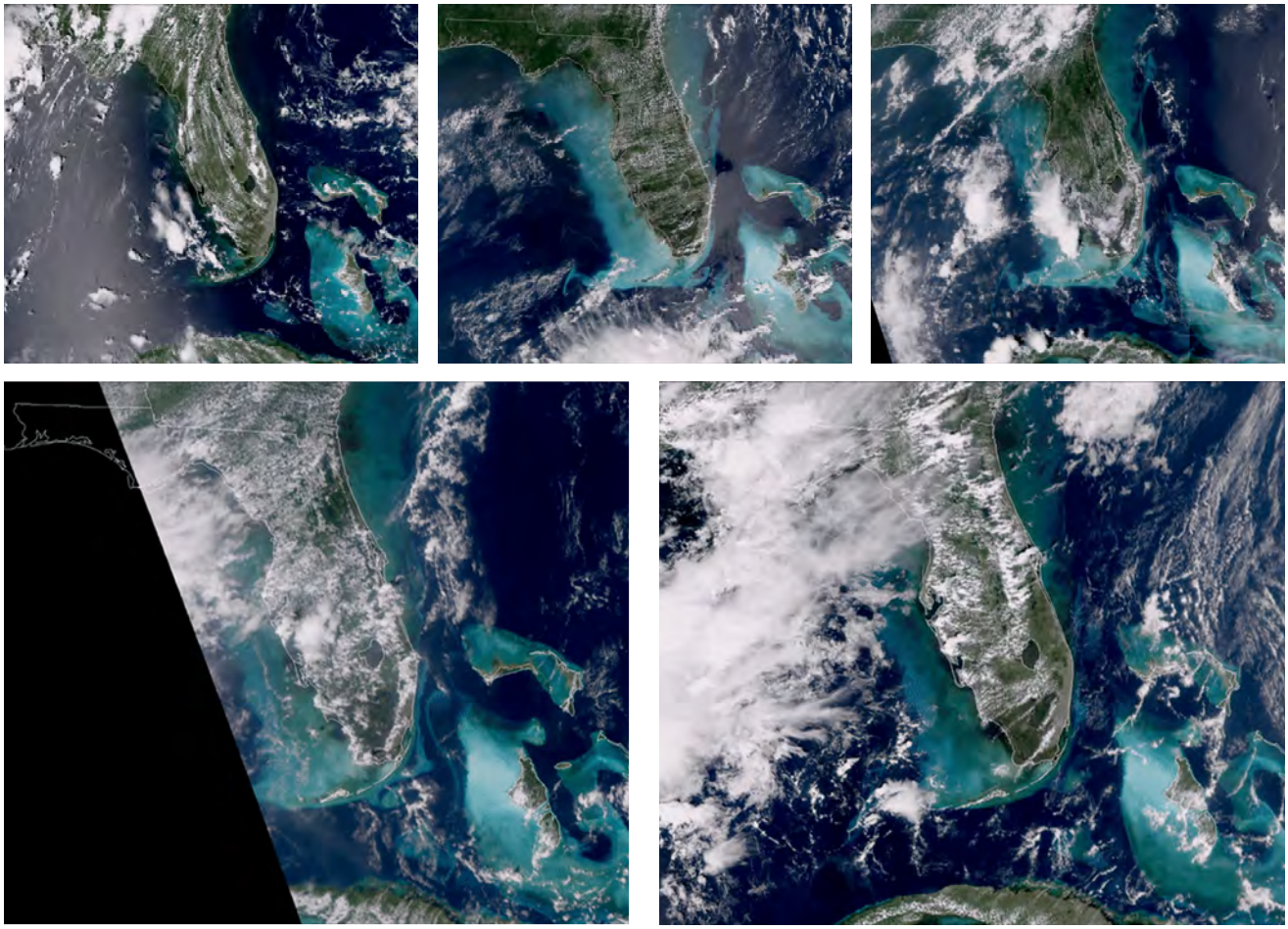
Apart from all the clouds, which are always different between two images, you can see a change in the color of the water surrounding Florida and, to a lesser extent, the Bahamas. What causes this change? The heavy rains, high winds, and storm surge brought by strong storms like Irma.

The winds and waves churn up sediment at the bottom of the ocean, at least in shallow areas like the Florida Keys and the Bahamas. The storm surge causes beach erosion and flooding along the coasts, while the heavy rains cause inland flooding (both "flash" and "river" flooding). If you look closely, you may even see this sediment and pollution getting swept along by the currents in the Gulf of Mexico as well as on the Atlantic side of Florida. And, remember that the Atlantic side of Florida is home to the Gulf Stream.

Although true-color images like these may appear to be photographs of Earth, they aren't. They are created by combining data from the three color channels on the VIIRS instrument sensitive to the red, green and blue (or RGB) wavelengths of light into one composite image. In addition, data from several other channels are often also included to cancel out or correct atmospheric interference that may blur parts of the image.

BEFORE, AFTER, AND BEYOND

Beyond comparing before-and-after images, we also can monitor the movement of sediment and pollution after storms for as long as it's there, such as in these images from before the storm (31 August 2017) and then the following 6 days (12–17 September 2017).



As you view these images, you should see two things:

- Sediment around the Florida Keys does get pulled into the Gulf Stream, with visible eddies where the polluted water meets the clean water.
- The polluted water generally gets darker with time, because more of the dirt and sand and garbage settle out with time, allowing the ocean to slowly return to its pre-Irma appearance.

You might also notice the ocean around the Bahamas is always lighter in color. This is true even in the "before" image, because the water is very shallow in the Bahama Banks, allowing satellites to "see" all the way to the bottom. However, offshore, on the west side of the largest island (Andros), the water becomes nearly white after Irma's passage.

To see other satellite images of Irma, visit our gallery on the NESDIS website[1].

References

This article is based on a blog post by Curtis Seaman that first appeared on the Suomi NPP (National Polar-orbiting Partnership) blog published by the Cooperative Institute for Research in the Atmosphere.

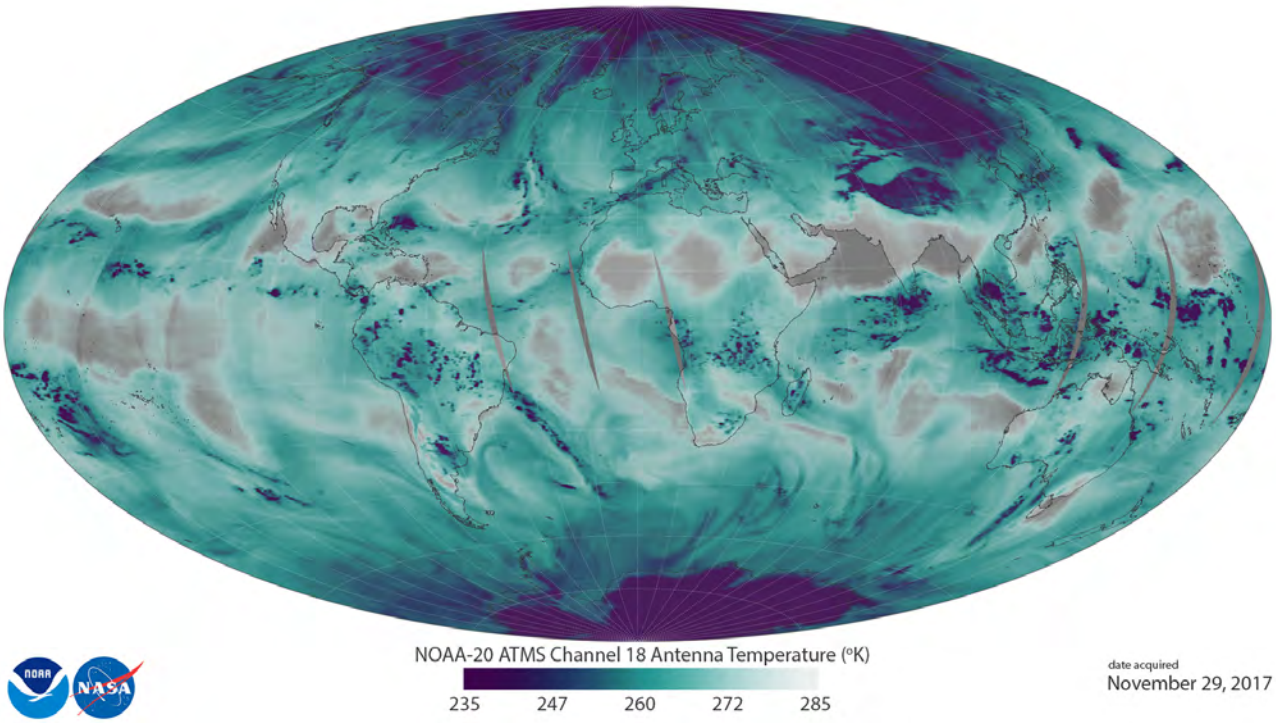
Footnotes

[1] https://www.nesdis.noaa.gov/content/multimedia

WEB FEATURE: NOVEMBER 29, 2017

NOAA-20 RETURNS FIRST ATMS DATA

Eleven days after JPSS-1 launched into Earth orbit, the satellite, now known as NOAA-20, has sent back its first Advanced Technology Microwave Sounder (ATMS) science data as part of a series of instrument startups and checkouts that will take place before the satellite goes into full operational mode. The NOAA-20 satellite carries five instruments that will improve day-to-day weather forecasting while extending the record of many long-term observations of Earth's climate.



ATMS receives 22 channels of radio waves from 23 to 183 gigahertz. Five water vapor channels, combined with other temperature sounding channels are used to provide the critical global atmospheric temperature and water vapor needed to provide accurate weather forecasts out to seven days. ATMS also maps global precipitation, snow and ice cover.

This image uses ATMS data to depict the location and abundance of water vapor (as associated with antenna temperatures) in the lower atmosphere, from the surface of the Earth to 5 kilometers altitude. Transparent/grey colors depict areas with less water vapor, while blue-green and purple colors represent abundant water in all phases (vapor, clouds, and precipitation) in low and middle latitudes. In the polar regions, purple depicts surface snow and ice. Water vapor distribution in space and time is a critical measurement for improving global weather forecasts. With detailed vertical information, forecasters can better identify the transport of water vapor associated with jet streams, which can fuel severe weather events.

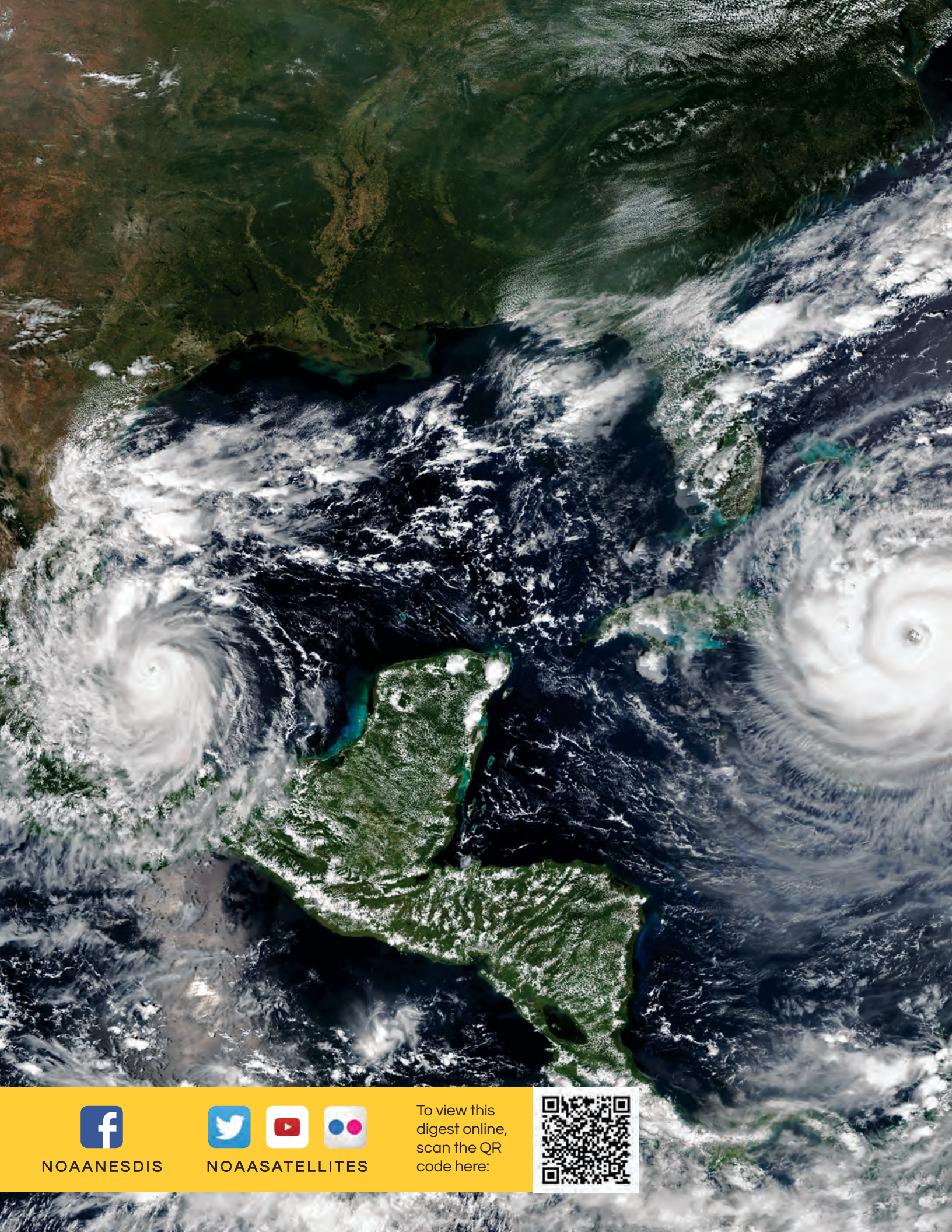
Front and back cover: This true-color image from the Suomi NPP satellite's Visible Infrared Imaging Radiometer Suite (VIIRS) instrument, shows Hurricanes Katia (left), Irma (center), and Jose (right) swirling over the Atlantic Ocean on Sept. 8, 2017.

Photo Credit: NOAA

Inside Cover: A United Launch Alliance Delta II rocket lifts off from Space Launch Complex 2 at Vandenberg Air Force Base in California carrying the Joint Polar Satellite System-1, or JPSS-1, spacecraft. Built by Ball Aerospace and Technologies Corp. of Boulder, Colorado, JPSS is the first in a series four next-generation environmental satellites in a collaborative program between NOAA and NASA. JPSS-1 will gather measurements of atmospheric, terrestrial and oceanic conditions, including sea and land surface temperatures, vegetation, clouds, rainfall, snow and ice cover, fire locations, atmospheric temperature, water vapor and ozone. Liftoff was at 1:47 a.m. PST (4:47 a.m. EST), Nov. 18, 2017.

Photo Credit: NASA/Kim Shiflett

JPSS 2017 Annual Science Digest designed by Joshua Brady, JPSS/GAMA-1 Technologies.



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