

# JPSS

SCIENCE SEMINAR  
ANNUAL DIGEST 2018

**ARTICLES  
+ FEATURES**

from the Nation's new generation  
polar-orbiting operational  
environmental satellite system



Image: From NOAA-20 on September 13, 2018 at 2:46 a.m. EDT

Front and back cover: Hurricane Florence, as observed on September 13, 2018, in a near-nadir pass from the NOAA-20 satellite at 2:46 a.m. EDT (front cover) and in an edge-of-scan pass from the Suomi NPP satellite at 3:36 a.m. EDT (back cover). Tropical cyclones can undergo rapid changes. Having both NOAA-20 and Suomi NPP satellites in orbits 50 minutes apart, allows hurricane forecasters to see these rapid changes and take appropriate action.

*Image credit: William Straka III, Cooperative Institute for Meteorological Satellite Studies (CIMSS)*

Inside Covers:

Front: At the top is a high-resolution VIIRS Natural Fire Color image—of the Camp Fire in Butte County, California on November 8, 2018—which allows you to see through the smoke to the perimeter of the fire and track changes. This can assist in the positioning of fire fighting resources to best respond to changing fire conditions. At the bottom is a NOAA-20 True Color image of the same fire. True color imagery can help identify land, ocean and atmospheric features. This VIIRS image shows the extensive smoke impacting a large part of northern California.

*Image credit: NOAA*

Back: The photos are from various fires in California. The Camp Fire burning off Pulga Road and Camp Creek Road near Jarbo Gap (top), CAL FIRE aircraft working at the Bear Fire (middle), and a view of burned areas from the Woolsey Fire (bottom). JPSS fire products were critical to the federal, state, and local emergency communities as they responded to another record-breaking fire season.

*Photo credit: CAL FIRE (top), CAL FIRE CZU (middle), and the CAL FIRE Butte Unit/Butte County Fire Department (bottom)*



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JPSS SCIENCE SEMINAR ANNUAL DIGEST

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## ANNUAL DIGEST CONTRIBUTIONS

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Lead Article Writer: **Julie Price**

Associate Editors: **Bill Sjoberg and Jenny Marder**

Design and Layout: **Joshua Brady**

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Sam Ahmed  
Richard Bankert  
Emily Berndt  
Carl Dierking  
John Forsythe  
Kevin Fuell

Vladimir Krasnopolsky  
Arunas P. Kuciauskas  
Tarendra Lakhankar  
Avichal Mehra  
Huan Meng  
Andrew L. Molthan

Jonathan Munoz  
Kim Richardson  
Lori A. Schultz  
Jennifer Patterson Sevadjian  
Nadia Smith  
Eric Stevens

William Straka  
Kris White  
Cara Wilson  
Bradley T. Zavodsky

## FROM THE SENIOR PROGRAM SCIENTIST



In 2017, the nation saw the launch of another next generation polar-orbiting satellite, NOAA-20. This launch – the second under the Joint Polar Satellite System (JPSS), ensured that NOAA-20 along with the NOAA/NASA demonstration satellite, Suomi National Polar-orbiting Partnership (Suomi NPP) would provide even more data and products into weather prediction models around the world. 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.”

Having two satellites in the same orbit, and in this case, separated by 50 minutes, ensures continuity of critical JPSS data, products, and capabilities. Should one of the sensors on a satellite experience degradation of its capabilities, or a partial or total failure, the complementary sensor on the other satellite will still be available to provide the data and products needed for assimilation into models, forecasting and environmental monitoring.

Another advantage is the opportunity to collect more detailed data from multiple instruments. Data from NOAA-20 and Suomi NPP, whether used separately or merged, helps forecasters track rapidly changing storm conditions, and other environmental hazards such as fire, smoke, dust, floods, and snow and ice, over time. Increased data and shortened latency associated with NOAA-20 provides more radiance data for assimilation into forecast models. With an additional overpass, NOAA-Unique Combined Atmospheric Processing System (NUCAPS) sounding products provide greater temporal coverage of the three-dimensional atmospheric structure. Beyond soundings, we now have two Visible Infrared Imaging Radiometer Suite (VIIRS) instruments that will enable us to better monitor ice motion, fire areas, smoke, dust, floods, cloud, and fog and better measure cloud and aerosol properties, ocean color, sea and land surface temperatures and so forth. The two VIIRS Day Night Bands (DNB) passes enable detection of changes of rapidly evolving phenomenon in data-sparse regions and at higher resolutions that can’t be achieved by other satellite sensors.

The value of NOAA-20 with a healthy Suomi NPP is expected to have a direct operational impact in high latitude regions like Alaska, where direct broadcast antennas receive polar satellite data from multiple sensors. Direct Broadcast provides access to satellite imagery as soon as 15 minutes after the satellite passes overhead. NOAA-20 stored mission data will also be available to the user on their baseline Advanced Weather Interactive Processing System (AWIPS II) much quicker. Suomi NPP stored mission data downlinks to only the JPSS ground system antenna at Svalbard, Norway (near the North Pole). NOAA-20 will download its data at Svalbard and at a new receiver at the McMurdo Station in Antarctica (near the South Pole). NOAA-20’s ability to downlink each time it passes an antenna at each pole is important in reducing end-to-end latency.

In 2013, we released the first JPSS Science Seminar Digest, which showcased ongoing projects from the Proving Ground and Risk Reduction (PGRR) Program. The featured articles underscored the value of JPSS data and products in environmental applications. Five years later, this 2018 Digest continues that tradition. We expect to continue reporting these accomplishments and hope that they spur dialog on new applications that leverage JPSS capabilities.

## **Additional highlights from this past year include:**

A new PGRR Call-for-Proposals was released in November 2017. Following a rigorous selection process, 45 new or continuing projects were selected for funding. These project activities include explorations of portals for air quality and regional ocean color satellite data; development of ice motion products from individual sensors, as well as the creation of new blended motion products; improvements to the National Weather Service operational forecasts of dust weather hazards through newly developed emission data assimilation with JPSS aerosol and land products; interfacing with the NOAA user community to help to demonstrate the utility of low-light visible imagery; to enhancing the capability of tropical cyclone forecasters to receive timely, added value JPSS data and products in their forecasting environment. For the new projects, an important and common feature is the exploitation of the 50-minute separation between Suomi NPP and NOAA-20.

In response to the funding of the new PGRR projects, three new initiatives were established: Aviation Weather, Innovation and Volcanic Hazards. The Aviation Weather Initiative began in March with a five-member team that has already expanded to 25 members who continue to offer insights to consumers of JPSS data products to create better and more informed outcomes for the Aviation community. NOAA's broad and comprehensive mission evolves with society's rapidly changing demand for environmental intelligence. In response, we created the innovation area, which is designed to uncover and cultivate new ideas, methods, and ways of doing things. Lastly, our Volcanic Hazards initiative was established to ensure that JPSS measurements, in combination with other relevant data, are being fully utilized for volcanic hazard applications.

Getting JPSS data and products in the hands of the user community and stakeholder groups are fundamental activities of the PGRR. But we don't stop there. We are constantly engaging with our stakeholders, product users, and developers to elicit product feedback. This close interaction ensures that there's an alignment between the performance our products exhibit and that which is expected. Here are examples of how PGRR initiatives put this into practice.

**Hydrology Initiative:** A JPSS requirement for a snowfall rate product secured long-term maintenance funding to monitor and develop a NOAA-20 SFR product. Also, a newly formed partnership with the National Water Center (as part of the NOAA Water Initiative) led to the creation of a project to compare satellite soil moisture with similar parameters used within the NOAA Water Model. The Initiative plans to continue working closely with NWS National Centers and forecast offices to determine the utility of JPSS baseline and emerging (PGRR) products.

**Numerical Weather Prediction (NWP) Impact Studies and Critical Weather Applications Initiative:** Past activities supported by this Initiative have been very successful in demonstrating applications of ATMS and CrIS in improving both tropical cyclone track and intensity forecasts. In 2018, improvements were made to data selection and uncertainty of NWP models via assimilation of data from the ATMS, CrIS, and VIIRS sensors. More importantly, an action plan to implement JPSS data in operations in the shortest time possible saw the use of NOAA-20 Key Performance Parameters (KPPs) within hours of being declared operational at the United States National Centers for Environmental Prediction (NCEP). NOAA-20 KPPs, in this case, CrIS and ATMS data in binary format (BUFR), ensure the continuity of global environmental data used in NWP, and imagery used for warnings in Alaska. Through direct readout antennas in Fairbanks, the NWS in Alaska started routinely using both Suomi NPP and NOAA-20 for its critical operations in March 2018. JPSS Program Science staff were instrumental in developing a pre-launch action plan aligning NOAA wide office's activities, to include NESDIS, NWS and CIO, to ensure satellite user readiness and risk reduction. JPSS Program Science tracked schedule and risk to ensure efficient plan execution.

**Ocean and Coastal Initiative:** Utilizes data from VIIRS, which is the only instrument that makes oceanographic measurements, i.e., surface chlorophyll and sea-surface temperature, to provide its user community with fit-for-purpose, accurate, consistent and timely, and long-term time series ocean data and derived products. Within the National Marine Fisheries Service (NMFS) and National Ocean Service (NOS), VIIRS ocean color data is used in a variety of different applications, many of which are not for near real time application. A sample of current and future planning efforts for the initiative's user communities include optimizing phytoplankton functional type algorithms for VIIRS ocean color data in the Northeast U.S. Continental Shelf Ecosystem; assimilating NOAA VIIRS data into Near-Real-Time Ocean models to support fisheries applications off the U.S. West Coast; extending and evaluating VIIRS ocean color neural network retrievals of Harmful algal blooms (HABs) and Inherent Optical Properties (IOPs) to complex inshore, bay and inland waters, and examining their applicability to different bloom types; and last but not least working with NOAA CoastWatch/OceanWatch to implement, process and serve JPSS program ocean products tailored for downstream user needs.

**River Ice and Flooding Initiative:** High-quality and high-resolution VIIRS Flood maps, which were developed through our River Ice and Flooding Initiative, and now are providing critical flood information not only to the NWS, but also the Federal Emergency Management Agency (FEMA). In fact, some products have been extended to regions outside of USA, and are now supporting elements of the International Charter for Disasters in the area of floods, fires and volcanic activity.

**Sounding Initiative:** NUCAPS soundings allows forecasters to give timely support during the critical pre-convective stages of storm development in areas where severe weather is expected. NUCAPS augments the less frequent conventional radiosonde data. Balloons are launched only at 00 and 12 UTC (and occasionally at 18 UTC), and the launch sites are often hundreds of kilometers apart. NUCAPS soundings provide the ability to track changes in atmospheric stability. Thus far, the Initiative has provided unique and useful data products to aviation weather forecasters. Prior to NUCAPS, forecasters had very limited access to observations with which they could verify models. Now NUCAPS helps them more accurately determine the onset, spatial extent, vertical depth and temporal evolution of these cold air blobs. At the Hazardous Weather Testbed Spring Experiment, which took place in May 2018, the initiative successfully demonstrated innovative uses of NUCAPS. NUCAPS using the Community Satellite Processing Package (CSPP) from North American direct broadcast stations generated soundings with latencies of 30 minutes as opposed to two hours from satellite ground stations. This was a major accomplishment which demonstrated the usefulness of NUCAPS in severe storm prediction impacting real-time decision making.

The entire Program Science efforts would not be possible without the outstanding interactions between the JPSS Program, the Center for Satellite Applications and Research (STAR), the NOAA cooperative institutes, government and international partners, government contractors, and of course the user community.

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**

Senior Program Scientist, Joint Polar Satellite System (JPSS)  
Satellite and Information Services  
National Oceanic and Atmospheric Administration (NOAA)  
U.S. Department of Commerce



## FROM THE PROGRAM DIRECTOR



One year has gone by in a flash. It feels like just yesterday we were at Vandenberg Air Force Base, some 150 miles northwest of Los Angeles, watching the Joint Polar Satellite System-1 (now NOAA-20) blast off into space. It soon joined its predecessor in the mid-afternoon orbit, the NOAA-NASA demonstration satellite, Suomi National Polar-orbiting Partnership (Suomi NPP). In 2018, we celebrated NOAA-20's first year in orbit and Suomi NPP's 7th—an accomplishment in itself as this is beyond its intended five-year lifespan.

Several milestones took place shortly after NOAA-20's launch. First, the key post-launch instrument and data product calibration/validation activities for the Advanced Technology Microwave Sounder (ATMS). Work on the Cross-track Infrared Sounder (CrIS) and Visible/Infrared Imager Radiometer Suite (VIIRS) sensors wasn't far behind.

The validation of these instruments assures their science integrity and readiness for use in operations. Eleven days after launch, the spacecraft sent back its first science data from its ATMS instrument. This was followed by science data from the VIIRS instrument on December 13, 2017, just 25 days after launch. And, on January 5, the covers on NOAA-20's Clouds and the Earth's Radiant Energy System Flight Model 6 (CERES FM6) instrument opened, allowing it to scan Earth for the first time. On May 30, 2018—after passing post-launch testing and completing its checkout phase—NOAA-20 was declared operational and became NOAA's primary operational satellite for global weather observations, while Suomi NPP became secondary. Both satellites continue to execute on plan and perform well as they circle the globe collecting valuable data about Earth's atmosphere, land, and oceans to support meteorological and environmental applications.

The combination of two satellites in the afternoon allows for lower latency data and increased global coverage for numerical weather, forecast applications, and emergency response. In 2018, major international weather forecast centers transitioned NOAA-20 soundings data into operations resulting in additional data incorporation in numerical weather prediction models and risk reduction.

In 2018, emergency managers increased their reliance on VIIRS imagery. During the Atlantic tropical cyclone season where there were 16 named storms, federal, state and local agencies benefited from JPSS products. The Federal Emergency Management Agency (FEMA) utilized JPSS flood mapping products and imagery to support communities in South Carolina and Florida impacted by Hurricanes Florence and Michael. Changes in VIIRS day-night band imagery light levels before and after storms, enabled decision makers to identify areas with potential power outages. In 2018 the Western United States experienced record-setting wildfires. Nighttime VIIRS images and model output from the High Resolution Rapid Refresh (HRRR) smoke forecast, which ingested both Suomi NPP and NOAA-20 fire radiative power, provided valuable information resources for park officials, fire crews as well as the local communities. The HRRR-Smoke model shows the areas with high levels of smoke concentrations, as well as their trajectory. State and local decision makers used the smoke forecasts to determine whether to cancel outdoor activities such as concerts, fairs and Friday-night football games.

The successful demonstration and increased implementation of JPSS products in operations represent key goals of the JPSS Proving Ground and Risk Reduction (PGRR) Program. The PGRR supports 13 initiatives. These initiatives provide forums where JPSS product developers and user community representatives work closely to evaluate forecast challenges and identify, test, and operationalize those JPSS capabilities that can help tackle those challenges.

Incorporating new topic areas and ideas broaden PGRR scope to include missions not previously envisioned. Periodic evaluation infused new ideas and provided feedback to developers and users and initiative teams to maximize their effectiveness. In 2018, the PGRR Program went through a comprehensive effort to encourage its stakeholders and users to propose new ways to use JPSS capabilities. This resulted in some changes to existing initiatives as well as the successful establishment of three new initiatives: Aviation Weather, Innovation and Volcanic Ash, which further represent the PGRR's commitment to improve NOAA services through optimizing the use of JPSS data along with other sources of data and information. The Aviation Weather Initiative was created following interest from stakeholders in the National Weather Service for potential products from JPSS that could be used in aviation weather decision support systems. At the JPSS Alaska Summit, the Federal Aviation Administration pilots and international partners also expressed interest in the initiative. In addition, JPSS data and products are being considered to assist the flight planning process.

The Volcanic Initiative identified a mission area where JPSS products could make an impact. The Initiative develops multi-sensor products for volcanic hazard applications such as volcanic cloud detection, tracking, and forecasting. Volcanic activity can produce an array of hazards including ash clouds and particulate emissions.

These efforts set the stage for the future, as the JPSS program prepares for the next satellites in its constellation. JPSS-2 cleared its critical design review (CDR) on October 4, 2018. Passing the CDR, signals that the project is ready to continue in its next phases: fabrication, assembly, integration and testing. The JPSS-2 spacecraft will feature several instruments similar to those found on NOAA-20, VIIRS, CrIS, ATMS and the Ozone Mapping and Profiler Suite-Nadir (OMPS-N). The JPSS-2 structure was delivered to Northrop Grumman Innovation Systems (NGIS), in Gilbert, Arizona, and tested. Flight harnesses were installed, and it was moved to a clean room. The Engineering Model Interface Electronics Module was delivered to the spacecraft and power was applied in November 2018. The JPSS-2 solar array has completed its unit-level testing and is ready for delivery. The JPSS-2 spacecraft bus is expected to be completed in November 2019 with instrument integration starting December 5, 2019. The planning launch readiness date is March 31, 2022.

And, there's more to come. The JPSS-3 and -4 spacecraft options have been exercised on the contract with NGIS, and a contractual kickoff meeting took place in November. At the J3/J4 kickoff meeting, NGIS presented the general plans, schedules and activities required to deliver the JPSS-3 and -4 satellites. JPSS-3 and -4 have planning launch readiness dates of September 2024 and December 2026.

The JPSS Program and its partners take pride in sharing accomplishments, challenges, lessons and future plans. The Department of Defense (DOD) is moving forward with replacement for the Defense Meteorological Satellite Program (DMSP). Meanwhile, DOD is optimizing use of JPSS satellites and leveraging advances in planning and design of the DMSP follow on. We assist Japan Aerospace Exploration Agency (JAXA) in maintaining data flow of the Advanced Microwave Scanning Radiometer 2 (AMSR-2). AMSR-2 data provides critical measurements for tropical cyclone forecasting including vertical structure and eyewall formation. Partnership with the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) ensures global coverage in both the morning and afternoon orbits. The November 7, 2018 launch of the MetOp-C satellite maintains important sounding imagery and scatterometry data that ensures continuity in the early morning orbit. These partnerships provide invaluable hardware, software, and science collaboration to guide instrument acquisition and operational use for decades to come.

The articles found in this Science Digest document just a fraction of the incredible work being done throughout the PGRR Initiatives and the meteorological community. Every story of the operational application of the JPSS capabilities represents lives that are impacted and resources safeguarded. As each new sensor is manufactured and carefully assembled on the satellite bus for launch, we hope that the critical importance of this work will come shining through. Every person involved in our JPSS Program can be proud of their efforts in providing “Global Weather for Local Forecasts.” Our users certainly express their appreciation loud and clear, and so do I.

## **Greg Mandt**

Joint Polar Satellite System (JPSS)  
Satellite and Information Services  
National Oceanic and Atmospheric Administration (NOAA)  
U.S. Department of Commerce





# FEATURED ARTICLES







# DEVELOPMENT AND APPLICATION OF GRIDDED NUCAPS FOR OPERATIONAL FORECASTING CHALLENGES

The information in this article is based, in part, on the October 23, 2017 JPSS science seminar presented by Nadia Smith, Emily Berndt, Kris White, and Brad Zavodsky. It contains work by Jack Dostalek, Eric Stevens, Carrie Haisley, Gail Weaver, Chris Waterhouse, David Hoese, Michael Bowlan, Bill, Line, Chris Barnet and Antonia Gambacorta.



Knowing your flight plan is helpful in the event of an emergency. Image credit: NPS. [www.nps.gov/articles/alaska-aviation-safety.htm](http://www.nps.gov/articles/alaska-aviation-safety.htm).  
Inset: A plane flies over the Arctic Circle. Image accessed from [www.fogonazos.es/2007/03/transpolar-flights-shortcut-through.html](http://www.fogonazos.es/2007/03/transpolar-flights-shortcut-through.html).

Weather forecasts help us make informed decisions on day-to-day activities, and at times can be the difference in taking action to save lives. One of the key foundations of a good forecast is detailed knowledge of the thermodynamic state of the atmosphere represented as profiles of temperature and moisture. These vertical profiles are used to identify localized extremes or areas of instability which, if sufficiently intense, can indicate the potential for hazardous conditions. Sources of temperature and moisture profiles, or “soundings”, are balloon-based rawinsondes, model soundings, and increasingly satellite-derived soundings. Each of these sources has its positive and negative aspects. The ground-launched rawinsondes have tremendous vertical resolution and measure fine-scale features in the atmosphere critical to a variety of weather phenomena. However, they are launched only twice a day at 00:00 UTC and 12:00 UTC from sites that are widely dispersed geographically. Model soundings, on the other

hand, are available at regular intervals, allowing changing weather conditions to be captured more frequently, but they may miss small-scale changes in weather and have inconsistencies from one model to another. JPSS satellite soundings have the benefit of being available in the space-time gaps between rawinsondes and as observations represent what is actually happening, unlike models that forecast what will happen based on theoretical calculations. The primary limitation of satellite soundings is their loss of accuracy in overcast and precipitating regions, which means that observations may be missing when they are most needed during critical weather periods.

The NOAA-Unique Combined Atmospheric Processing System (NUCAPS) derives soundings from the Cross-track Infrared Sounder (CrIS) and Advanced Technology Microwave Sounder (ATMS) onboard the joint NOAA/NASA Suomi National Polar-orbiting Partnership (Suomi NPP) and the Joint Polar Satellite System’s (JPSS),



NOAA-20, which launched in November 2017. Since they first became available on Suomi NPP in 2012, these soundings have shown their value to forecasters in a variety of different weather environments.

To better capture the quality of a user's experience when interacting with NUCAPS sounding products or applications, developers and users are given opportunities to test them in real-world weather environments. The NASA Short-term Prediction Research and Transition (SPoRT) Center has played a key role in the evaluation of NUCAPS soundings in Alaska. These soundings are an especially important forecast resource given the region's limited options for conventional observations. For more details on this effort, let's first look at SPoRT as an organization.

## **NASA SHORT-TERM PREDICTION RESEARCH AND TRANSITION CENTER**

The NASA SPoRT Center is funded by NASA's Research and Analysis Program and the Weather Focus Area with supplemental funding from the JPSS and Geostationary Operational Environmental Satellites (GOES) Proving Ground and Risk Reduction (PGRR) Programs. SPoRT was established in 2002 to transition unique NASA and NOAA observations and research capabilities to the operational weather community to improve short-term weather forecasts on a local and regional scale. SPoRT matches specific research and experimental products and derived technologies from NOAA and NASA satellite observations to user-identified forecast challenges. Understanding the impact of sounding products on forecast challenges in an operational environment is important for developers. SPoRT plays a critically important role by developing solutions to the challenges and then infusing the capabilities created to meet these challenges into the end users operational environment. Its ability to transition NASA and NOAA satellite data directly into decision support platforms such as the Advanced Weather Interactive

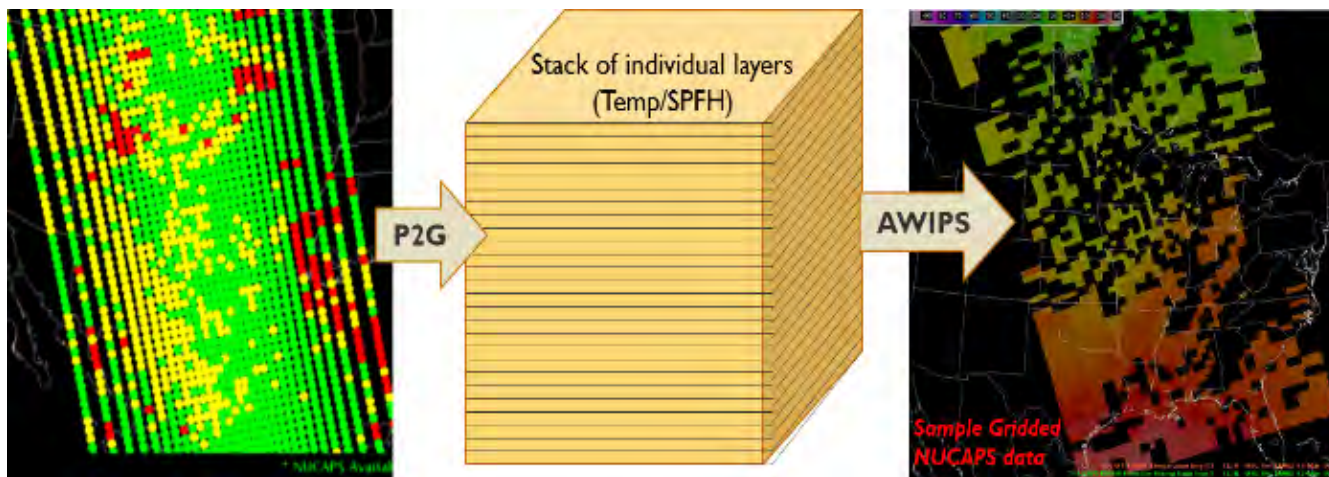
Processing System II (AWIPS-II) has widened the range of unique products forecasters can view in near- to real-time operations.

Through a JPSS initiative on NUCAPS, SPoRT teamed up with various scientists and forecasters to form a multi-organization group focused on demonstrating the capabilities of NUCAPS to meet the needs of NOAA National Weather Service (NWS) Weather Forecast Offices (WFOs) in various forecasts challenges. The group developed the capability to view displays of NUCAPS Soundings in AWIPS-II in two-dimension gridded plan view and cross section (i.e. Gridded NUCAPS). The capability was initially developed in conjunction with the Anchorage, Alaska, Center Weather Service Unit (CWSU) to diagnose layers of cold air aloft (CAA), which are hazardous to aviation activities. The CWSU routinely issues Meteorological Impact Statements (MIS) to alert the aviation community of hazardous weather conditions. Gridded NUCAPS provided an additional dataset beyond model data and observations to diagnose such events.

The following section outlines the progress made in the development of the Gridded NUCAPS product for display in AWIPS-II and highlights application examples from the 2016-2017 winter evaluation with the CWSU as well as the 2016 and 2017 HWT Spring Experiments.

## **GRIDDED NUCAPS PRODUCT OVERVIEW**

At first, NUCAPS soundings were introduced into the AWIPS-II environment like rawinsondes and visualized one by one over specific locations, allowing forecasters the ability to interrogate individual soundings. This has value in the summertime when convective thunderstorms pop up mid-afternoon over much of the Southern and Midwest U.S. NUCAPS soundings from Suomi NPP are available at -18:00-19:00 UTC over this region and thus characterize conditions ahead of storm development. Forecasters often require the launch of special rawinsondes at this time and with NUCAPS gained access to "hundreds of 18:00 UTC



soundings” (Dan Nietfeld Pers. Comm.). Gridded NUCAPS was initially developed to address the CAA forecast challenge in which forecasters need to analyze the horizontal and vertical extent of a feature whereby plan view and cross-section displays would be preferred over interrogating individual soundings. The NUCAPS CAA product is based on a prototype first developed at the University of Wisconsin Space Science Engineering Center (SSEC) with Dual-Regression sounding products. Researchers at SSEC added the capability to polar2grid, a software tool in the Community Satellite Processing Package (CSPP), to ingest satellite soundings and output them as 2-D gridded images that depict spatial gradients of sounding information on a regular grid. The capability for a Gridded NUCAPS product had to be developed to display the spatial and vertical extent of CAA features. A CIRA web-based display ([rammb.cira.colostate.edu/ramsdisk/online/cold\\_air\\_aloft.asp](http://rammb.cira.colostate.edu/ramsdisk/online/cold_air_aloft.asp)) demonstrated the value of this type of visualization for NUCAPS soundings and still provides a backup for forecasters today when AWIPS-II is down. As forecasters and developers continued to work together, they realized that NUCAPS soundings had broader application beyond CAA. With 2,200 km wide swaths of vertical profiles from pole to pole, NUCAPS not only characterizes localized vertical structure but the full three-dimensional atmospheric state. With funding from the JPSS program, forecasters and developers continued to consider the value of visualizing NUCAPS soundings not only as individual profiles but as horizontal planes of

temperature, moisture, and derived convective parameters or stacks of two-dimensional fields at pressure levels from Earth’s surface to the upper troposphere.

Gridded NUCAPS was developed through a collaborative effort between software developers, product developers, algorithm developers, and forecasters. SPoRT was able to use the experimental version of polar2grid (P2G) to process NUCAPS data as gridded fields to be displayed in AWIPS. With data from Direct Broadcast (DB), the Gridded NUCAPS data are made available in near-real time within 40 to 60 minutes of the satellite overpass and distributed to Alaska Region NWS partners via the Unidata Local Data Manager (LDM). Ultimately this approach led to the creation of a new visualization of NUCAPS Soundings, which has gained tremendous value in the forecast decision support system, AWIPS-II.

In the NUCAPS Soundings view shown above on the left, forecasters need to click on each “point” to review the vertical information. The advantage of this view is that a forecaster can choose specific locations, or analyze a sounding at locations where conventional observations are not available routinely. However, this requires a lot of individual interrogation. The operational NUCAPS Soundings are formally distributed to NWS WFOs through the Satellite Broadcast Network (SBN). The experimental Gridded NUCAPS, derived from Level 2 NUCAPS data obtained from the Geographic Information Network of Alaska (GINA) and University of Wisconsin DB sites are processed and delivered to users by

SPoRT. The center image on the previous page shows how NUCAPS Soundings are processed through P2G to create a stack of individual, gridded temperature and moisture layers. The experimental Gridded NUCAPS data files consist of a subset of 58 NUCAPS layers and only contain temperature, specific humidity, surface pressure and temperature, and topography variables. The gridded NUCAPS data (figure on the right; previous page) are ingested into AWIPS-II on a uniform model grid. This allows AWIPS-II to interrogate the information in the same way it handles model data, meaning forecasters are able to see plan views and cross sections of temperature, moisture, and stability indices.

## LIMITATIONS/CONS

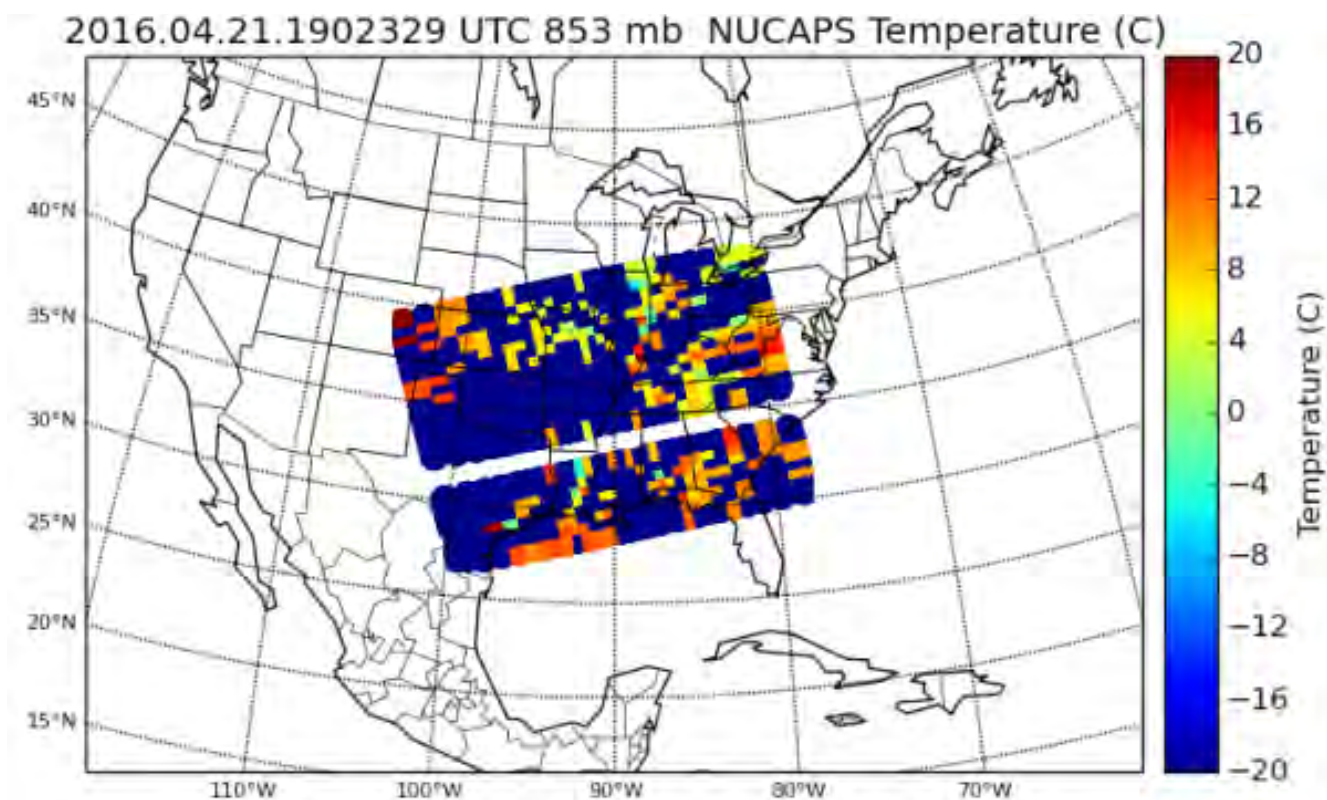
Currently, the Gridded NUCAPS contains only the highest quality (i.e., “best”) data that comes from a combination of both microwave and infrared (see image below).

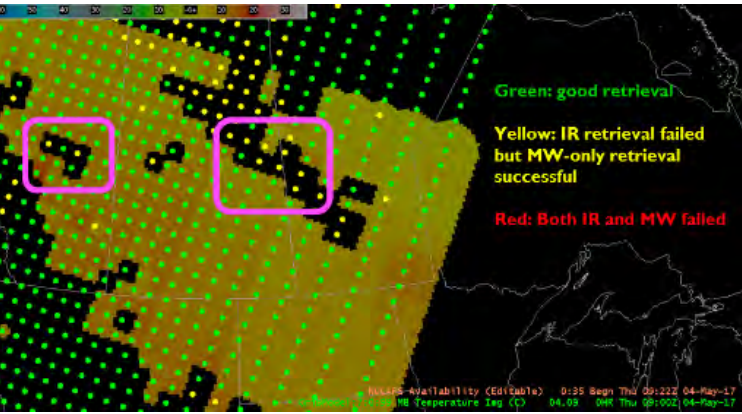
Even the best tools have shortcomings. For one, cloud cover and failed retrievals tend to cause gaps in gridded data. As a result, good data can be flagged as bad and not processed.

In the image below, the dark blue pixels represent the data that are discarded due to quality control issues. However, this quality control can be strict at times and leave out “good” data that can still be useful to the forecasters.

Differences in the way data are processed can also cause discrepancies between NUCAPS Sounding output and Gridded NUCAPS (i.e. CAPE values differ). As shown at the top left of the next page, a mismatch in quality flags and retrieval quality at cloud edges can occur due to differences between operational and DB processing (only 7 of 9 CrIS FOVs processed via DB).

Another limitation is that individual retrievals are not preserved, therefore, when one zooms into the gridded product they end up with multiple 10-12 km grid boxes placed inside each NUCAPS footprint. Another limitation with infrared observations arises from their sensitivity to surface temperature which can give a bias to the data. These sensitivities can be caused by differences in land versus the ocean, or day vs. night, or local conditions. Some of these limitations are the result of experimental processing and use of differing





data sources, future iterations of the Gridded product as it is baselined in AWIPS-II will address and mitigate some of these limitations. For SPoRT, the next step was to see if this gridded approach, with its strengths and weaknesses would be a valuable data set for the CAA forecast challenge. The Anchorage, Alaska, NWS Center Weather Service Unit (CWSU) forecasters, who provided direct input to the development of the Gridded NUCAPS, evaluated the experimental Gridded NUCAPS for the first time during the 2016–2017 winter.

## NUCAPS ASSESSMENTS IN ACTION

Forecasting weather phenomena, particularly in regions with sparse conventional observations can be quite challenging. The Gridded NUCAPS was initially developed to address the challenges related to forecasting cold air aloft (CAA) events, which occur when air temperatures decrease to minus 65°C and below. In the high latitudes, these pockets of cold air form at altitudes used by passenger and cargo aircraft. These temperatures can cause jet fuel to thicken and crystallize, which can impact the operation of jet engines. Fuel efficiency can be reduced, driving up costs, and long-term exposure to cold air can cause damage to aircraft engines. Thus, the location of these “cold” air pockets is important for weather forecasters to highlight to the Federal Aviation Administration (FAA) and aircraft operators.

## COLD AIR ALOFT FORECAST CHALLENGE

Alaska is a region whose size, geography, weather patterns, remoteness, and regional infrastructure present many unique challenges for weather forecasting and warning services. Close to 90 percent of the state is not served by roads. Thus, it has a unique dependency on air transportation. The CWSU provides weather support to air traffic controllers to direct flights around the 3D “cold” air features over the Arctic Ocean and Alaska. Operational weather forecasters in the region have traditionally relied on analysis and model fields and limited radiosonde observations to guess the 3D extent of the CAA. But these observations only provide an idea of horizontal and vertical extent of the CAA, which amplifies the need for higher temporal and spatial resolution observations of vertical temperature profiles in the atmosphere. Accordingly, forecasters at the NWS CWSU in Alaska expressed the need for an observational product from satellites that can help locate these cold areas, and also provide supportive evidence for comparison to numerical weather model output.

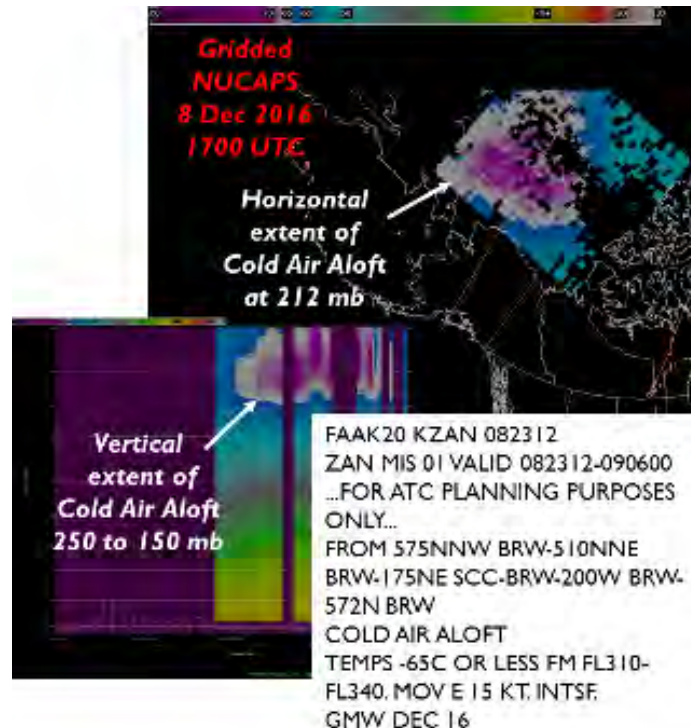


Alaska CWSU domain (green line) and warning guide for January 11, 2017. Purple hatched area is an advisory for Cold Air Aloft.

The CWSU forecasters had a first look at the Gridded NUCAPS during an evaluation conducted Winter 2016–2017. To prepare for

the product evaluation, training material was covered during an in-person visit to the CWSU in the fall season. In addition, the forecasters gave direct feedback regarding the preferred display of the product in AWIPS-II. These included the creation of a specific color curve (example shown right) to outline the coldest air and threshold for CAA, used to issue the CAA impact statement (shown along with the image). Also, a procedure was created to allow forecasters to quickly toggle through the vertical layers to enhance analysis. And lastly, short videos demonstrating installation and application of the data were made available.

It was expected that this evaluation would help improve CAA analysis and increase confidence when issuing operational MIS products used by the FAA and airlines.



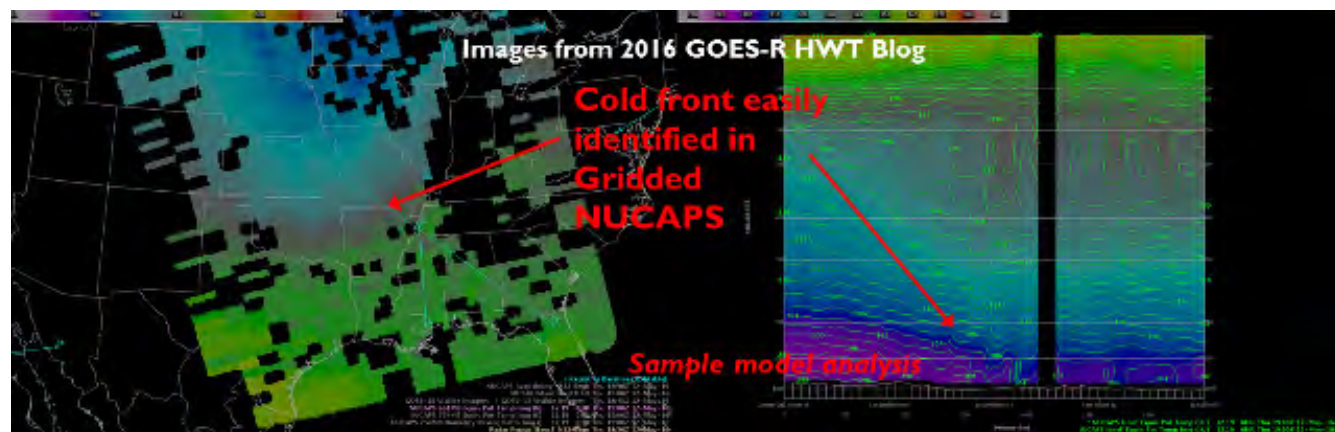
## PRE-CONVECTIVE ENVIRONMENT FORECAST CHALLENGE

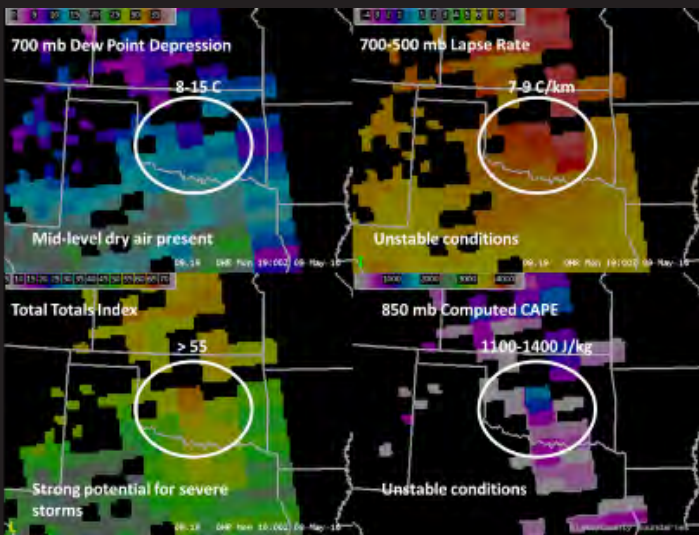
Although the Gridded NUCAPS was initially developed for the CAA forecast challenge, the capability was introduced to forecasters in a testbed environment at the Hazardous Weather Testbed (HWT) during the 2016 Spring Experiment. Forecasters had the opportunity to analyze temperature and moisture fields through plan view and cross section visualizations of NUCAPS data during the Spring Experiment and provide feedback on the utility of the data for convective forecasting. Typically, the vertical distribution of temperature and moisture in the lower atmosphere is used to determine convective potential, and forecasters use a combination of in situ observations, satellite

data, and models to determine the location of boundaries and areas of instability. This initial demonstration was used to answer the question as to whether Gridded NUCAPS was relevant to assessing the pre-convective environment.

The Gridded NUCAPS products allow for isobaric plan views of temperature and moisture that forecasters can use to gain confidence in the model output or compare to surface based observations. The plan view and cross sections below show an event that was captured by a forecaster at the 2016 HWT.

Feedback from the initial HWT demonstration was applied to improve the Gridded NUCAPS





product before the 2017 HWT demonstration. The Gridded NUCAPS capability was expanded to allow for it to be used more broadly. SSEC software developers updated P2G to output all pressure levels, surface variables and mask values below the surface. Since Gridded NUCAPS was initially developed for assessing upper-level temperature for the CAA forecast challenge in the Alaska Region, these capabilities were necessary to be included in P2G to fully utilize Gridded NUCAPS for other applications. During the 2016 HWT, forecasters were only able to interrogate temperature and moisture from the Gridded NUCAPS. Since the NUCAPS vertical layers are based on the Community Radiative Transfer Model (CRTM), it was impossible to leverage the “derived parameters” capability in AWIPS-II to calculate and display stability indices. When model or gridded data are ingested into AWIPS-II, the derived parameters will calculate any fields such as CAPE, CIN, Lapse Rate, etc., as shown in the image, as long as the temperature and moisture variables are available at standard meteorological levels (e.g., 1000, 925, 850, 700, 500,... mb). To take advantage of the full capability of derived

parameters in AWIPS-II, some of the layers in the Gridded NUCAPS file were changed to standard levels (e.g. data at 853 mb was represented as 850 mb). As proof of concept, this allowed for the calculation and display of stability indices relevant to assessing the pre-convective environment (shown in the image). In addition, several AWIPS-II procedures were developed to make it easier for forecasters to analyze the Gridded NUCAPS with soundings, other satellite imagery, and model fields. More robust training slides and Quick Guide were produced. During the 2017 HWT demonstration, a wider variety of fields were available in AWIPS-II, including Potential Temperature, Virtual Temperature, Dewpoint Depression, Mixing Ratio, Relative Humidity Showalter Index, K Index, and Cross Totals.

## PRODUCT EVALUATION AND FEEDBACK FROM FORECASTERS

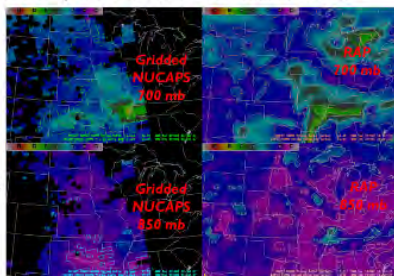
Forecasters provided feedback (some of which is captured below and on the following pages) on the utility of Gridded NUCAPS products in forecasting CAA events and the HWT demonstrations.

The feedback received thus far has widely indicated that Gridded NUCAPS data have a positive impact on identifying CAA events and results in increased confidence when issuing meteorological impact statements.

- 2/2/17 6:00a **Some Operational Impact, High Confidence:** "NUCAPS images on the WEB site were about 5 degrees C too cool over the eastern Bering and western Alaska compared to 12Z raobs and the NAM/GFS. **NUCAPS 12Z image on AWIPS at 212 mb was right on though with temperatures and with the models and observations.**" –unnamed AK CWSU forecaster
- 2/24/17 8:00p **Very Large Operational Impact, High Confidence:** "**Both the GFS and gridded NUCAPS showed an area of CAA moving into the central Aleutian's,** with the GFS being slightly better tonight in bringing in colder values in the same area depicted by both models, 25/00Z soundings did not help since the CAA was moving up from the south after 00Z." – Gail Weaver, AK CWSU
- 2/28/17 2:00p **Very Large Operational Impact, High Confidence:** "I used the Gridded NUCAPS CAA heights today since the new area of CAA did not include any upper air sounding sites (it was located over the Bering Sea). The GFS model seemed to be weaker and depicted a smaller area of CAA than the NUCAPS, so I had more confidence in the NUCAPS data today." –Gail Weaver, AK CWSU
- 3/1/17 8:00a **Very Large Operational Impact, High Confidence:** "GFS model data showed temps near -65C over the northern Bering Sea this morning. SYA and SNP 12Z raobs did show -65C right around FL330, but it was only about 500 feet deep. The NAM was slightly colder than the GFS in the area between and north of SYA-SNP to the FIR boundary. **Based on the SNPP-NUCAPS it showed a deeper layer, nearly 5000 feet, from FL350-FL400 in this area that was not sampled by the raobs. Due to the models trending colder the next 12-24 hours I decided to issue a MIS for Cold Air Aloft based on the Gridded NUCAPS data. I felt very confident in the NUCAPS data based on the surrounding raobs, model data, timing, and intensity of the data represented in these graphics.**" –unnamed AK CWSU forecaster

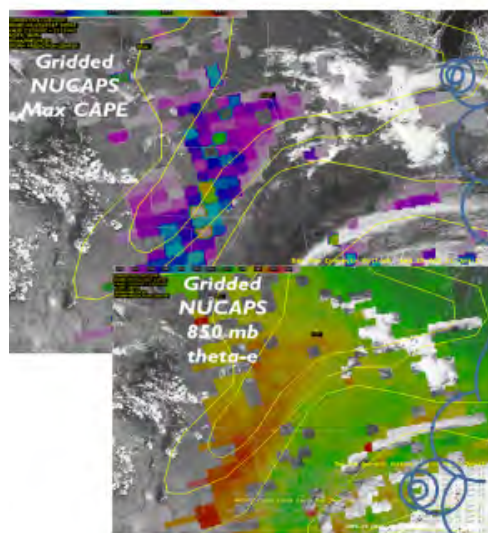
On the Satellite Proving Ground HWT Blog<sup>1</sup> a forecaster noted:

"At 700 mb (top two panels with NUCAPS on left and RAP on right), it looks like both are generally showing a dry tongue stretching up from Tennessee across Missouri. They are also both in good agreement on the mixing ratios over our new forecast area of FSD. Overall, very impressed how well NUCAPS matches up with the latest model data at 700mb." – HWT forecaster 11 July 2017



"Looking a bit farther lower at 850mb (lower panels), it looks like mixing ratios overall are slightly less than what the RAP is indicating... Thus, confidence may be a bit better at levels at or above 700mb, but not so good for 850mb or lower."

In the next example (below), a forecaster evaluated the Gridded NUCAPS data at approximately 19Z from the southern/central Plains near an area of subsequent deep convection in western Kansas and also provided the feedback on the Satellite Proving Ground at HWT Blog<sup>1</sup>.



Notice that the axis of max CAPE values is very close but a little to the east of the Slight Risk area, suggesting perhaps that the better axis of instability lay just to the east of the Slight Risk. Also, the 850 mb theta-e analysis from the NUCAPS gridded

Convection did subsequently develop in western Kansas during the afternoon... Although data from NUCAPS are a few hours old now, the earlier data indicated sufficient instability to keep convection development ongoing downstream and that increased intensity is possible as it

## WHAT'S NEXT?

The product feedback from forecasters helps SPoRT scientists and researchers assess its value in operational forecast environments and to make decisions regarding either needed improvements or a transition plan. Forecasters identified several CAA events that occurred during the 2016–2017 evaluation and plan a deeper dive that will include comparisons

between the Gridded NUCAPS, soundings and Aircraft Meteorological Data Relay (AMDAR) data. The findings of this deep dive will be presented at the annual American Meteorological Society Meeting (AMS) in 2018. In addition, developers are looking to add Gridded NUCAPS data on flight levels following a request from the CWSU forecasters. Future plans also include another Cold Air Aloft demonstration with the CWSU during the 2017–2018 winter season. Also planned is a transition of processing to GINA to reduce product latency.

During the HWT demonstrations, forecasters noted that while Gridded NUCAPS data enable greater situational awareness by enabling quick and easy visualization of spatial patterns, there is much to be done to improve the quality of this product in AWIPS-II. Suggested improvements include a simplified menu/list of

derived products, better consistency in values between soundings and the gridded product, improving the availability and display of derived fields such as CAPE, and only providing data on standard levels. Forecaster feedback from the CAA evaluations and testbed activities had led to direct improvements of the Gridded NUCAPS product and expansion of capabilities beyond the original intent of the product. This capability has been so successful that NOAA NWS has

tasked AWIPS-II developers to baseline the Gridded NUCAPS in AWIPS-II as a standard capability available within AWIPS. Therefore, future work includes providing working with AWIPS-II developers to baseline Gridded NUCAPS and improve visualization in AWIPS and exploration of other applications such as winter weather, fire weather, or other aviation hazards.







# ENHANCEMENTS AND EXPANSION OF NESDIS SNOWFALL RATE PRODUCT FOR INCREASED APPLICATIONS

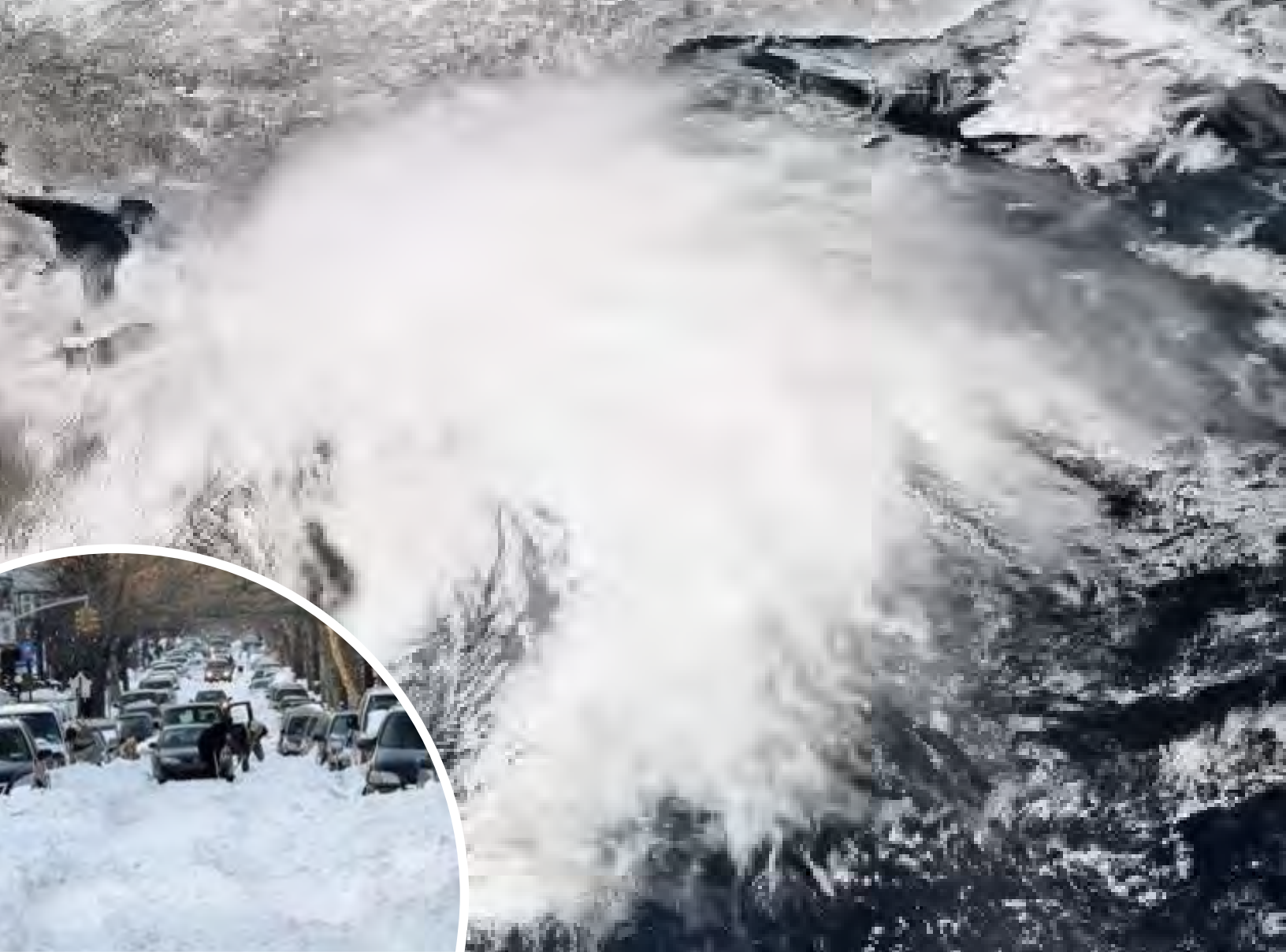
The information in this article is based, in part, on the November 20, 2017 JPSS science seminar presented by Huan Meng, NOAA/NESDIS/Center for Satellite Applications and Research, and Kris White, NWS, Huntsville, AL and NASA SPoRT. It contains work by Ralph Ferraro<sup>1</sup>, Banghua Yan<sup>1</sup>, Jun Dong<sup>2</sup>, Cezar Kongoli<sup>2</sup>, Limin Zhao<sup>3</sup>, Emily Berndt<sup>4</sup>, Bradley Zavodsky<sup>4</sup>.

<sup>1</sup>NOAA/NESDIS/Center for Satellite Applications and Research

<sup>2</sup>ESSIC/Cooperative Institute for Climate and Satellites—Maryland

<sup>3</sup>NOAA/NESDIS/Office of Satellite and Product Operations

<sup>4</sup>NASA/MSFC/Short-term Prediction Research and Transition Center



Suomi NPP satellite image taken at 18:30 UTC on March 14, 2017 shows a nor'easter over the Northeastern United States. The storm brought extremely heavy snow to the Northeast. [www.weather.gov/images/okx/NorEaster\\_Mar142017/Suomi%20NPP\\_2017-03-14\\_1830Z.png](http://www.weather.gov/images/okx/NorEaster_Mar142017/Suomi%20NPP_2017-03-14_1830Z.png).

Snowfall, an important weather element, is challenging to measure accurately and consistently. Much of the Earth's surface, is not well-monitored by conventional observations due to a variety of challenges. Conventional methods such as surface gauges and ground-based radar networks are often limited by coverage or capabilities. Snowfall retrievals from polar-orbiting satellites can help fill in voids from the conventional observational network, thus providing a more comprehensive and effective way to monitor snowfall with global coverage. However, it wasn't until recently that satellite-derived snowfall rates could be attained, given past challenges in detecting and quantifying them from space.

The slightest change in a storm's evolution and track can alter the magnitude of a particular event. In an instant, a seemingly low-impact event can turn into a significant one with long lasting impacts such as disruptions on the ground and in the air. Often, the impacts are felt more widely in major metropolitan or heavily populated areas. While major snowstorms have the potential to cause the most disruption, minor events too can have some undesired disruptive consequences.

In urban areas, snowfall rates and accumulation totals are often well covered, but there are vast stretches of the U.S. where existing observations are extremely sparse and these measurements are lacking. Satellite data is especially important in these locations.

In March 2017, heavy snow spread across parts of Northeastern United States, New England and Canada, leaving some areas, including New York and Vermont, buried in up to 3 feet of snow. Initially, the National Weather Service (NWS) had predicted that New York City (NYC) would be buried in 1-2 feet of snow, bringing it almost on par with the Great Blizzard of 1888. But, the totals were later lowered due to the change in the system's track. While NYC was spared the worst, a slew of areas including the Greater Binghamton airport, broke 24-hour snowfall records when 31.3 inches of snow fell between 03:00 UTC on the 14th and 01:00 UTC on the 15th. The blizzard's evolution was captured by the National Environmental Satellite, Data, and Information Service (NESDIS) Snowfall Rate (SFR) product, which provides a unique, space-based perspective on the locations of frozen precipitation that can be used to easily identify the extent of a snow storm and the location of the most intense snowfall.

## SNOWFALL RATE (SFR) PRODUCT BACKGROUND

This feature highlights the NESDIS SFR product, which processes direct broadcast (DB) satellite data to provide forecasters with more timely assessments of how storms evolve and travel. It is most valuable in filling observational gaps in mountains and remote regions where weather stations are sparse and radar blockage and overshooting are common. The SFR algorithm uses multiple channels that are sensitive to different atmospheric levels in order to sample the intensity of snowfall through the entire precipitation layer. SFR utilizes measurements from several sensors including the Advanced Technology Microwave Sounder (ATMS) aboard the National Oceanic and Atmospheric Administration's recently deployed polar-orbiting spacecraft, NOAA-20, and the joint NOAA/NASA Suomi National Polar-orbiting Partnership (Suomi NPP), the Advanced



NWS NY twitter page informing the public of expanded blizzard warnings.

Microwave Sounding Unit/Microwave Humidity Sounder (AMSU/MHS) sensor pair aboard NOAA POES and EUMETSAT Metop satellites, and more recently on the Special Sensor Microwave Imager/Sounder (SSMIS) and the GPM Microwave Imager (GMI) instrument onboard the Defense Meteorological Satellite Program (DMSP) F16 and the NASA Global Precipitation Mission (GPM) satellites respectively.

In a 2015–2016 assessment, the product developers utilized DB data provided by the University of Wisconsin-Madison and University of Alaska Fairbanks/GINA and reduced the SFR latency from 60 to 30 minutes. An important point to note is that earlier iterations of the SFR were based on AMSU/MHS data which were not available from GINA, so their latencies ranged anywhere from 30 minutes to three hours. The reduced latency has made the SFR product more useful for situational awareness of snow events. The AMSU/MHS SFR product has benefited from continuous improvement since it became operational at NESDIS in 2012. With the support of the Joint Polar Satellite System (JPSS) Proving Ground and Risk Reduction Program, an algorithm—based on the AMSU/MHS SFR, and derived from Suomi NPP ATMS—was developed and is expected to transition to operation in the near future. ATMS is the follow-on sensor to AMSU and MHS. Compared to its predecessors, ATMS has improved sampling configuration and more channels, especially two more water vapor channels that can be used

for precipitation retrieval. With five satellites—NOAA-18, NOAA-19, Metop-A, Metop-B, Suomi NPP—SFR can provide two daily snowfall rate estimates per satellite over land in mid-latitudes with more frequent estimates toward the poles. In the future, the SFR will include ATMS sensor data from the NOAA-20 satellite that was launched on November 18, 2017, which will provide NOAA better coverage and data continuity.

## ALGORITHM METHODOLOGY

The SFR algorithm has two main components, snowfall detection (SD) and snowfall rate estimation (SFR). Both components rely on the microwave scattering signal from snow particles in the atmosphere. At frequencies around 165/157 GHz and above, the signal is highly sensitive to solid precipitation.

The original SD is a statistical algorithm that uses high frequency measurements as predictors (Kongoli et al., 2015). It couples principle component and a logistic regression model to produce the probability of snowfall. The satellite-based model has two temperature regimes because the measurement characteristics are different under relatively warm and cold conditions. The snowfall rate component is a physical algorithm (Meng et al., 2017; Ferraro et al., 2018) that retrieves cloud properties following a variational method (Yan et al., 2008). Snowfall rate is further derived based on these properties.

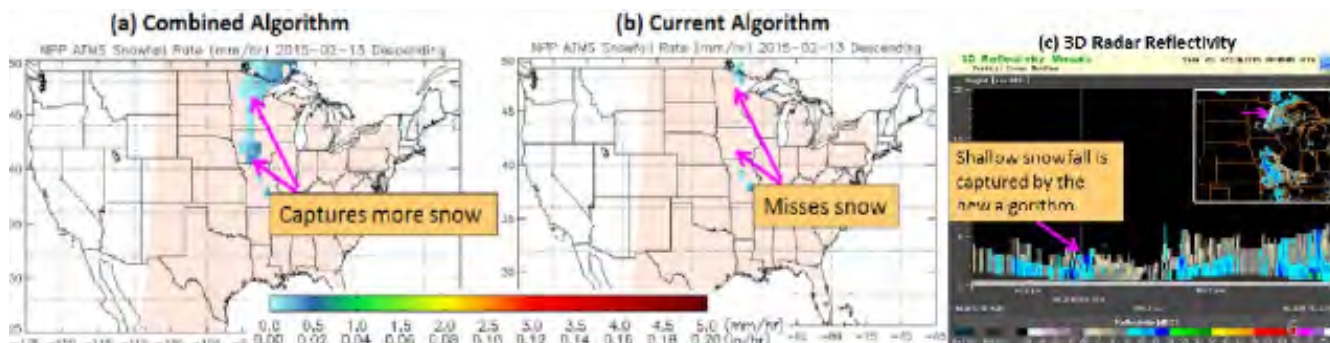
The SFR product has limitations under certain weather and surface conditions that weaken, mask, or contaminate the signal. For example, low clouds are one of the most common factors that can weaken scattering effect

and lead to missed snowfall detections. In addition, the signal gets weakened by shallow-cloud snowfall and snowfall with abundance of supercooled cloud liquid water due to its emission effects. This weakened signal deteriorates SFR algorithm's detection efficiency and rate accuracy, causing it to miss snowfall or underestimate the snowfall rate. The algorithm developers are already tackling these limitations with product quality improvements that include an environment-based weather module as well as a satellite module.

## ENHANCEMENTS

### Snowfall Detection (SD)

The previous SD model relies on a satellite module. It uses three principal components derived from the high frequency measurements above 89 (MHS)/88.2 GHz (ATMS), i.e. 5 from MHS and 7 from ATMS. The enhanced algorithm adds a Numerical Weather Prediction (NWP) model-based weather module that uses environmental variables such as relative humidity and cloud thickness as model predictors. The final probability of snowfall is derived from optimally combining the output from the satellite module and the weather module. In addition, the algorithm's accuracy is improved through further screening. The figure below shows the snowfall detected from the enhanced algorithm (left), the satellite-only algorithm (middle) and 3D radar reflectivity (right) under low clouds. The results show that the combined SD algorithm captures much more shallow cloud snowfall than the satellite-only algorithm.



The combined SD improves statistics for both shallow and thick-cloud snowfall over the satellite-only algorithm. The table below shows ATMS SD statistics against gauge snowfall observations in both warm and cold regimes. The main performance statistics computed were the probability of detection (POD) and false alarm rate (FAR). The values in parenthesis represent the statistics from the satellite-only algorithm. These results clearly demonstrate the improvement made by the newly-developed SD algorithm over the previous one.

	Warm Regime	Cold Regime
POD (%)	51 (41*)	52 (30)
FAR (%)	5 (4)	9 (6)
HSS	0.5 (0.43)	0.42 (0.28)

### Snowfall Rate (SFR)

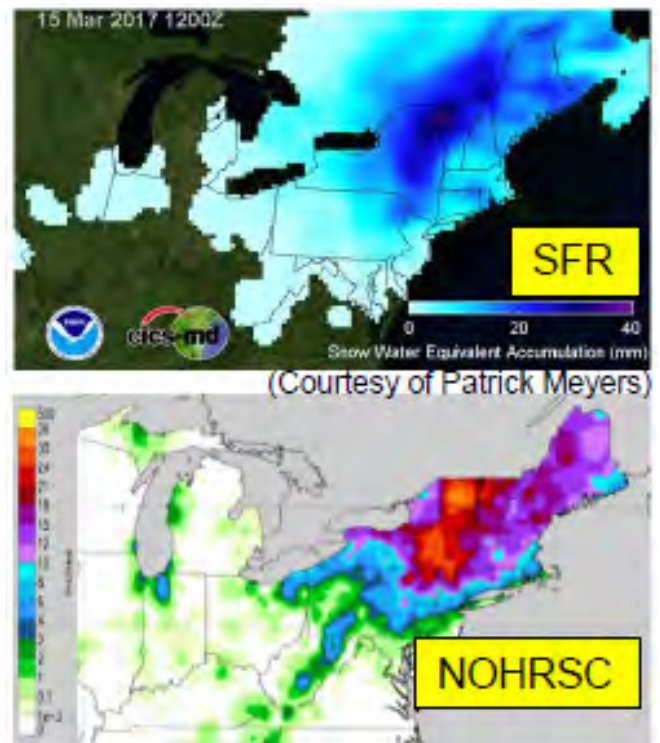
The foundation of the SFR algorithm is the retrieval of cloud properties from a one-dimensional variational (1DVAR) model. The properties are then used to derive ice water content. Due to the lack of information on ice particle distribution in cloud column, calibration is required to ensure the quality of retrieved SFR. Since the development of the original SFR product, it has been recalibrated using the Multi-Radar Multi-Sensor (MRMS) radar precipitation data because MRMS has better spatial (via integration) and temporal compatibility with SFR than Stage IV precipitation.

In addition, the effect of cloud liquid water (CLW) has also been included in the radiative transfer model (RTM) of the algorithm. This leads to increased SFR in most cases, which helps mitigate the dry bias in SFR. However, there is ongoing research to develop a more robust initialization of cloud properties.

## SNOWFALL RATE (SFR) APPLICATION TO THE MARCH 14-15, 2017 NOR'EASTER

A major nor'easter swept through the Mid-Atlantic on March 14-15, 2017 and moved up the east coast of the U.S. spreading heavy

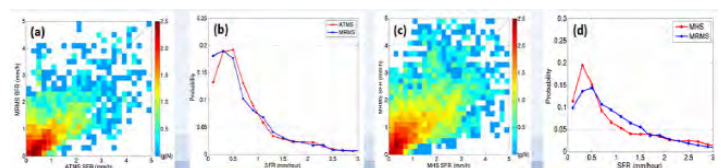
snow across parts of central New York and northeast Pennsylvania. The ATMS and MHS SFR products captured the evolution of the snowstorm with five satellites including Suomi NPP, POES and Metop.

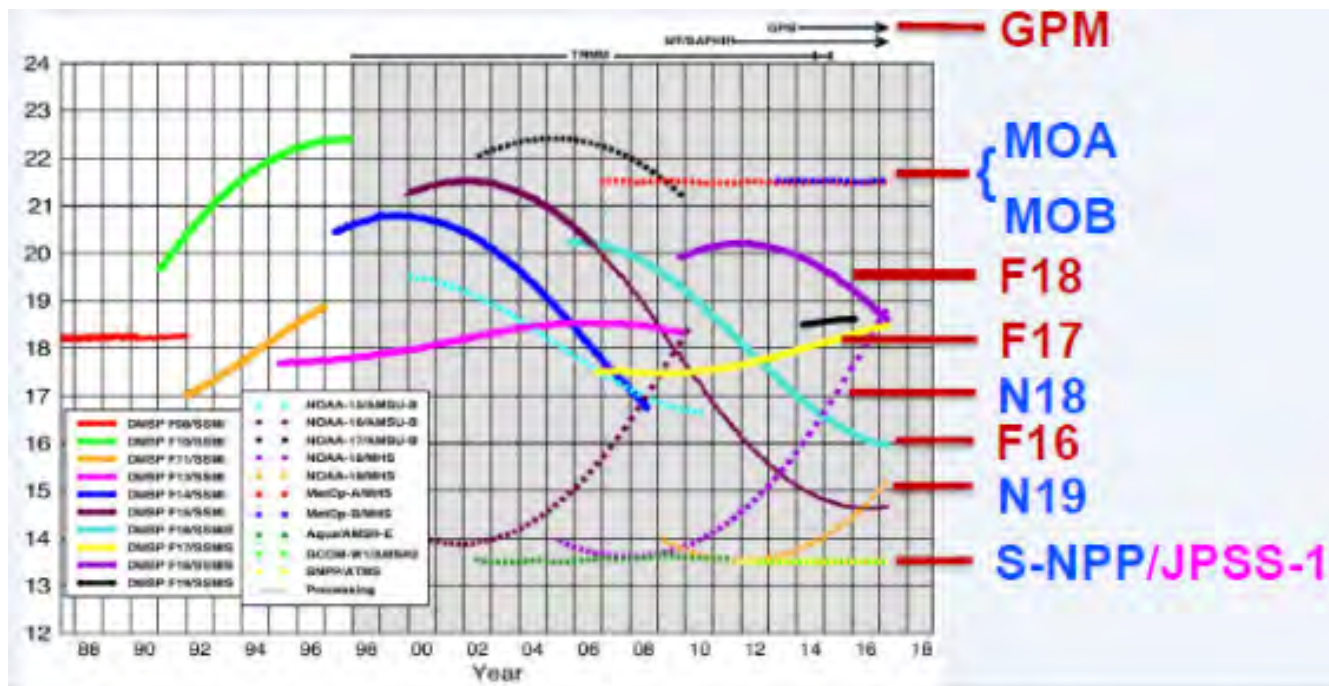


Top image shows 24-hour SFR and NOHRSC snowfall accumulation ending March 15, 2017 12:00 UTC.

According to a March 2017 summary report<sup>1</sup> from the Weather Prediction Center (WPC), some places received 31.3 inches of snow between 03:00 UTC on the 14th to 01:00 UTC on the 15th.

In the images above, the 24-hour snowfall accumulation ending March 15, 2017 at 12:00 UTC, is shown for SFR (top) and the snow analyses from NWS National Operational Hydrologic Remote Sensing Center (NOHRSC). The two images show similar snow distribution patterns. Furthermore, the figure below compares the ATMS/MHS SFR product and MRMS through scatter plots and histograms with favorable results.





## SFR EXPANSION

Snowfall is highly dynamic, and therefore it is difficult to rely on a few observations coupled with time gaps. As the current SFR is generated from five satellites, this leads to large time gaps between observations. Therefore, leveraging all available passive microwave sensors with high frequencies will significantly reduce the temporal gaps between satellite overpasses and improve the SFR temporal resolution. As stated earlier, the current algorithm was recently added to the SSMIS onboard the DMSP F16 and F17 (a critical channel has failed on F18 which causes larger SFR bias than for F16 and F17; more research is required for F18 SFR), and the GMI instrument onboard the NASA GPM satellite to the SFR product suite. This brings the total number of satellites used to retrieve SFR from five to nine. The figure above shows the existing satellites generating the SFR product (marked in blue) as well as the satellites (marked in red) planned for additional SFR retrievals.

The SSMIS and the GMI are conical scanners. SSMIS is an imager/sounder while GMI is a radiometer. On the other hand, ATMS and MHS are cross scanning sounders. And even though they belong to the same family of sensors, an SD model is developed for every individual satellite due to differences in the characteristics of the

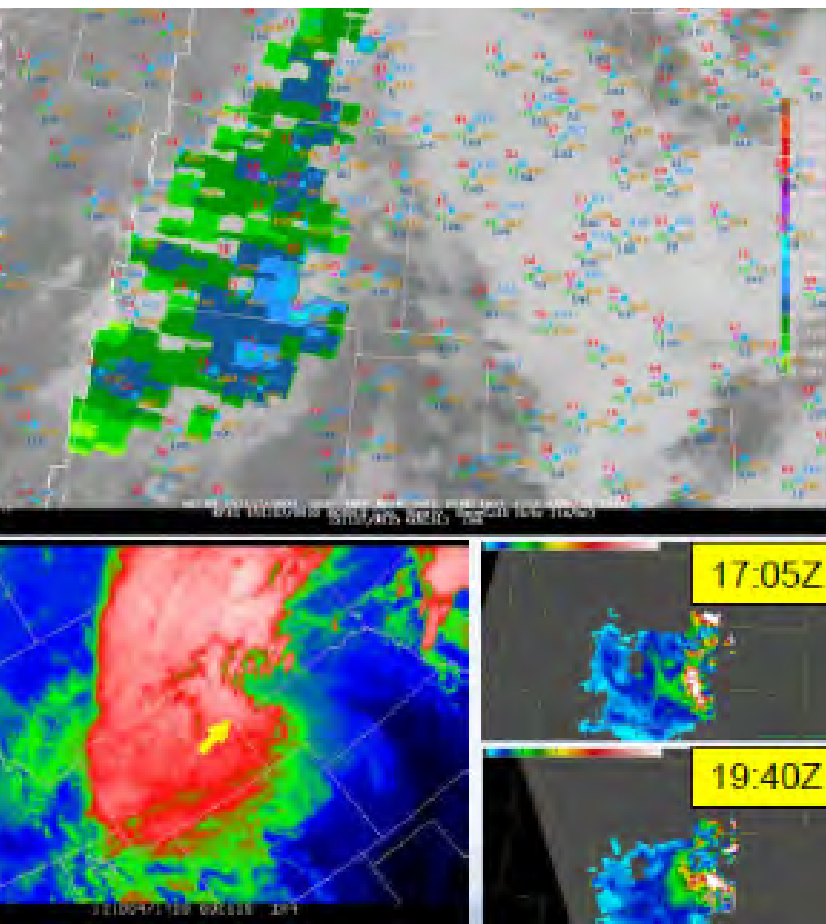
sensors and also because some channels end up failing. The SSMIS and GMI SD algorithms partially inherit the framework of the ATMS SD. The SSMIS SD consists of a blended model that optimally combines a satellite-based module and a NWP model-based module, and additional screenings from NWP model data that are applied to the SD output to reduce the occurrence of false alarms. Ground observations were used to train the two above-mentioned modules. The SSMIS SFR algorithm also adopts the 1DVAR approach. The RTM was modified for SSMIS including radiometric bias correction. The algorithm was calibrated against MRMS. The GMI SD and SFR follow similar framework as SSMIS. Due to the lack of a temperature sounding channel, model derived 2-meter temperature is utilized to divide data into warm and cold regimes for SD determination.

There are key differences as well. Much like the ATMS, SD algorithm employs a statistical logistic regression model, whereas the SSMIS also employs a logistic regression model, but without any principle component analysis as it has fewer water vapor sounding channels. In addition, the SSMIS SD uses 52.8 and 53.6 GHz, which has significantly improved the F16 and F17 model performance. Lastly, the SSMIS SD only uses one temperature regime.

# MERGED GEO/POLAR ORBITING SFR: THE FUTURE OF SATELLITE PRODUCTS

## GEO and LEO

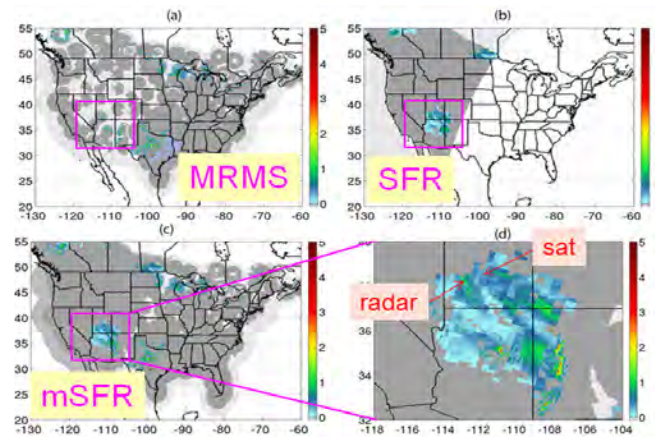
Fusing microwave data from polar orbiting satellites with infrared (IR) data from geostationary satellites takes advantage of the MW product's accuracy and the temporal resolution of IR data. This will allow users to track the movement of a snowstorm between LEO overpasses using GEO data, and also help them to identify trends in snowfall intensity. Below is an image of the SFR product laid over GOES IR data. Underneath it are images of the SFR generated roughly two hours apart at 17:05Z (upper right) and 19:04Z (lower right). The white streaks indicate the maximum snowfall. And, on the left is a GOES IR image in which the yellow arrow shows the snow maximum, which corresponds with the MW data.



Top: SFR overlaid on GOES IR with METAR reports (Courtesy of Bill Line); Bottom: GOES IR (left) (Courtesy of Michael Folmer); the corresponding SFR (upper right) and SFR 2:35 minutes later (lower right).

## Radar and Satellite (mSFR)

Merging MRMS instantaneous snowfall product and SFR (i.e. mSFR) provides better spatial and temporal (10-min) coverage and ability to loop the data. The SFR product is added where MRMS indicates radar data are of low quality or out of range (most useful in western U.S.). In the blended product, MRMS data are time lagged by 30 minutes to ensure product is viewing the same features. One image is generated every 10 minutes to provide looping capability. Over the continental U.S., the product helps fill in spatial gaps due to the use of the SFR product and the temporal gaps due to the MRMS radar data.



The boxed area in the MRMS image shows the gaps induced by limited radar coverage.

The SFR product's usefulness extends beyond weather forecast applications such as filling observational gaps in conventional snowfall observations. The product can also be used in hydrological applications, especially as most blended satellite precipitation datasets do not include satellite snowfall rate product. Instead they use data sources such as model and ground observations. The Climate Prediction Center MORPHing technique (CMORPH), for example, is a NOAA global blended precipitation analysis product with wide-ranging applications. The first generation algorithm only has rain rate. As a result, the SFR product has been integrated into the second generation CMORPH helping to make it a pole-to-pole product.

Beyond product development there are activities dedicated to user interaction and support. These include the production of SFR and mSFR in near real-time at the Cooperative Institute for Climate and Satellites—Maryland (CICS-MD) using DB data from University of Wisconsin Madison. As stated earlier, this has resulted in SFR production within 30 minutes of observation from polar orbiting satellites. Also, SFR and mSFR data are provided to the NASA Short-term Prediction Research and Transition (SPoRT) Center, where the products are converted to AREA file-based imagery for ingestion and display into the NWS Advanced Weather Interactive Processing System (AWIPS) and National Center for Environmental Prediction AWIPS (NAWIPS) and disseminated to the Weather Prediction Center (WPC) and some NWS Weather Forecast Offices (WFOs). NASA SPoRT is funded by NASA’s Earth Science Division and the JPSS and Geostationary Operational Environmental Satellites (GOES)

Proving Ground and Risk Reduction (PGRR) Programs to facilitate the transition of research to operations.

Additional displays of the SFR product are available on the CICS-MD website in near real-time to support those user communities that rely on DB. The global user community, available on NOAA STAR’s website, benefits hydrological applications such as blended global precipitation analysis.

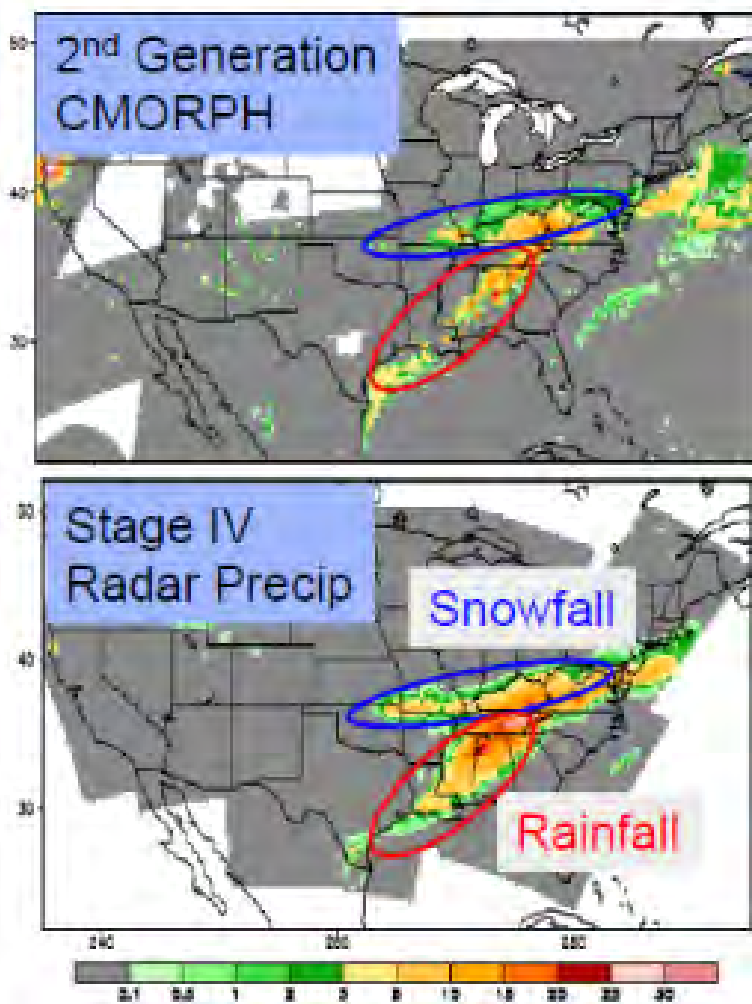
## APPLICATION AND ASSESSMENT OF NESDIS SNOWFALL RATE

When adding a new product to a user’s operational environment or replacing an existing product, concerns about whether or not the application provides the needed functionality must be taken into consideration. As a result, the SFR development team works with NASA SPoRT, a partner through the JPSS PGRR

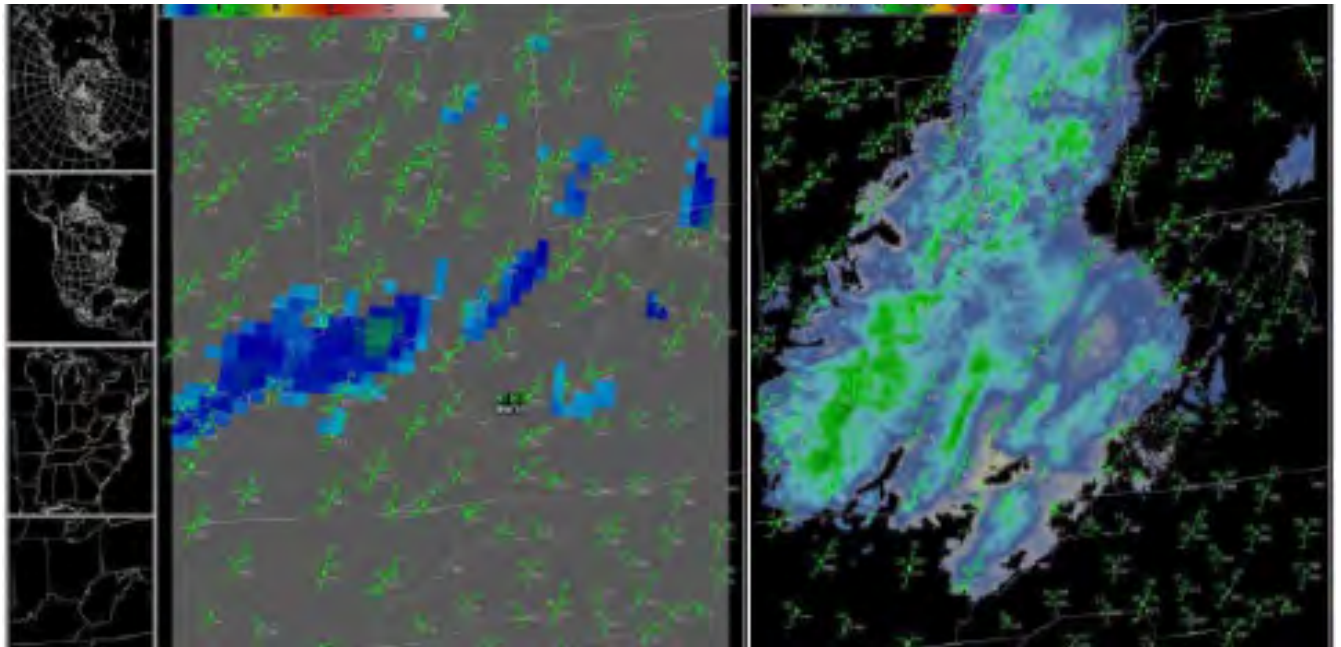
that matches specific products and derived technologies from NOAA and NASA satellite observations to user-identified forecast challenges. From a partnership that began in 2013, NASA SPoRT has helped transition the NESDIS SFR product to NWS forecasters and conduct product assessments to gain feedback on the utility of the product in operations. Through these assessments, which include user engagement and training, the teams have worked to test the proficiency or competency of the product and help answer all the questions related to implementing a new or enhanced product in the user environment.

## WINTER 2014 ASSESSMENT

In the winter of 2014, SPoRT began an assessment in January and continued through to mid-April. This assessment sought to determine the utility of the SFR product for tracking snow features in areas that consistently had gaps in data due to limited radar coverage or beam blockage/overshooting. It also sought to







SFR product (left) and radar reflectivity (right) from Charleston, WV for 11:00 UTC on January 25, 2014.

determine the edge and maxima of the snowfall in large precipitation systems. Participating offices included NWS WFOs in Albuquerque, NM (ABQ); Burlington, VT (BTV); Charleston, WV (RLX); and Sterling, VA (LWX) NWS WFOs; and the NOAA/NESDIS Satellite Analysis Branch (SAB).

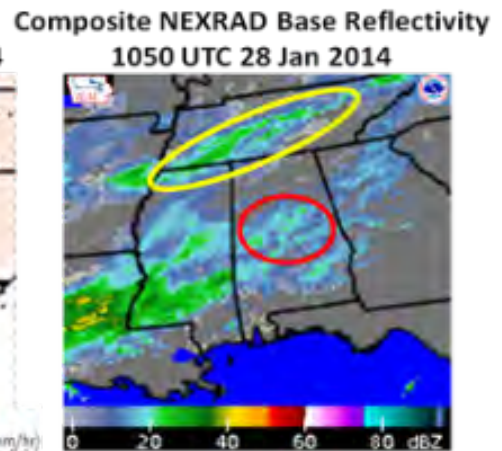
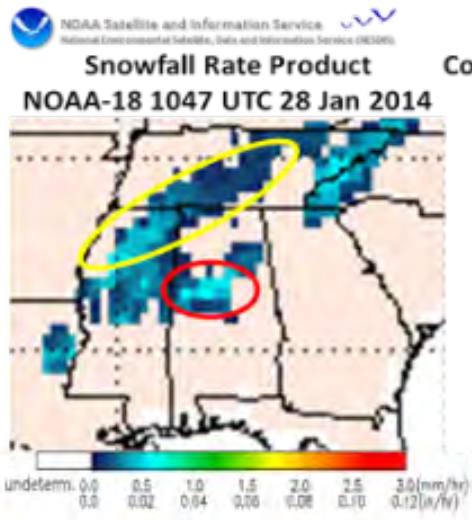
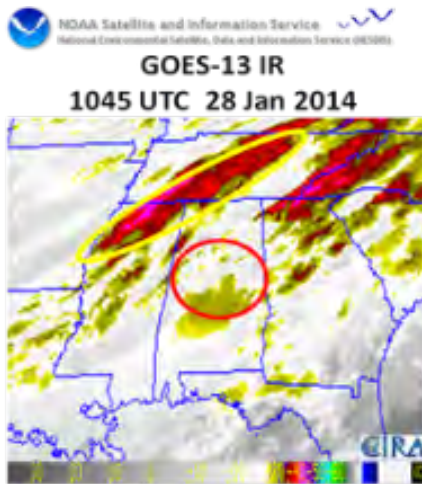
Earlier iterations of the SFR were based on AMSU/MHS from NOAA-18, -19, Metop-A, -B. Up to 8 SFR retrievals were available per day at mid-latitudes. These were land only retrievals, and they were restricted to regions with surface temperature greater than 22°F, which, to some extent limited the product's usefulness, as was the case in Burlington, VT. As noted earlier, the AMSU/MHS data were not available from GINA, so their latencies ranged anywhere from 30 minutes to three hours. The data was made available to NASA/SPoRT for reformatting and integration into AWIPS/NAWIPS, making it easier for the NWS to access in operations.

During the 2014 assessment, forecasters discovered that the advantage of the satellite-derived snowfall product was an observed 30- to 90-minute time lag between retrieved snow and snow reaching the ground. Forecasters were able to use the SFR as a short-term forecast product to identify in-cloud snow

conductive for cloud seeding and anticipate the increased likelihood of snow reaching the surface. This 2014 assessment uncovered some limitations including missed snowfall that was captured by radar, and the inability of the SFR to detect lighter snowfall amounts. Using the images above, a forecaster from the Charleston, WV, WFO noted *“it looks like the SFR product did not detect all of the snow that was falling around 11 UTC. But the misses can either be described as either (1) the surface temperature being too cold or (2) the probabilistic model that is part of the calculations, indicating probabilities were too low to determine if there was snow.”*

Under the right conditions, SFR can be used as a short-term forecast product, and also to increase forecaster confidence as well as for situational awareness of snowfall development aloft as in-cloud snow not reaching the surface can seed existing clouds to increase the likelihood of snow reaching the surface. The SFR Product offered such an example during a snowfall event on January 24, 2014 over the Birmingham area in Alabama.

The SFR showed snow in-cloud at 10:47 UTC (next page, center), however no snow was observed at the surface in Birmingham. Though



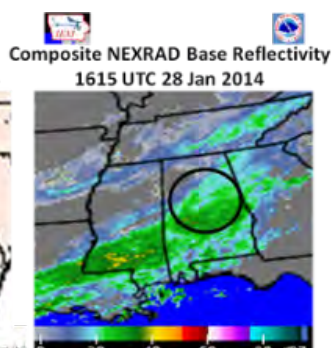
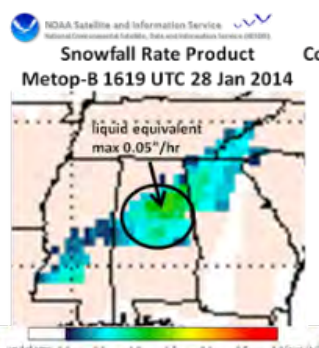
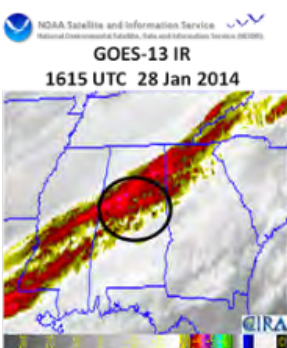
10:47 UTC, no snow at BHM (red oval).

GOES imagery is more timely and frequent, it is at times harder to spot the areas with or without snow, or its intensity. This is because the GOES infrared sensor cannot penetrate the clouds like with the microwave. As shown above, both GOES-IR (upper left) and radar (upper right) gave limited indications of the magnitude of in-cloud seeding that was occurring. Thus, 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. Sheldon Kusselson, now retired from the NESDIS Satellite Analysis Branch (SAB) provided more insight on this event<sup>2</sup>. According to Kusselson, the SFR product's detection of snow in the clouds provided an inkling of "seeding existing clouds (a precursor) and with increased moisture more easily support snow eventually reaching the ground later in the morning." Based on his analysis, if forecasters were able to recognize this potential, it is possible that the product could be used in a way that would provide additional guidance or lead

time on a snow forecast. By 16:19 UTC, the SFR product (below, center), GOES IR (below, left), and composite NEXRAD (below, right) imagery/data all reported snow, approximately five hours after the 10:47 UTC SFR had detected snow in the clouds.

A majority of the respondents indicated that they found it quite useful for verification of ground reports of snow, particularly in regions with limited radar coverage. However, many respondents also indicated that the product was not timely enough for nowcasting applications at the current latencies. Nonetheless, overall feedback was positive with more than 75 percent of responses indicating the product was useful to improve data coverage in areas with radar gaps and in combination with satellite observations to track snowfall maxima.

Some recommendations coming out of the 2014 assessment included reducing the product's latency to less than 60 minutes; improving the low snowfall rate detection efficiency; and



16:19 UTC, snowing at BHM (black circle).

investigating the ability to retrieve snowfall rates in colder air masses. This would enable its use in regions like Alaska, which struggle with extremely limited radar coverage, but have the advantage of frequent overpasses from polar-orbiting satellites.

## WINTER 2016 ASSESSMENT

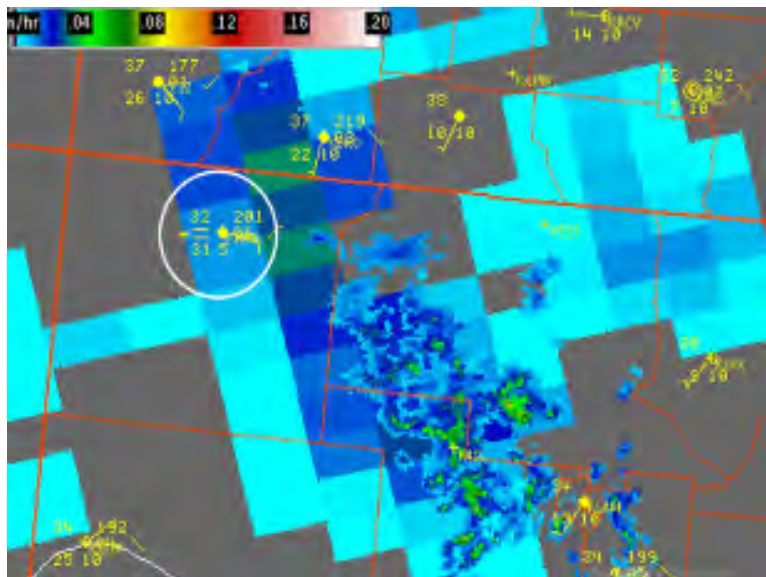
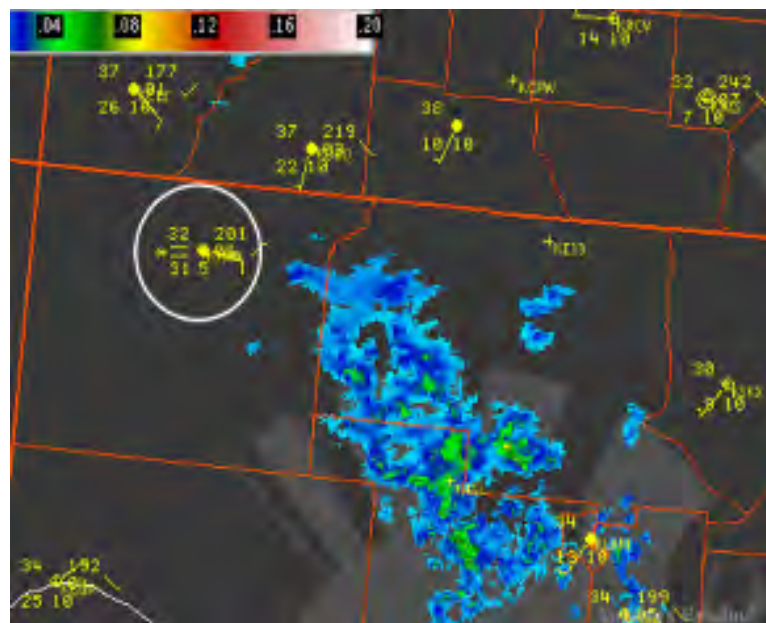
The next iteration of the SFR made its debut in 2016 at the winter assessment. The goals of this assessment were similar to those in 2014, but included an additional goal to determine areas where cloud seeding may be occurring ahead of falling precipitation. The participating WFOs remained partly the same as in 2014 with the inclusion of Anchorage, AK (AFC); Juneau, AK (AJK); and Boulder, CO (BOU).

This iteration of the SFR utilized measurements from the ATMS instrument. In addition the algorithm included a cold extension that lowered the minimum 2-meter temperature for SFR from 22°F to 7°F. This drastically increased the probability of detection of snowfall in colder environments and extended its use to regions such as Alaska. Also groundbreaking for this SFR was its availability through DB, which reduced its latency to less than 30 minutes. A noteworthy upgrade given the recommendation to reduce the latency to less than 60 minutes in 2014. Further in the future, the SFR will include ATMS sensor data from NOAA-20.

This iteration also included three distinct liquid equivalent values or snowfall-to-liquid ratios of 10:1, 18:1, and 35:1. These specific rates were chosen based on feedback from WFOs, which highlights the advantage of the research-to-operations/operations-to-research R2O/O2R activities. In addition, the SFR product was merged with the MRMS instantaneous precipitation data to generate a radar-satellite merged product, mSFR.

The first week of January 2016 was very active across the state of New Mexico as back-to-back winter storms crossed the area. By then, forecasters in this data-sparse region had already put the mSFR to test at NWS Albuquerque. For example, on January 4, 2016, a storm crossed over the region producing light to moderate snowfall rates for several hours. Brian Guyer, the forecaster on shift noted the observation at Farmington, NM (KFMN) indicated light snow with a visibility of 5 statute miles. In the figure on the right (top) SFR shows the extent of any precipitation echoes well to

the east of KFMN at 00:00 UTC January 5, 2016. The nearest radar (KABX, not shown) is located roughly 150 miles southeast of KFMN near Albuquerque, NM. The mSFR (bottom) from 00:10 UTC January 5, 2016 showed the extent of the precipitation was much greater. Sampled liquid equivalent values in the light green areas to the east of KFMN were near 0.03"/hour.

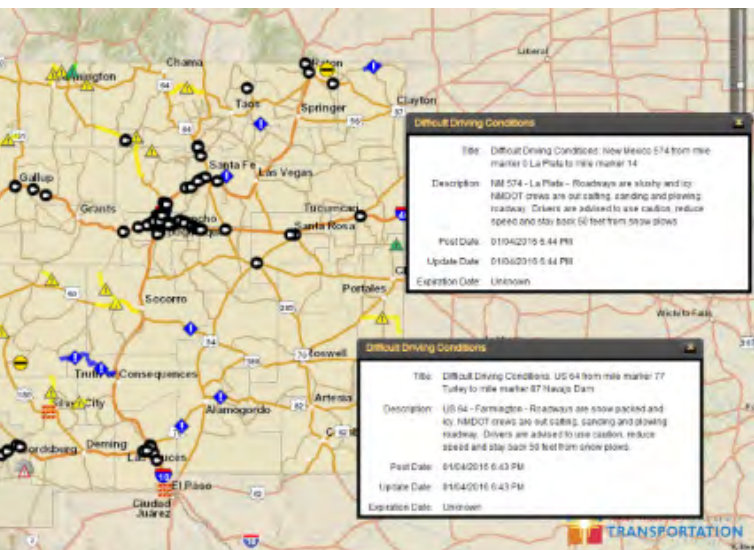


The webcam available at San Juan College just a short distance from the KFMN observation showed significant decreases in the visibility between 15:30 UTC and shortly after sunset. The picture on the next page shows the decrease in surface visibility as well as some accumulation on grassy surfaces. The merged SFR product did in fact show higher rates immediately to



Webcam at San Juan College shortly after sunset showing decreased visibility and light snow accumulations on grassy surfaces.

the east of KFMN. The image below shows the impact on travel conditions as noted on the NM Department of Transportation web page. The areal coverage of the difficult travel impacts (yellow highlights) was greater than that depicted by what can be seen based on poor radar coverage.



Screen capture of NM DOT web page showing areal coverage of difficult travel conditions (yellow highlights) and some text summaries detailing the impacts.

For more information on Guyer’s analysis of the event, please visit: [nasasport.wordpress.com/category/nesdis-snowfall-rate/](https://nasasport.wordpress.com/category/nesdis-snowfall-rate/)

Feedback from forecasters indicates that SFR and mSFR are useful for operational forecasts of winter weather events. More than 75 percent of respondents indicated low to medium confidence in SFR values. Not surprising though, the SFR was mainly used to identify snowfall

in data-deprived regions. But there were some cases where the product failed to meet their needs, for example when it underestimated snowfall amount, or when it missed the location of light/moderate snow that had been detected by other sources. In addition, for WFOs catering to communities in or near coastlines, such as Juneau in Alaska, the product’s unavailability over water or coastlines greatly limited its usefulness.

For the mSFR, while more than 85 percent of respondents indicated medium to high confidence in its values, 100 percent of responses indicated the product was useful. They were especially satisfied with the length of time it took to receive the product as well as the accuracy of its data. 75% of forecasters indicated the ability to loop the product with blended radar made the product more useful. Most responses indicated that the mSFR was used to identify snowfall in data-deprived regions and track the maxima. But, much like the SFR, when the mSFR underestimated snowfall amounts, missed the location of light/moderate/heavy snow detected by other sources they found it not as useful. The same survey also revealed that despite improvements in product latency compared to the 2014 assessment, some respondents indicated that the product was still too latent for nowcasting applications.

## SUMMARY

The SFR algorithm has benefited greatly from continuous development and improvement since it became operational at NESDIS in 2012. Traditionally, radar and satellite visible and IR imagery has been used to detect snowfall, but the SFR product allows for detection of snow in cases when radar coverage is limited. With the support of the JPSS PGRR, a blended algorithm was developed for the AMSU/MHS SFR, and the Suomi NPP ATMS helping improve snowfall detection for both shallow- and deep-cloud snowfall. The radiative transfer model has been modified to include cloud liquid water, and is further being modified for more robust initialization of cloud properties. The product

has been validated extensively against gauge observations and radar snowfall rate estimates and has produced satisfactory results.

Another milestone for the SFR product has been the utilization of measurements from the GMI sensor aboard NASA GPM and from SSMIS sensors aboard DMSP F16 and F17. The addition of these new sensors to the SFR suite has increased the number of satellites used to retrieve SFR from five to eight and will significantly improve the temporal resolution of the product and will greatly benefit its applications. The SFR product was also added to the NOAA CMORPH product—which lacks snowfall estimates—to include satellite-based winter precipitation estimates. In addition, the ATMS SFR has been added to JPSS Level 1 Requirements Document (L1RD), which identifies the top-level, user-driven requirements for NOAA’s polar environmental satellite observing capability (data products and functional and performance requirements) needed to achieve NOAA’s mission.

Efforts led by NASA SPoRT to assess the SFR at NWS WFOs culminated in a winter assessment in 2014 which focused on its use where radar observations are limited and led to product improvements to reduce latency and improvements to usability in colder temperature regimes. A second product assessment in 2016 indicated the updates to the product gave forecasters more confidence for identifying snowfall in radar-deprived regions. Throughout these assessments the product has evolved iteratively. Moreover, the algorithm developers will continue to improve product quality as well as develop the SFR for new microwave sensors. The next assessment is planned for the 2017–2018 winter season, for the full-suite of SFR products from eight satellites including the NASA GPM and two DMSP SSMI/S sensor satellites. These SPoRT-led assessments provide opportunity for product developers to interact with operational forecasters at NWS WFOs. They have become key venues to gain insight into the product’s strengths and limitations in operational applications. ❖

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## Footnotes

<sup>1</sup><https://www.weather.gov/bgm/pastWinterMarch142017>

<sup>2</sup><https://nasasport.wordpress.com/2014/02/24/birmingham-alabama-surprise-snow-of-january-28-2014-or-was-it/>

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# THE JOINT POLAR SATELLITE SYSTEM IN ALASKA. IT'S ALL ABOUT LOCATION, LOCATION, LOCATION

The information in this article is based, in part, on the December 18, 2017 JPSS science seminar presented by Eric Stevens and Carl Dierking, Geographic Information Network of Alaska (GINA), University of Alaska Fairbanks (UAF)



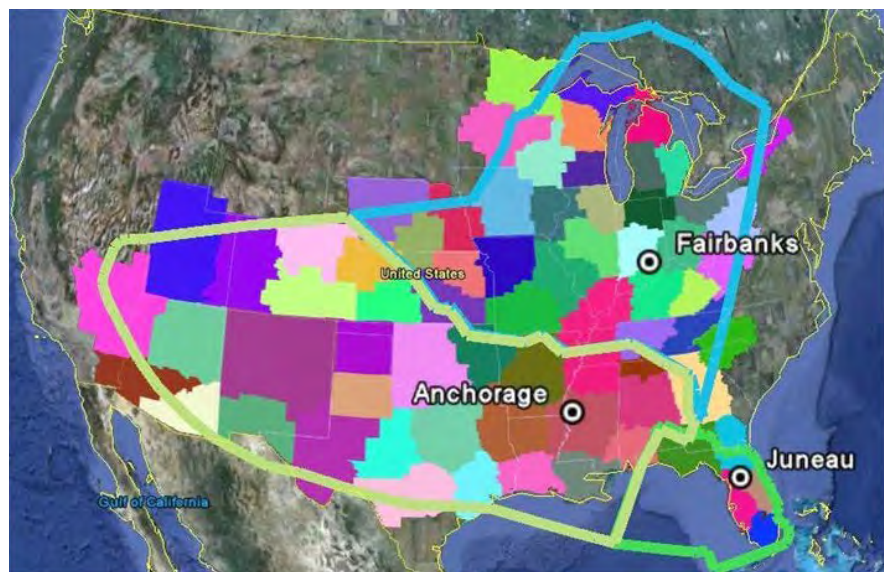
Airplanes sitting at Merrill Field: the first official airport in Anchorage, Alaska. [www.facebook.com/MerrillFieldAirport](http://www.facebook.com/MerrillFieldAirport).

Weather forecasting is a considerably complex and challenging skill that involves observing and processing vast amounts of data. For the Alaskan meteorologist, these challenges become even more complex in connection with surveilling weather in a comparatively large, remote, topographically complex landscape with prominent microclimates. On the right is a map of warning areas for National Weather Service offices in the continental United States (CONUS) with an overlaid outline of the Alaskan warning areas for NWS offices in Fairbanks, Anchorage and Juneau.

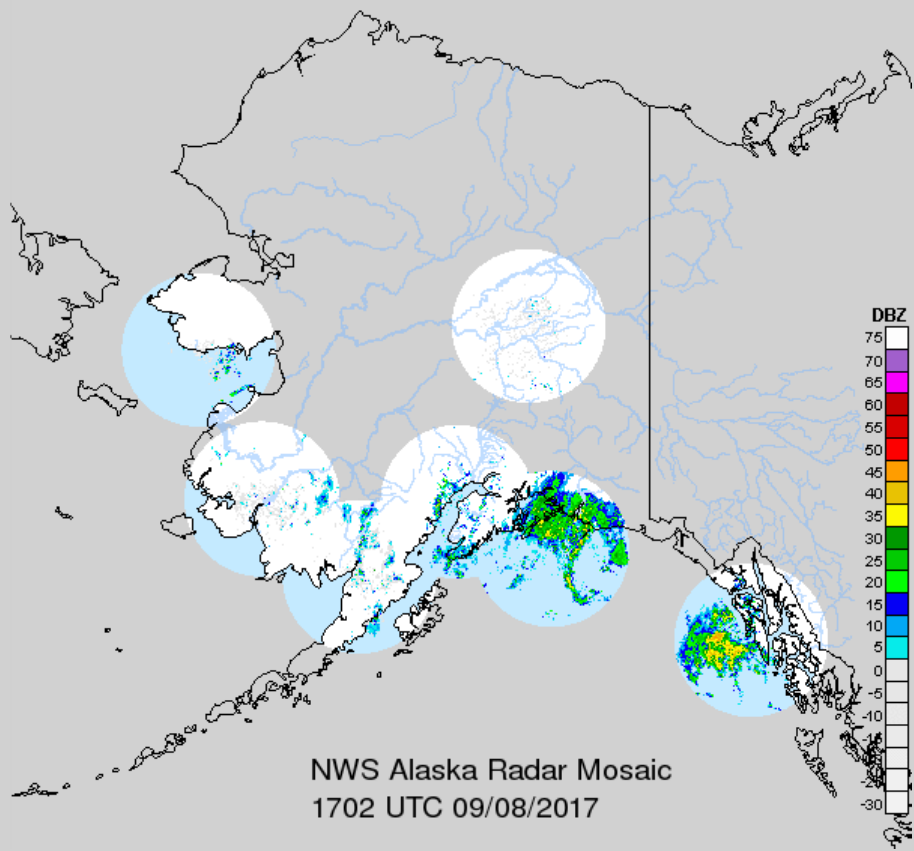
Good weather prediction depends on the availability of accurate and timely

observations as well as an accurate view of the current weather conditions. In the Contiguous U.S., weather forecasters rely on data supplied by a dense network of weather radars, numerous automated surface observation stations, and more than 100

upper air stations. Alaska, is faced with the challenge of trying to generate forecasts in a region with a few conventional observation resources. This is illustrated in the map on the next page which shows how the Alaskan radar network is limited in coverage and located







Imaging Radiometer Suite (VIIRS) instrument on the joint NOAA/NASA Suomi National Polar-orbiting Partnership (Suomi NPP) and NOAA-20 help forecasters pick out low clouds from fog, and snow from low clouds. These weather observations are critical, and more so in industries like aviation where weather elements like snow, ice, fog, and low clouds can exact a toll on flight operations. Some satellite bands are used to identify the extreme cold temperatures and even the extended periods of winter darkness are well served by the Day-Night Band, which is highly sensitive to faint light sources such as moonlight and the Aurora.

mainly along coastlines. This allows forecasters to help track land-falling coastal storms, but leaves much of interior Alaska without this critical data. To make matters worse, these limited observation platforms cannot accurately represent large areas as they might do in the CONUS, or “Lower 48” because the radar beam is often blocked by steep topography.

These challenges highlight the importance of observations from polar orbiting satellites in Alaska. With numerous satellites available, often overlapping each other in coverage of their passes, Alaska benefits from much more frequent coverage in time by polar orbiting satellites than any other state in the nation. Data from NOAA satellites

and those of its national and international partners are accessed through direct broadcast antennas and then are quickly sent to the Alaskan Weather Forecast Offices (WFOs) and other NOAA offices. Since polar satellites orbit much closer to the Earth’s surface than geostationary satellites, they are able to record more detailed changes in temperature and moisture in the atmosphere. This data, which helps describe the current atmospheric conditions, is fed into numerical weather prediction (NWP) models, which as their name implies, forecast the future state of the atmosphere. The accuracy of forecasts produced by NWP models relies on the observations (Collard et. al, 2011). The high-resolution imagery of the Visible Infrared

## THE ROLE OF THE GINA AND THE HIGH LATITUDE PROVING GROUND



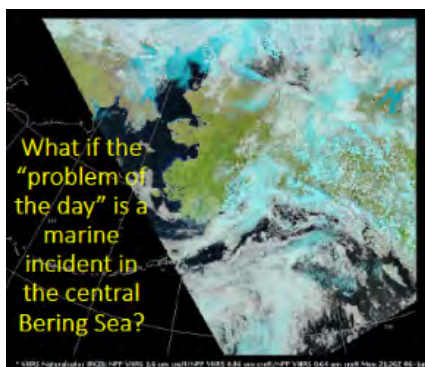
The Geographic Information Network of Alaska (GINA) at the University of Alaska Fairbanks (UAF) operates two Direct Broadcast (DB) antennas to track and receive data from a number of polar orbiting satellites. The data are then processed by GINA and delivered through a Local Data Manager (LDM) pathway into Alaska’s NWS Advanced

Weather Interactive Processing System (AWIPS) which is a computer workstation used by NWS forecasters. The data are also available in other formats for use in environments outside of AWIPS. The advantage of this approach is a reduction in latency. That is, the latest imagery on AWIPS is placed in front of a forecaster, eyeballs within approximately 15 minutes of a satellite's passage over Alaska, with the motivation that even the highest quality satellite imagery is of little use to forecasters if it arrives too late to be included in the decision making process.

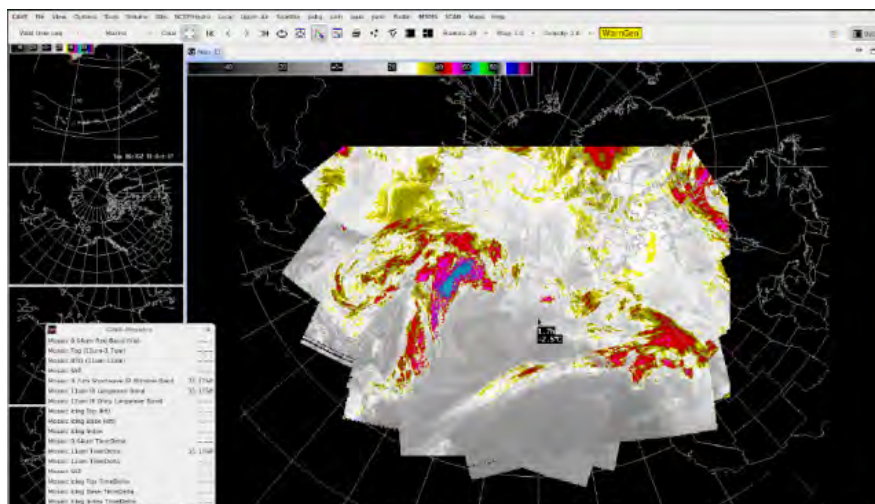
## HIGHLIGHTS FROM 2017

The High Latitude Satellite Proving Ground has served Alaska for a number of years, with each year bringing upgrades and improvements. Building on this success, several new products and enhancements to existing products were implemented in 2017.

### Mosaics



The superior spatial resolution of imagery from polar orbiting satellites provides much



clearer views of many surface features. However, one of the weaknesses of these satellites is the limited swath extent of each pass. For a forecaster, it can be quite frustrating when the feature needing observation is on the wrong side of the edge of the swath. The image above illustrates how a product enhancement focused on the generation of mosaic imagery helped mitigate this challenge. With mosaic imagery, successive passes of a given wavelength are stitched together with the most recent image always on top. This provides a larger scale region-wide composite of all recent satellite passes with the ability to zoom in and still see a highly detailed view of a local feature.

### New VIIRS DB Multispectral Imagery for Alaska Fire Service

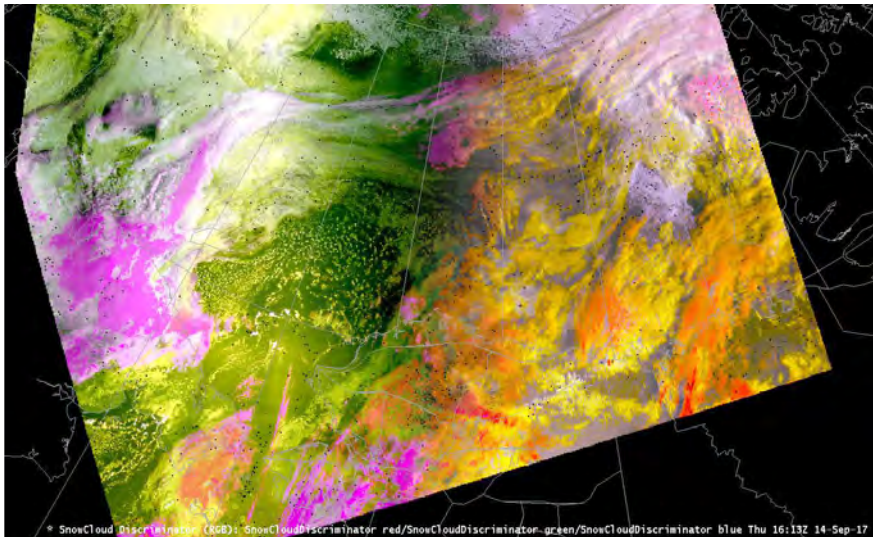
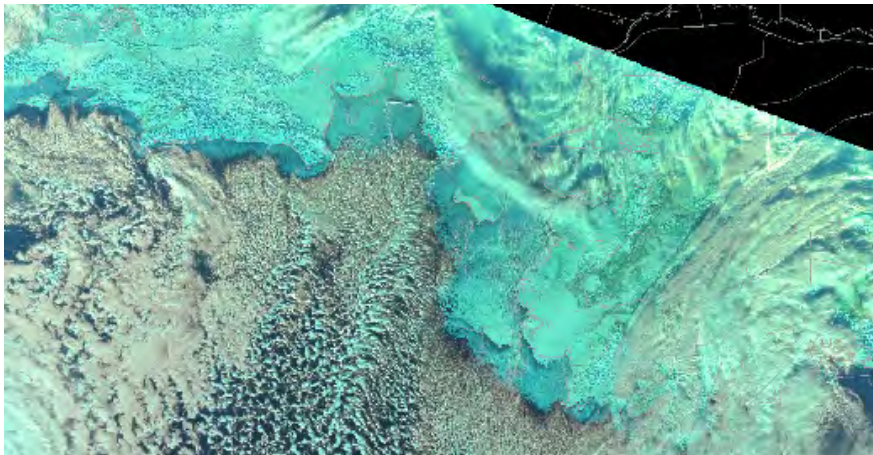
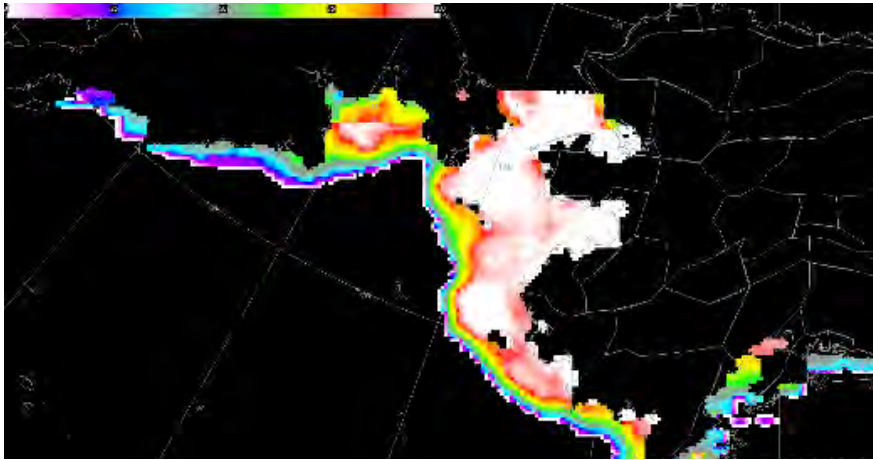
There are data packages for non-AWIPS distribution as well. Among these is imagery in Geo-TIFF format for use in a GIS environment outside of AWIPS. Two new multispectral RGBs developed specifically for use in the fire weather

context were enthusiastically embraced during the summer wildfire season.

### NWS Alaska Sea Ice Program (ASIP) Springtime Assessment of new microwave products

A number of microwave-based products have also been introduced. A formal assessment of new microwave imagery used by the NWS Alaska Sea Ice Program (ASIP) was conducted during the spring of 2017, which led to the introduction of additional microwave-based products.

The advantage of using microwave imagery to observe sea ice is that it can detect sea ice motion at night even when obscured by clouds. This is illustrated in the top image on the next page, which is the MiRS Sea Ice Concentration product from the Advanced Technology Microwave Sounder (ATMS) with a resolution of 15–20 km. It depicts the concentration of sea ice in percent, however the utility of microwave products can be limited by its coarse spatial



resolution. Visible imagery, on the other hand, has a resolution of 375 meters and by combining different channels, a color image can be created that is ideal for distinguishing sea ice (cyan) from low cloud (white) in high-resolution as

shown in the middle image above. Visible imagery has limitations as well, since it's only useful during the day and when ice is not obscured by clouds. So this is one example of how multiple products can be complementary.

## PLANS FOR 2018

Plans are also in the works to continue expanding the relationship between GINA and NWS Alaska in 2018. Among the products planned under this partnership include a snow/cloud discriminator in which colors represent different cloud layers and surface ice/snow. This product makes use of multiple bands and even incorporates the nighttime use of the VIIRS Day Night Band (DNB).

For years, the spatial resolution of imagery products has been degraded due to considerations of bandwidth and storage. However now, with the implementation of a “tiling” approach, GINA will soon deliver full-resolution imagery to NWS Alaska for display in AWIPS. And lastly, a handful of cloud products are planned for production in 2018.

## SUMMARY

For the NWS meteorologist in Alaska, complex topography and a prominence of microclimates present many challenges for weather forecast operations. Surface observations can be of limited use, which compounds the challenge of having to address diverse forecast areas where multiple weather patterns and events occur simultaneously. The availability of DB imagery and other data products from polar orbiting satellites, including Suomi NPP and soon NOAA-20, has been vital to forecasting operations in

Alaska, and has helped ensure that forecasters are better equipped for the analysis and understanding of current weather conditions.

The accuracy and reliability of weather forecast operations in Alaska has come to depend on the availability of, and rapid access to, satellite observations. The JPSS Program, through GINA, is able to provide data

from several polar orbiting satellites, including Suomi NPP and soon NOAA-20, to Alaska's WFOs with minimized latency for analysis and situational awareness of current weather conditions.

Several new products and enhancements to existing products were implemented in 2017. These include mosaic, multispectral RGBs for

Alaska Fire Service, as well as additional microwave-based products. These products are moving forward quickly and more new innovative products are in the pipeline. For Alaska, its high latitude will always make it the natural proving ground for the JPSS program and other polar orbiting satellite systems of the future. ❖

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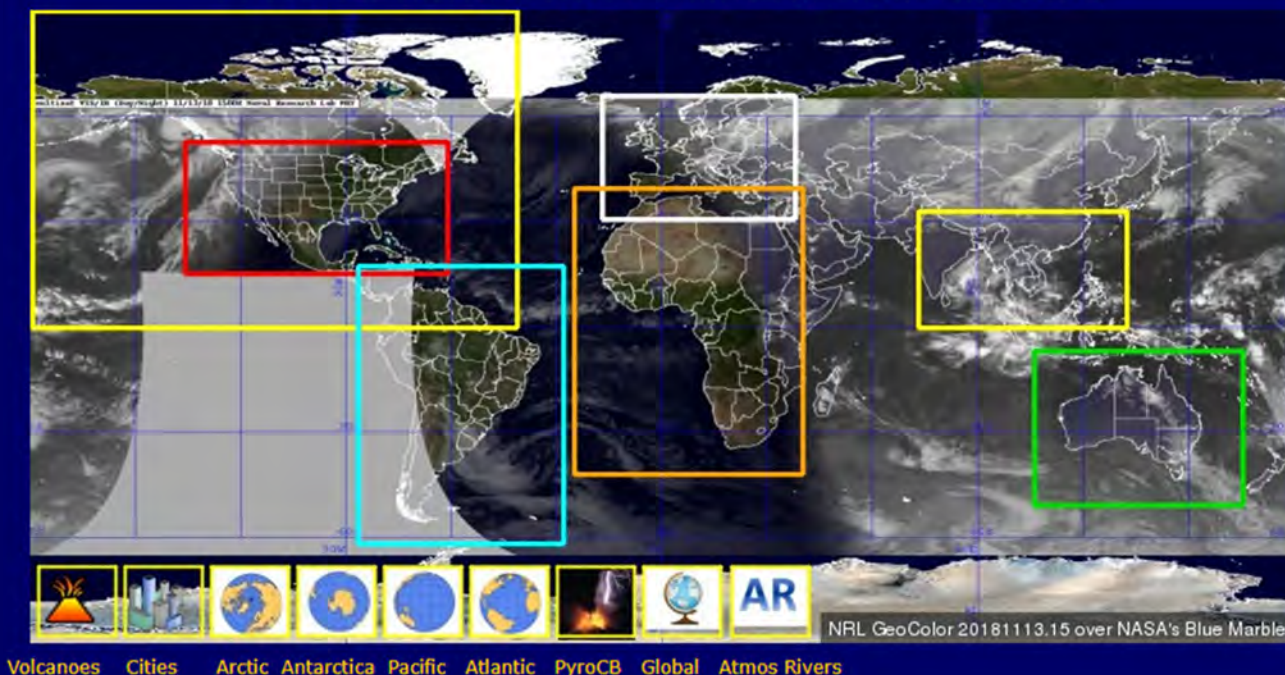


# EXPLOITING NEXT GENERATION SATELLITE DATA WITH NEXSAT

NRL/JPSS Next-Generation Weather  
Satellite Demonstration Project

The information in this article is based, in part, on the January 22, 2018 JPSS science seminar presented by Kim A. Richardson, Naval Research Lab (NRL), Marine Meteorology Division (MMD), Monterey CA. It contains work by Arunas Kuciauskas, Jeremy Solbrig, Tom Lee, Jeff Hawkins, Mindy Surratt, Kim Richardson, Richard Bankert, Steven Miller, Cooperative Institute for Research in the Atmosphere (CIRA), and John Kent, Science Applications International Corporation (SAIC)

Select NEXSAT area of interest in the image map or icons below.



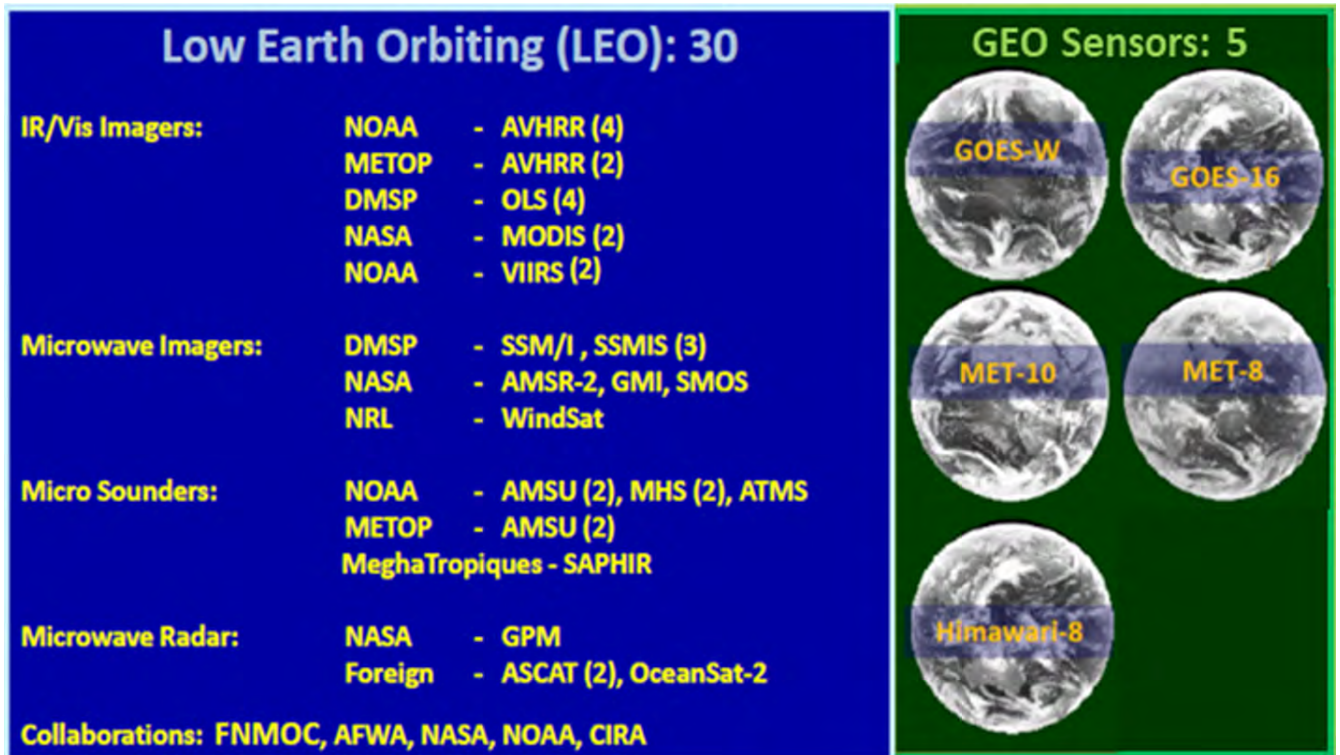
Home page of NexSat, a public-access website that provides global satellite imagery. Colored boxes define the domains where image products are available. The icons along the lower left contain customized product sets for ocean basins and select applications (Volcanoes, Cities, PyroCB, etc.).

The Naval Research Laboratory's Marine Meteorology Division (NRL-MMD) in Monterey, CA, provides advanced scientific and technological capabilities needed to enhance global naval power and protect national security. Activities contributing to this history span the science spectrum from monitoring and evaluating atmospheric conditions and measuring parameters in the world's oceans to initiating new developments and applying them to support various requirements in the Department of Defense (DoD).

NRL-MMD demonstrates satellite-derived products that can be utilized in near real time (NRT) by weather forecast operations both nationally and globally. The products serve customers that includes the Navy, other DoD agencies, as well as civilian user communities. NRL-MMD partners with its next door neighbor at the Fleet Numerical Meteorology and Oceanography Center (FNMOOC), providing both R&D and operational resources to military assets around the world.

Since 1995, NRL-MRY has been producing datasets and imagery from a constellation of low earth orbiting (LEO) and geostationary (GEO) satellites. These data products are demonstrated through NRT products on the public-accessible website NexSat ([www.nrlmry.navy.mil/NEXSAT](http://www.nrlmry.navy.mil/NEXSAT)) (see figure above), and the NRL-MMD Tropical Cyclone Page ([www.nrlmry.navy.mil/TC](http://www.nrlmry.navy.mil/TC)). These web sites are accessed on a daily basis by the operational user community and the general public. The focus of this article is NexSat. Specifically, examples will be provided to illustrate the scope and breadth of applications supported by the data and imagery harnessed from this online resource.

NexSat is supported in part by the STAR Joint Polar Satellite System (JPSS) Program and was initially designed in 2004 to demonstrate the capabilities that would be available from the then-anticipated Visible and Infrared Imaging Radiometer Suite (VIIRS) sensor. These capabilities would later be realized with the subsequent launch of the NOAA/NASA Suomi



Satellite sensors contained within NexSat.

National Polar orbiting Partnership (Suomi NPP) satellite in 2011 and the NOAA-20 satellite in 2017 (JPSS-1 prior to launch). Between 2004 and 2011, developers of NexSat products demonstrated VIIRS capabilities from a rich dataset of heritage sensors, which include the U.S. Air Force (USAF) Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS), the NASA Moderate Resolution Imaging Spectroradiometer (MODIS) and Sea-Viewing Wide Field-of-View Sensor (SeaWiFS), and the NOAA Advanced Very High Resolution Radiometer (AVHRR) to help communicate its capabilities in NRT and in a visually intuitive way. NexSat allows the global research and operational user community to monitor the environment such as cloud properties, tropical cyclones, and airborne dust plumes.

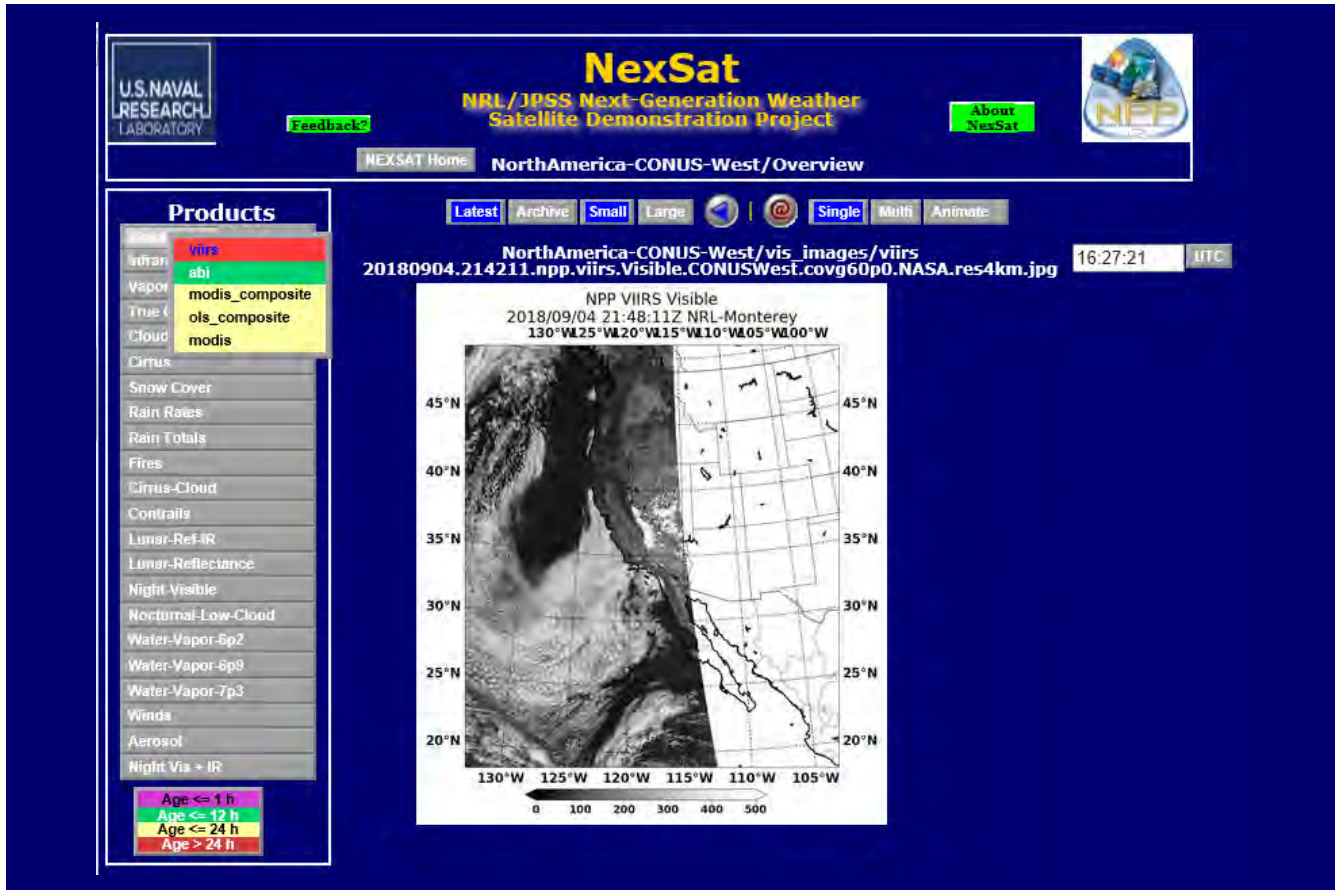
Now, more than two decades since its inception, NRL-MMD has developed products derived from 30+ LEO satellite sensors and six GEO satellite sensors. Visitors to the NexSat website stand to benefit from this wealth of resources.

With a new stream of satellites and sensors being brought online, NRL-MRY's satellite applications

team ingests and produces value-added NRT satellite sensor products for distribution on several websites, including NexSat.

## NAVIGATING THE NEXSAT BROWSER

The screen capture on the following page shows the basic layout of NexSat from the user perspective. Each one of the boxes in the first figure covers a geographic coverage area of the globe, and is an active link to a web page. Products can be shown by geographic areas and can be grouped by the satellite sensors, which are the source of the data products. Selecting a box opens another website that houses the pull-down menu for products, as shown below. The corresponding satellite imagery for the selected product is displayed to the right of the menu. In addition, product displays enable the selection of options such as zooming in on what is happening in their area of interest. The website functionality also allows for comparisons amongst sensors, product fusion or standalone sensor demonstrations. For example, VIIRS provides a robust suite of new



Screen shot of the product display showing visible imagery from VIIRS over the eastern Pacific and western U.S.

capabilities including higher spatial resolution, multiple spectral channels, and a broader swath over legacy sensors. Thus at swath edge, it may be compared against MODIS, AVHRR, and/or the OLS to demonstrate the spatial resolution improvements.

## NEXSAT PRODUCTS: HELPING INFORM AND EDUCATE

The table to the right provides a listing of NexSat products comprised of organic (developed at NRL-MMD) and leveraged products that METOC and civilian users have found to be valuable. The U.S. military forecasters apply these products in their decision making matrix to guide force deployment and operations<sup>1</sup>. Various NWS Weather Forecasting Offices have also implemented NexSat products within their forecast discussions. NexSat has assisted operational users to detect, assess, and predict weather events within their individual forecast areas of responsibility (AOR). Examples include cloud products to help discern cloud layers (low,

Standard products		Cloud products	
Visible (daytime)		Cloud layers (snow, low-middle, high)	
Visible (nighttime)		Cirrus cloud detection	
Infrared		Contrail detection	
Water vapor		Nocturnal low-cloud detection	
True color		Convective cloud top height	
Pseudogeostationary true color		Cloud properties	
Rain rates		• Effective radius ( $\mu\text{m}$ )	
Lidar	• Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO)/Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP)	• Optical depth	
	• MPLNET	• Cloud top temperature ( $^{\circ}\text{C}$ )	
		• Cloud top height (m)	
		• Cloud type	
Rain totals		<b>Environmental products</b>	
• 3, 6, 12, 24 h		Aerosol amounts (optical depth)	
• 2-7, 10, 12, 14 days		Biomass (vegetation type)	
Winds	• Scatterometer (surface)	Dust detection	
	• Geostationary	Total precipitable water	
	• low level	Fire detection (hot spots)	
	• midlevel		
• upper level			
<b>Model products</b>			
<b>Navy global (NAVGEN)</b>		<b>Navy dust (NAAPS)</b>	
Sea level pressure (hPa)		Total aerosol optical depth (AOD)	
500-hPa heights		Coarse AOD	
Surface, 700, 500, 300 hPa winds		Fine AOD	
1000-500-hPa thickness		Dust concentration ( $\mu\text{g m}^{-3}$ )	
Surface temperature ( $^{\circ}\text{C}$ )			
Jet stream			



middle, high) as well as over snow, low cloud detection at night, and environmental products such as aerosol optical depth, vegetation types, dust detection and fire detection.

## EXAMPLES OF NRL SUPPORT TO JPSS

With the launch of Suomi NPP, NRL-MMD began to actively download VIIRS level 1B data sets. Through partnerships with the University of Wisconsin's Cooperative Institute for Meteorological Satellite Studies (UW-CIMSS), NRL-MMD ingests VIIRS SDR downloads via the Science Investigation Processing Systems (SIPS). NRL-MMD is sponsored by STAR JPSS to take part in the calibration/validation (CAL/VAL) efforts for evaluating JPSS VIIRS Products. As part of the objectives, NRL-MMD routinely compares VIIRS satellite imagery products against a host of other satellite sensors over various regions of the Earth. Calibration ensures consistency and reduces the uncertainties associated with data from different instruments. A few examples follow to reflect the wide breadth of applications covered by NexSat products.

### DAY-NIGHT BAND (DNB) COMPOSITE WITH IR

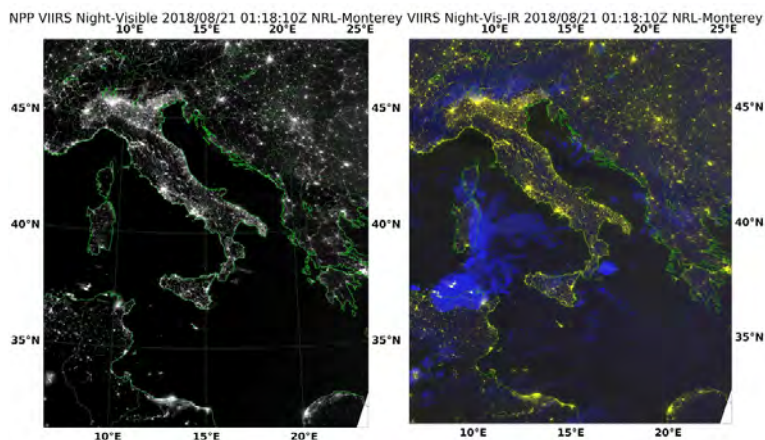
The Day Night Band (DNB) of the VIIRS instrument has proven its value to provide low light or visible-like images at night. The DNB has been equally valuable for forecasting in

the arctic regions during the winter months' extended hours of darkness. But VIIRS wasn't the first sensor to produce the DNB. The Operational Linescan System (OLS) on the Defense Meteorological Satellite Program (DMSP) was the heritage sensor for the DNB. Prior to the Suomi NPP launch in 2011, NRL-MRY conducted algorithm development with the OLS to assist the JPSS Program in bringing the VIIRS DNB into operations. The example on the left illustrates how during night time conditions, more insight can be gleaned from a combination of DNB and Infrared channels compared to DNB only. The left-hand panel shows the low light DNB original imagery from the low-light visible channel at night, in which light sources appear fuzzy. The right panel is a blended image from the low-light visible channel at night and the IR channel, in which cloud masses, and particularly low clouds are easier to discern. From this image one can infer that the low clouds are obscuring the city lights and therefore the most likely cause of fuzziness appearing in the left panel.

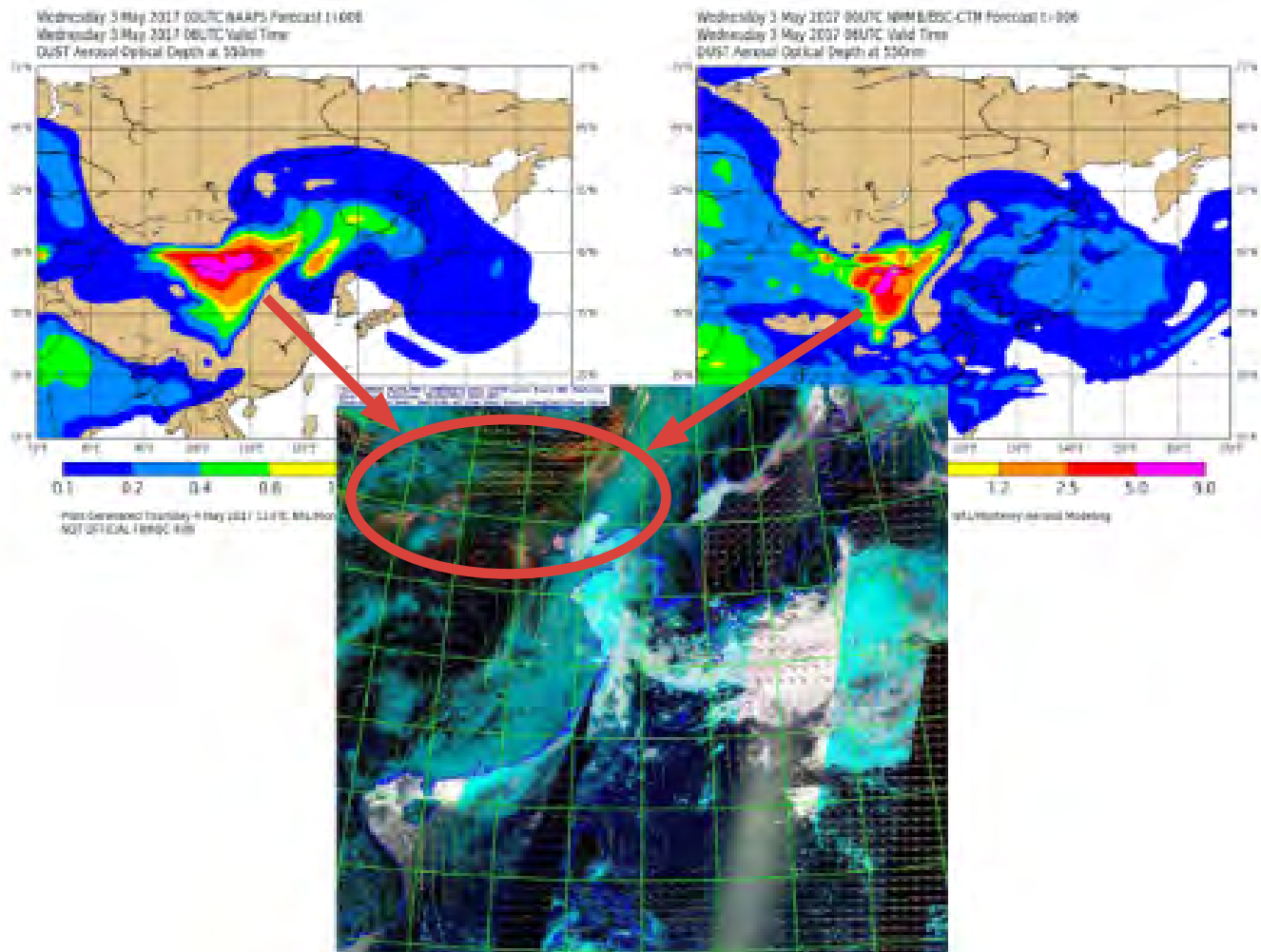
### Dust Over Land

Dust storms form when sufficient wind passes over a dust source containing loose particles such as dirt, clay, silt and debris, resulting in lofting and transport processes. Dust can rise over several thousand feet and spread over hundreds of miles. Satellite observations are commonly used to detect and monitor dust storms. Dust storms can have a huge impact on human health (respiratory) and outside military equipment (radars, weapons), both aspects that are sensitive to large quantities of airborne particles.

The figure set on the following page shows significant dust outbreaks over China. The aerosol optical depth displayed on the left is generated from the NRL Aerosol Analysis and Prediction System (NAAPS), while the right product is generated from the Non-hydrostatic Multiscale Model on the B-grid/Barcelona Supercomputing Center (NMMB/BSC)-Chemical Transport Model. Both top



Night time views of VIIRS Day Night Band (DNB, left panel) and multi-channel (right panel) products centered over Italy that reveal city lights and cloud fields in blue shades. Embedded lightning streaks in white are also visible over northern Libya.



Set of dust model products from NAAPS (upper left) and NMM/BSC (upper right) with a corresponding MODIS-derived dust image product that also contains an overlay of low level winds as provided by NAVGEM (lower center). The warm colors (pink-red-orange) field in the upper panels point to the region of orange (dust) within the image.

panels point to the corresponding region of dust displayed within the center panel; a MODIS-derived dust enhancement product that is overlaid with the Navy Global Environmental Model (NAVGEM) 1000 millibar (mb) modeled wind vectors to derive the dust's origins and projected path.

## MONITORING TROPICAL CYCLONES

Tropical cyclone forecast centers such as the National Hurricane Center (NHC), the Central Pacific Hurricane Center (CPHC), and the Joint Typhoon Warning Center (JTWC) are responsible for forecasting tropical cyclone activity in their respective areas of responsibility. Mission planners aboard deployed U.S. Navy ships are particularly concerned about how tropical storms in both the Atlantic and the

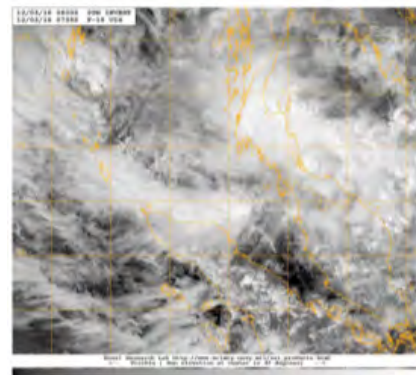
Pacific can impact operations. Additionally, Navy vessels within their home ports might be required to relocate if threats of high winds, waves, and storm surge associated with a tropical cyclone are possible.

It is paramount for these forecast centers to accurately evaluate vital meteorological conditions that can serve as precursors to tropical cyclone development. Satellite imagery may identify an easterly wave moving off the African Coast as well as synoptic disturbances off the coast of Japan. If a forecaster determines that these disturbances will move over warm waters or into areas of weak vertical wind shear, they will begin to pay close attention to any potential storm development. When appropriate, forecasters will declare this nascent system an "INVEST." The National Hurricane Center (NHC) describes this as "a weather system for which a tropical cyclone forecast center is interested in

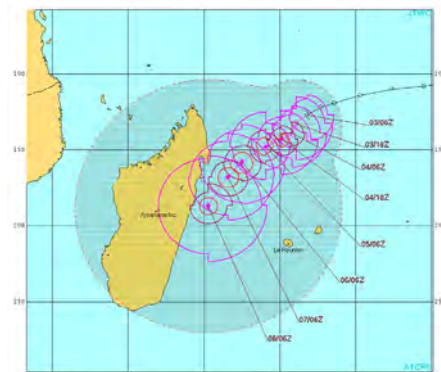
collecting specialized data sets (e.g., microwave imagery) and/or running model guidance. Once the storm is designated as “INVEST,” data collection and processing is initiated on a number of government and academic websites, including NRL-MMD and the UW-CIMSS<sup>2</sup>.” In the Atlantic and eastern Pacific ocean basins, NHC uses numbers 90 through 99 to identify such systems, with further designations of ‘L’ as Atlantic, or ‘E’ as east Pacific. These ID numbers, signifying the order of development, are rotated throughout a hurricane season and can be repeated as many times as needed. The NHC further notes that an invest designation does not correspond to how likely a system may develop into a tropical depression or storm. NRL-MMD provides NRT access to satellite imagery (such as the ones shown on the right) over these invest areas on their Tropical Cyclone Page<sup>3</sup>, which the forecast centers use to observe the disturbance and see whether it has enough vorticity to begin the circular pattern indicative of a tropical cyclone formation.

If the system develops into a tropical cyclone, it is labeled with a number as well as an alphanumeric character denoting its basin of formation. On the bottom right is an illustration showing TC 09S.ENAWO, which formed in the southern hemisphere, and as a result falls under the jurisdiction of the JTWC. In this case the JTWC would apply the Automated Tropical Cyclone Forecasting (ATWC) system to begin warning on the radius of winds or for ship navigation reasons.

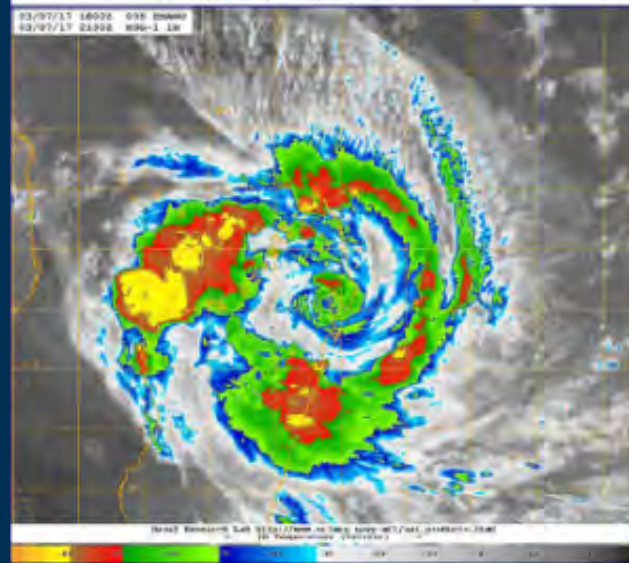
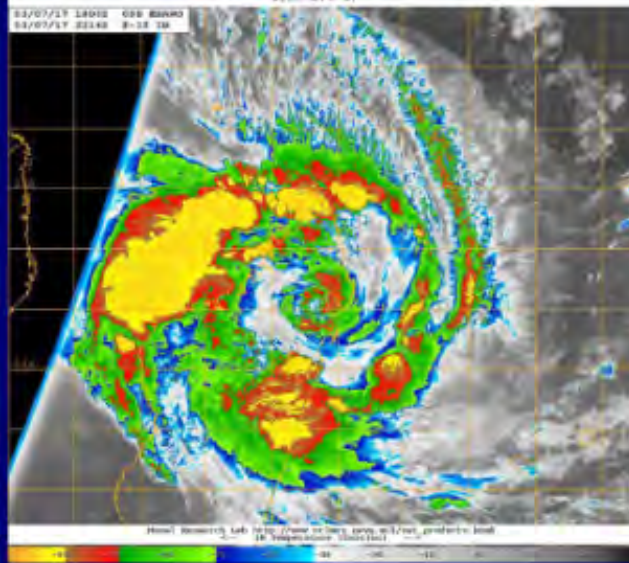
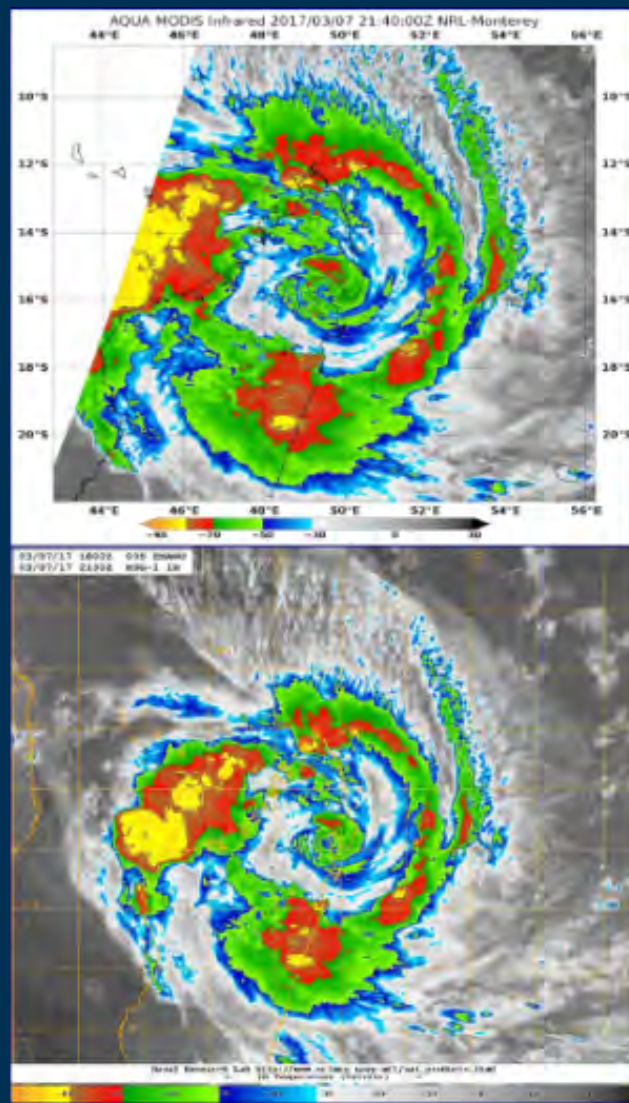
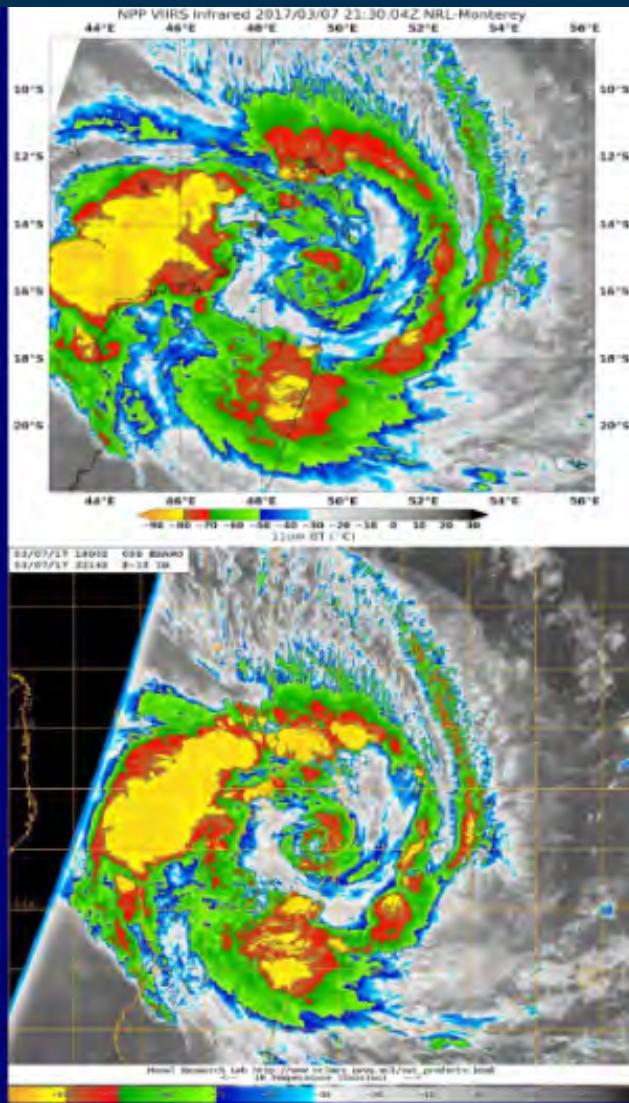
TC detection and monitoring is conducted primarily with weather satellites, particularly within the data sparse ocean basins. The use of multiple satellites and sensors to monitor TCs has helped assess their location and intensity. While visible and infrared (vis/IR) data provide the bulk of TC information, upper-level cloud obscurations can greatly limit their utility. As a result, data and imagery from microwave sensors is utilized to help offset many of the vis/IR spectral limitations. The following section continues the TC Enawo case studies to illustrate how multiple datasets helped the JTWC monitor aspects of this storm’s organization and development.



Images derived from VIIRS (top), AHI (middle), and the OLS (bottom) depicting a disturbance forming in the Strait of Malacca, located between the Malay Peninsula and the Indonesian island of Sumatra.



Automated Tropical Cyclone Forecasting System (ATCF) map that is tracking 09S.ENAWO as it approaches Madagascar.



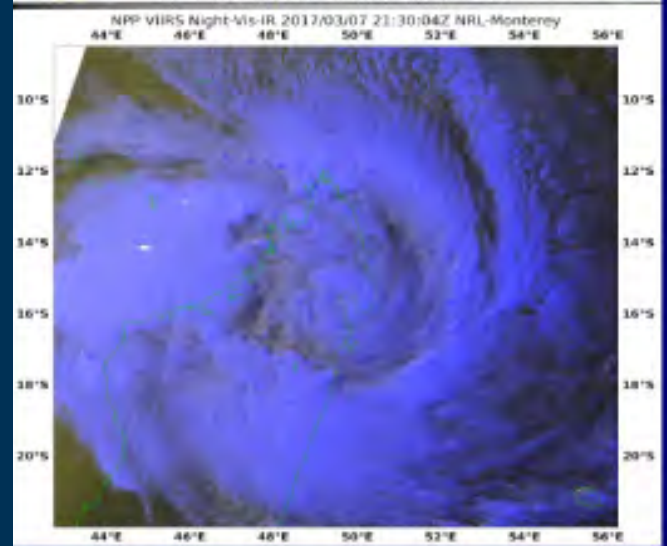
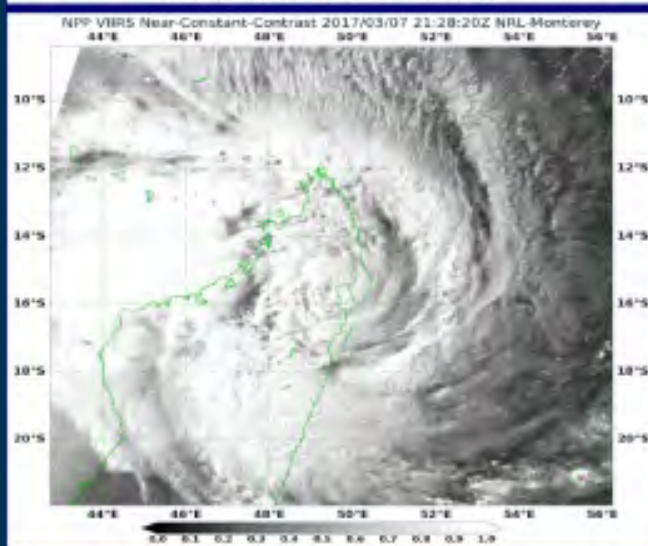
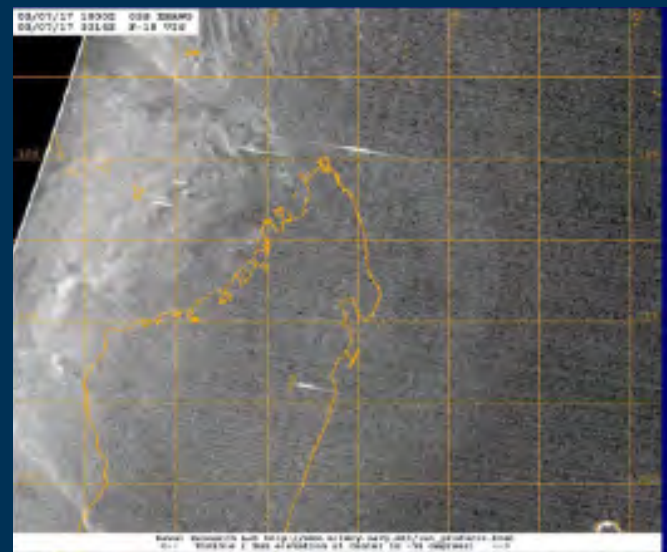
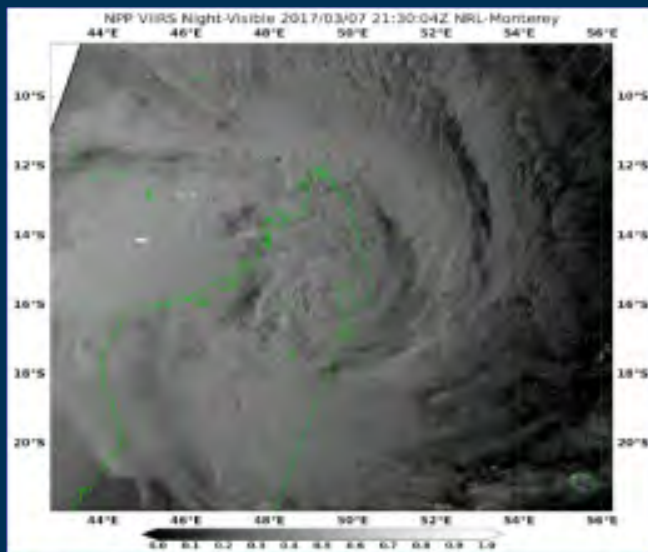
4-panel display of similarly timed infrared color products from derived VIIRS, MODIS, OLS, and MSG (clockwise from upper left) respectively, that monitor TC ENAWO during March 7, 2017.

The images above show the colored IR for TC Enawo. The VIIRS image (top left) generated from an overpass at 21:30 shows good skill in detecting cloud tops as well as the feeder bands and the cirrus being blown off the center. MODIS (top right) 10 minutes later shows that the storm has not changed much. The DMSP pass (bottom right) is 45 minutes later and shows the major cloud tops have stayed intact and are beginning to define the center of circulation. The MeteoSat-8 MSG (lower right) while in a similar time frame as the VIIRS (upper left) does not have the same resolution so the cloud heights are not nearly as well defined.

Nighttime visible imagery (shown on the following page) provided some indication of low-level

circulation and also reveals lightning detected by the DNB (top left) and the OLS (top right). However, since the OLS is the heritage instrument for the DNB, it is easy to see that its resolution is much less impacting its ability to define the TC. The VIIRS Near-Constant-Contrast (NCC) (bottom Left) incorporated with the night visible IR (bottom right) depicted a lot more detail about the general circulation of the storm as compared to that depicted by visible imagery alone.

NRL-MMD staff leverages many sources of satellite data in order to provide its users with detailed tropical cyclone information; this remains a vital resource for deployed naval forces around the world.



## SUMMARY

NRL-MMD remains an effective stakeholder in supporting the JPSS Program as related to operational and research applications of JPSS products. NexSat offers the operational user community a visual component toward interrogating various types of datasets and imagery from the full complement of satellite sensors in near real-time. As a result, U.S. Navy forecasters are able to apply NexSat products toward effective mission-planning endeavors. These products are also available through the operational portal at FNMOC.

NRL-MMD has partnered with an ever increasing number of government and academic satellite programs that result in a rich dataset of data from sensors onboard 30 LEO and five GEO satellite platforms. New and improved sensors will shortly become available; this addition will augment existing datasets and provide enhanced capabilities. ❖

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## Footnotes

<sup>1</sup>NexSat does not provide 24/7 operations

<sup>2</sup>[www.nhc.noaa.gov/aboutgloss.shtml](http://www.nhc.noaa.gov/aboutgloss.shtml)

<sup>3</sup>[www.nrlmry.navy.mil/TC.html](http://www.nrlmry.navy.mil/TC.html)

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# TRACKING WATER VAPOR WITH MULTI SATELLITE LAYERED PRECIPITABLE WATER PRODUCTS

The information in this article is based, in part, on the February 26, 2018 JPSS science seminar presented by John Forsythe, Cooperative Institute for Research in the Atmosphere (CIRA), Colorado State University, Fort Collins, CO. It contains work by CIRA Team members: Stan Kidder, Andy Jones, Dan Bikos, Ed Szoke, and collaborators: Sheldon Kusselson (retired NESDIS), Kevin Fuell, Anita LeRoy, Frank LaFontaine (NASA SPoRT), Michael Folmer, Ralph Ferraro (NOAA), Chris Grassotti (CICS), Chris Gitro (NWS), and Mike Jurewicz (NWS).

# Periods of Rain and Mountain Snow This Week

## Storm #1 Details (Mon night-Wed)

- Light rain showers likely at times
- 0.20-0.75 inches of rain, highest north of Pt Conception
- Snow levels above 7500 feet

## Storm #2 Details (Thu-Sat)

- Periods of rain likely Thu-Fri with scattered showers into Saturday.
  - Potential for brief heavy downpours and isolated thunderstorms
- Snow levels 4000-5000 feet
- Gusty southwest winds

## Potential Impacts Storm #2

- Debris flows possible in recent burn areas
- Urban and small stream flooding
- Winter weather driving conditions in local mountains



Credit: NWS/Los Angeles. [twitter.com/NWSLosAngeles](https://twitter.com/NWSLosAngeles).

Accurately forecasting precipitation is a challenge many forecasters face on a daily basis. Precipitation events, be they in the form of a passing shower, torrential downpours, light snow showers, or freezing rain have the potential to impact every level of society. Precipitation events can bring great benefits such as water for humans, animals and plants. On the other hand, too much precipitation, can lead to flooding, which has consequences that may include property damage or loss of life. NOAA has looked for ways to better define precipitation occurrence and

where it occurs, precipitation totals. Radar, rain gauges, and other ground-based measurements are the backbone of this precipitation measuring system. However, satellite precipitation products have become increasingly important to meeting this challenge. Sensors on polar-orbiting and geostationary satellites have provided datasets and products to support precipitation forecasting. This has been done to such an extent that forecasters face a “deluge” of information, making it difficult for them to sort through and create a coherent picture of precipitation possibilities.

Researchers and developers at the Colorado State University’s Cooperative Institute for Research in the Atmosphere (CIRA) took up to answer several science questions: “How do we merge disparate sensors in space, time, and algorithm to create a seamless blended product?” and “How do we know they are helping forecasters?”

## **MAKING A CASE FOR BLENDED PRODUCTS**

While there are various sensors/satellites that can obtain water vapor measurements, they carry different biases and sampling



errors due to differences in algorithms, instruments, and also temporal and spatial sampling resolutions. The end result can be an overwhelming variety of data to sort through and analyze. But, challenges drive science activities. Infrared Sensors (IR) and microwave sensors are both valuable to providing precipitation datasets. The IR sensors are more numerous and can be found on many domestic and foreign satellites. However, they struggle to get data in cloud cover and heavy precipitation areas. Microwave sensing instruments—aboard polar-orbiting satellites—are able to see through non-precipitating clouds, helping mitigate IR limitations.

In 2006, CIRA created a seamless easy-to-use blended observational product, the Blended TPW. The intent was for forecasters and analysts to have one uniform, globally-composited, TPW product instead of separate TPW products from various remote-sensing entities. The product, which has been available in NWS operations since 2009, is derived from multiple sensors/satellites including the NOAA/National Aeronautics and Space Administration (NASA) Suomi National Polar-orbiting Partnership (Suomi NPP), the Special Sensor Microwave/Imager Sounder (SSM/IS) from the Defense Meteorological Satellites Program (DMSP), the Advanced Microwave Sounding Unit (AMSU) from Polar Operational Environmental Satellites (POES), as well as

from ground-based Global Positioning System (GPS) measurements. The product has a wide variety of uses related to heavy precipitation and flooding, such as measuring the amount of moisture in an atmospheric river originating in the tropics. However, it conveys no information on the vertical distribution of moisture, which is relevant to a variety of forecast concerns. It also does not use advection techniques such as demonstrated by the University of Wisconsin Cooperative Institute for Meteorological Satellite Studies (CIMSS) MIMIC TPW product. CIRA also began the initiative to include data from geostationary satellites in this blended product. On November 17, 2017, NOAA-20 was launched joining Suomi NPP in the same orbit. NOAA-20 (JPSS-1 prior to launch) operates about 50 minutes ahead of Suomi NPP, allowing important overlap in observational coverage.

The JPSS Proving Ground and Risk Reduction (PGRR) program supports the development and enhancement of data, algorithms and products from the Nation's next generation polar-orbiting satellites in user applications. The program's risk reduction initiatives involve the fusion of data from multiple satellites, models as well as from in-situ sources. CIRA scientists built upon previous work the NASA Short-term Prediction Research and Transition (SPoRT) Center to further exploit the synergy of the existing and new data platforms. This has enabled

the creation of a blended seven-satellite, four-layer product of layered precipitable water (LPW), from NOAA investments in polar orbiting satellite sounding retrievals from passive microwave radiances, in particular, the Microwave Integrated Retrieval System (MiRS). The system uses data from the Suomi NPP, NOAA-18 and -19, the DMSP F17 and F18, and Europe's Metop-A and -B satellites. NOAA-20 data should be added later in 2018. NASA SPoRT continues to support distribution of the LPW products to select NOAA national centers and weather forecast offices (WFO's).

This article focuses on the CIRA blended seven-satellite, four-layer, advected (ALPW) product which allows forecasters to see the vertical distribution of water vapor in near real-time. Usage examples in forecast operations are presented as well.

## **THE NOAA MICROWAVE INTEGRATED RETRIEVAL SYSTEM: EVOLUTION IN CONCEPT AND PRACTICE**

Prior to 2011, atmospheric moisture products from passive microwave instruments were produced over water but not over land. The land portion data were retrieved from infrared or surface based data. But traditional point observations, such as radiosondes, leave gaps, while other layers of the

# MiRS: An All-Weather 1DVAR Satellite Data Assimilation and Retrieval System

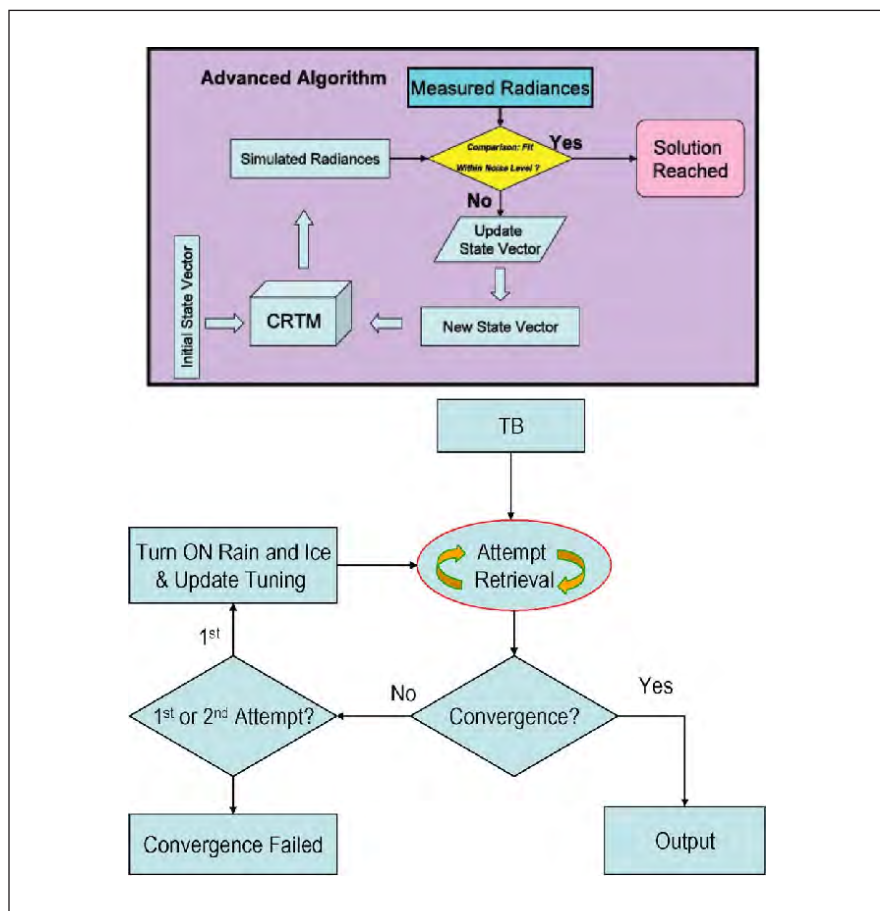
Sid-Ahmed Boukabara, Kevin Garrett, Wanchun Chen, Flavio Iturbide-Sanchez, *Member IEEE*, Christopher Grassotti, Cezar Kongoli, Ruiyue Chen, Quanhua Liu, Banghua Yan, Fuzhong Weng, Ralph Ferraro, Thomas J. Kleespies, Huan Meng

## FILLING THE NICHE WITH A BLENDED, LAYERED WATER VAPOR PRODUCT

The experimental Advected Layered PW (ALPW), developed by CIRA scientists, is analogous to TPW, but focuses on layers. It allows forecasters to see the vertical distribution of water vapor in near real-time at four distinct layers (surface-850, 850-700, 700-500, 500-300 mb). Blended LPW is created from the MiRS 1DVAR retrieval (Boukabara et al. 2011), Version 11. Advective blending offers a drastic reduction to the visual limitations seen with traditional LPW imagery, as satellite swath lines and data discontinuities are largely removed. The 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.

atmosphere are missed by infrared sensors because of clouds. Thus, a reliable source of vertical profile information is particularly lacking over water to see the totality of moisture systems. To account for observation-poor regions, such as the oceans, a blend of water vapor profile data from the NOAA MiRS retrieval system from the SSMI/S, AMSU and ATMS sensors was included.

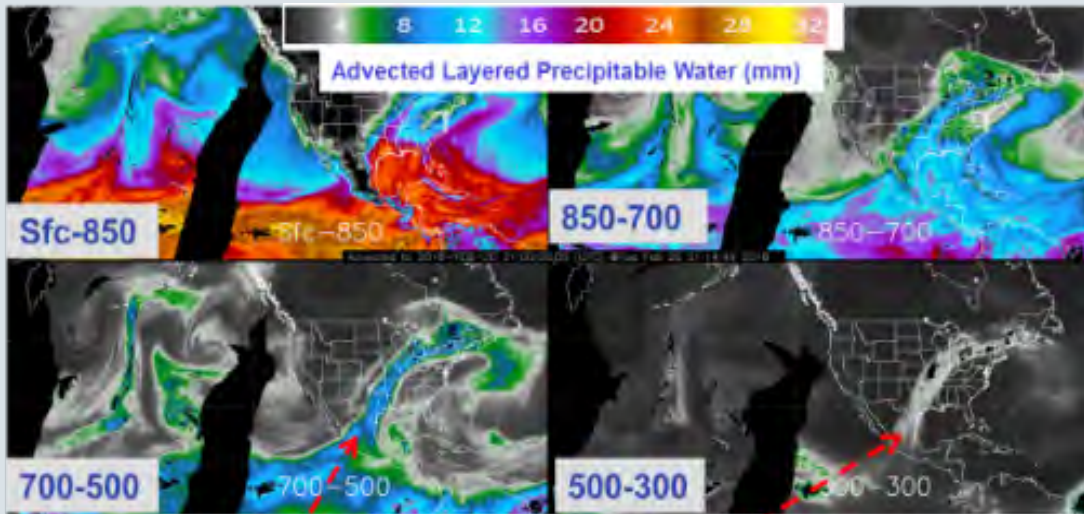
The NOAA operational MiRS retrieval system was a breakthrough in several ways. It integrated profile and total column retrievals in a common software package. Atmospheric profiles of several state variables, including temperature and water vapor, could be retrieved over land, the once all too common barrier with microwave remote sensing. And, it could be applied to multiple sensors (conical and cross-track).



Diagrams of the MiRS retrieval algorithm. The bottom panel describes the retrieval attempts. The top panel shows the iterative approach adopted in MiRS to reach a solution within each retrieval attempt.

## IMPACT ON OPERATIONS

The ALPW can show convergence of moisture from different sources. The case on the following page depicts a flooding event in the midwest and Mississippi Valley. An analyst at the NOAA Weather Prediction Center (WPC) noted that the ALPW product



MESOSCALE PRECIPITATION DISCUSSION 0020  
 NWS WEATHER PREDICTION CENTER COLLEGE PARK MD 847 PM EST TUE FEB 20 2018 AREAS  
 CONCERNING...HEAVY RAINFALL...FLASH FLOODING POSSIBLE VALID 210145Z - 210745Z

...DISCUSSION... A DEEP FETCH OF MOISTURE EXTENDED INTO THE ARKLATEX REGION ALONG A SLOWLY ADVANCING COLD FRONT...WITH PRECIPITABLE WATER VALUES NEAR THE UPPER ECHELONS OF WHAT HAS BEEN OBSERVED AT SOUNDING SITES IN THE MONTH OF FEBRUARY. IN FACT...THE 00Z SOUNDING FROM SHREVEPORT LA RECORDED 1.72 INCH PW...WHICH BROKE THE FEBRUARY RECORD (1.49 IN. CIRA LAYER PW PRODUCTS REVEAL A PLUME OF SUBSTANTIAL MOISTURE THAT EXTENDS INTO THE MID-UPPER LEVELS (BOTH THE 700-500MB AND 500-300MB LAYERS)...AND THIS DEEP MOISTURE PLUME ORIGINATED AS FAR SOUTH AS 10N IN THE TROPICAL EASTERN PACIFIC. THE DEEP MOISTURE PROFILE AND RECORD PWATS SHOULD FAVOR EFFICIENT RAINFALL PRODUCTION IN CONVECTIVE BANDS THIS EVENING AND INTO THE OVERNIGHT HOURS.

revealed a plume of moisture that extended into the mid and upper levels of the atmosphere (above, red arrows). Sometimes moisture can come from very different directions at different levels in the vertical from a long distance away to contribute to a flood event as noted by the analyst in regard to the plume's connection with the tropical eastern pacific.

## TROPICAL WEATHER APPLICATIONS

The ALPW product can be used to support tropical cyclone forecasting. In order for tropical cloud clusters to organize into a tropical depression, the environment must be sufficiently moist. In the example below, the ALPW product is being used by the

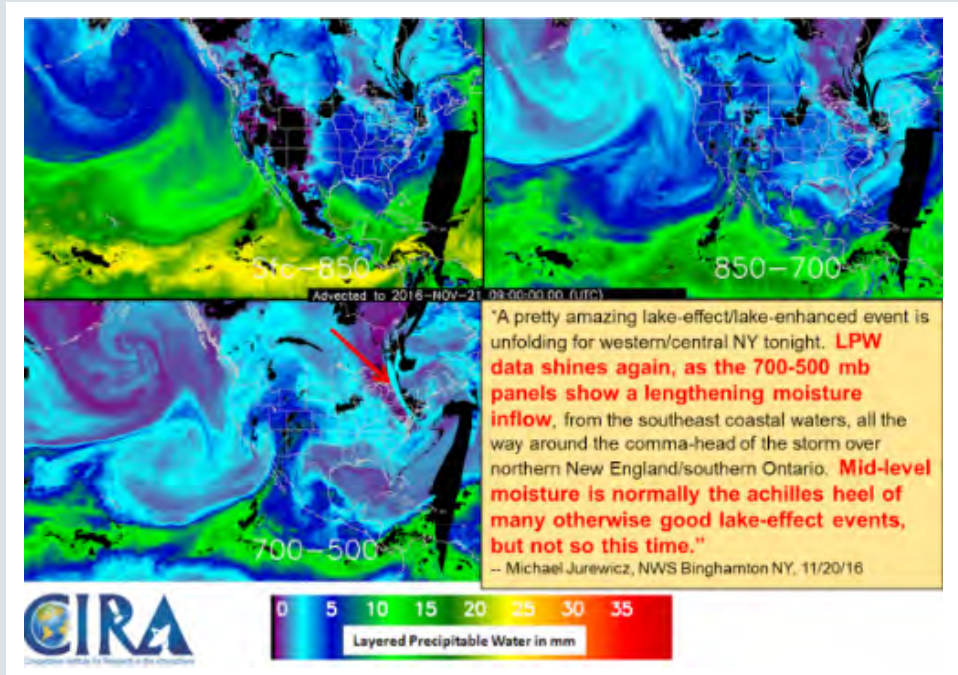
National Hurricane Center (NHC) to analyze whether conditions are favorable for a tropical depression or storm to form. In July 2017, in the NHC Atlantic Tropical Weather Discussion (TWDAT), CIRA LPW was mentioned 53 times in the 110 discussions. Passive microwave retrievals perform around clouds, unlike GOES water vapor imagery or the Saharan Air Layer (SAL) product. Thus the ALPW is widely used in complement to the SAL product in cloudy skies to assess the environment around tropical waves.

NWS National Hurricane Center Miami FL  
 616 AM EDT SUN JUL 10 2016

...TROPICAL WAVES... A tropical wave is in the central Atlantic with axis near 32W, moving west at 15 knots within the last 24 hours. The wave is embedded in **a mainly low moist environment from surface to 850 mb as indicated by CIRA LPW imagery...** Meteosat imagery show Saharan dry air and dust in the last 24 hours. **The wave is embedded in a moderate moist environment from surface to 850 mb as indicated by CIRA LPW imagery.** A diffuent environment aloft ahead of the wave supports scattered showers across the Windward Islands and adjacent waters. A tropical wave is in the central Caribbean with axis near 75W, moving west at 15 knots within the last 24 hours. **CIRA LPW imagery show the wave is embedded in shallow moisture whereas water vapor imagery show strong subsidence aloft.**

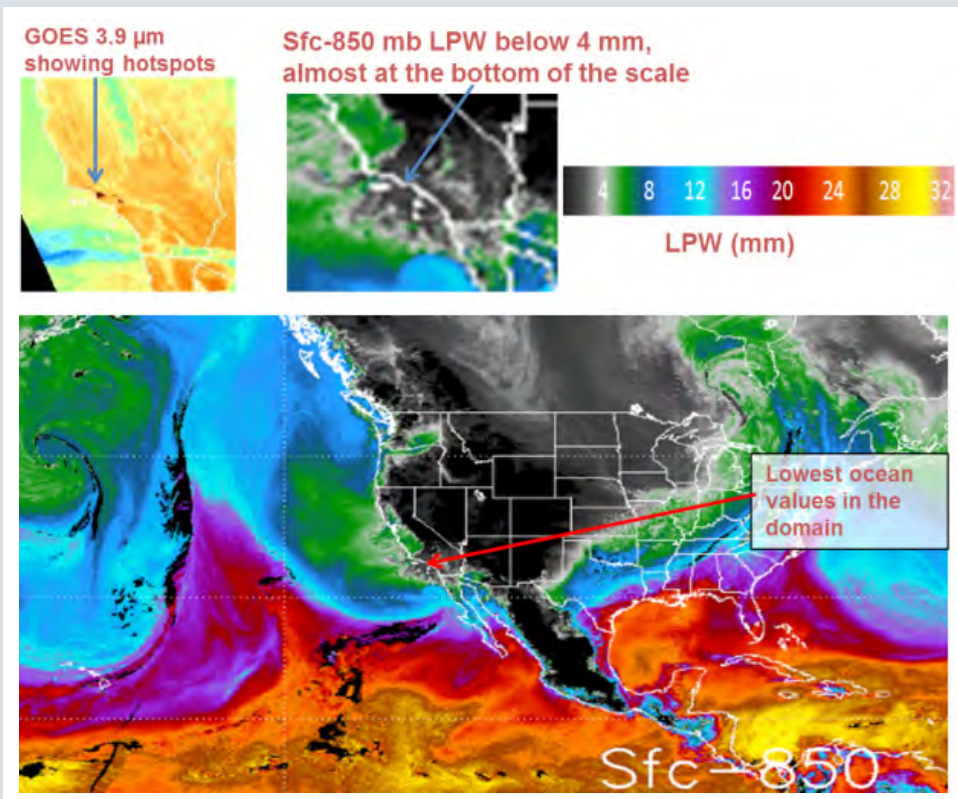
## HEAVY SNOW FORECASTING

While ALPW has been mostly used to forecast heavy rain, CIRA's partner NWS office in Binghamton, NY, noted a usage of the ALPW product for forecasting heavy snow. In the example on the top right, LPW data indicated a moist layer at 700–500 mb, which connected back to the Atlantic Ocean. As forecaster Micheal Jurewicz noted, moisture in this layer is often what is lacking for a good lake effect event. This lake effect snow event produced over two feet of snow in portions of New York state.



## SOUTHERN CALIFORNIA FIRES, 18:00 UTC DECEMBER 5, 2017

Another possible use of ALPW products is to determine how it performs in conditions supporting forest fires. The panel on the bottom right shows an example of the sfc-850 mb LPW over southern California, when devastating fires were raging as seen in the GOES-West 3.9  $\mu\text{m}$  imagery (upper left image in the same panel). Extremely low LPW values (<4mm) are seen in the offshore region over the Pacific, as winds advected dry air offshore. These values were lower than anywhere else over the ocean in the domain. This would give forecasters confidence in forecasting dry weather to continue with no improvements in fire conditions.



## SUMMARY

The NOAA operational Blended TPW and experimental Advected LPW exploit multisensor techniques to improve the depiction of water vapor and fill a void in moisture analysis. The Advected LPW takes advantage of the water vapor profiling capability of the MiRS retrieval system providing the critical vertical

distribution of moisture that is absent in the blended TPW product. Forecasters have been evaluating Advected LPW in a wide variety of different storm conditions, enabling forecasters to track individual layers of moisture ahead of and during developing hazardous weather, especially heavy precipitation. In operational evaluations, the NOAA WPC and NHC are using

the Advected LPW in many of their forecast discussions. With this successful operational application, one could anticipate that it won't be long before Advected LPW products could transition from the JPSS proving ground and CIRA production into operational production at NESDIS to benefit the entire NWS. ❖

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# **IN THE AFTERMATH OF HURRICANES HARVEY, IRMA, AND MARIA: SPOTTING OUTAGES WITH JPSS**

The information in this article is based, in part, on the March 19, 2018 JPSS science seminar presented by William Straka Cooperative Institute for Meteorological Satellite Studies (CIMSS), University of Wisconsin, and Lori Schultz NASA Marshall Space Flight Center. With contributions and support from Andrew Molthan (NASA) and Steve Miller (CIRA).



Hurricanes: William Gould, Director, USDA Caribbean Climate Hub, US Forest Service International Institute of Tropical Forestry in Río Piedras, Puerto Rico, “Challenging People and Institutions to Sustain Services and Learn to Adapt” November 27, 2017. Accessed from [www.usda.gov/media/blog/2017/11/27/hurricanes-challenging-people-and-institutions-sustain-services-and-learn](http://www.usda.gov/media/blog/2017/11/27/hurricanes-challenging-people-and-institutions-sustain-services-and-learn), May 14, 2018.

The 2017 hurricane season was a brutal one for residents in multiple regions including the United States, Puerto Rico, and the Caribbean Islands as they were battered by a trifecta of storms—Hurricanes Harvey, Irma and Maria. These storms left significant trails of damage and destruction in their wake. Harvey made initial landfall along the Texas coast. Its slow movement and record-setting rainfall over the Houston metro led to widespread urban and river flooding over multiple days. Irma crossed over the Caribbean Islands and Florida, and moved into the southeastern United States. In its aftermath, residents were left having to cope with coastal and inland flooding, extensive wind damage, and numerous power outages. The long-lasting impacts to the electrical infrastructure of Puerto Rico from Maria were widely reported and even months later some areas were still without power.

This article highlights the work done by the Joint Polar Satellite System (JPSS) Program’s

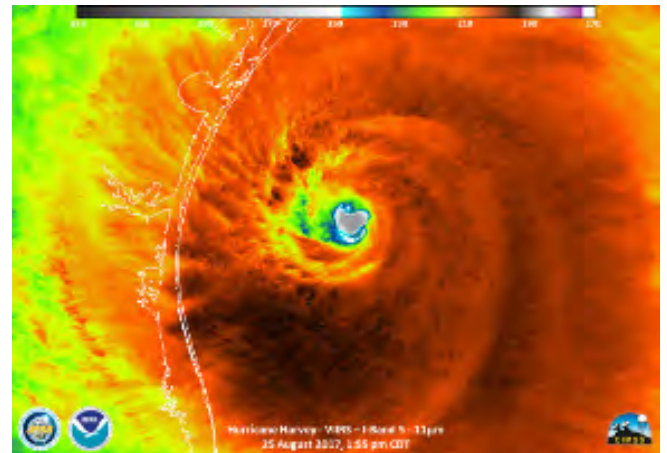
staff and their partners from NOAA, NASA, and academia, to assist the Federal Emergency Management Agency, the U.S. National Guard, and others in their assessment, response to, and recovery from this triad of disaster events. The JPSS Program expeditiously mobilized resources, including imagery from the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument aboard the Suomi National Polar-orbiting Partnership or Suomi NPP. The imagery showed the changing light levels tied to power outages from these storms. As time went on, this imagery was used in decision support systems (DSS) to track the improvement in light levels. Many of these improvements could be attributed to generators—which temporarily became the primary sources of power in much of the island—and repairs to some of the island’s electric power grids. This application of the JPSS capabilities is the result of decades of work done by scientists from multiple agencies, including the Department of Defense, NOAA and NASA.



# HURRICANES, IN: POWER, OUT!

## Harvey

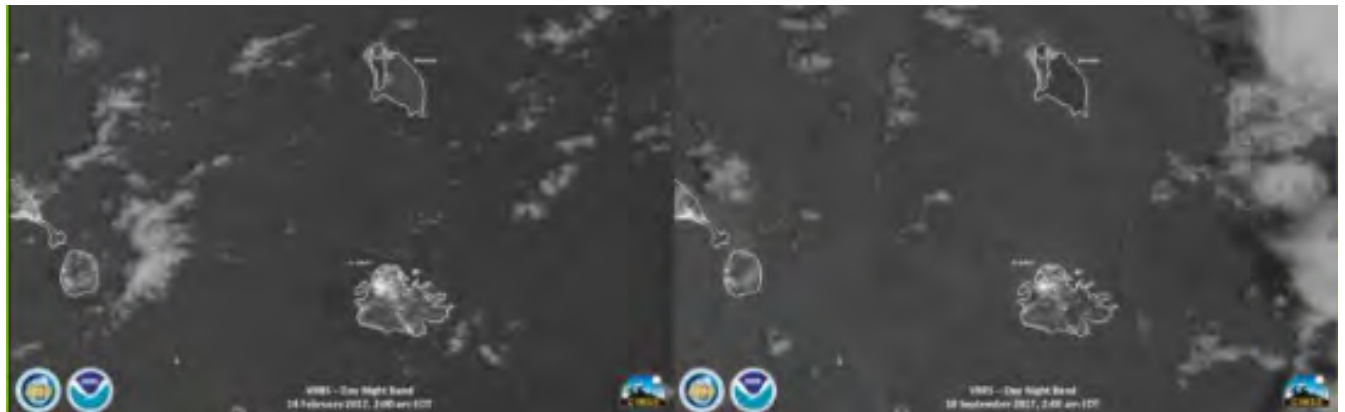
Hurricane Harvey, the first major hurricane of the season, shown in the figure on the right from a satellite overpass on August 25, 2017, made landfall multiple times on the U.S. mainland in late August. The first U.S. landfall was on August 26, 2017 at roughly 03:00 UTC near San Jose Island and then near Rockport, in south-central Texas as a Category 4 hurricane. Harvey lingered for quite a few days over mainland Texas and brought historic rainfall to the area. At least 68 people died and current estimates of at least 125 billion<sup>1</sup> in damages place Harvey as the second costliest hurricane to hit the U.S. mainland since 1900.



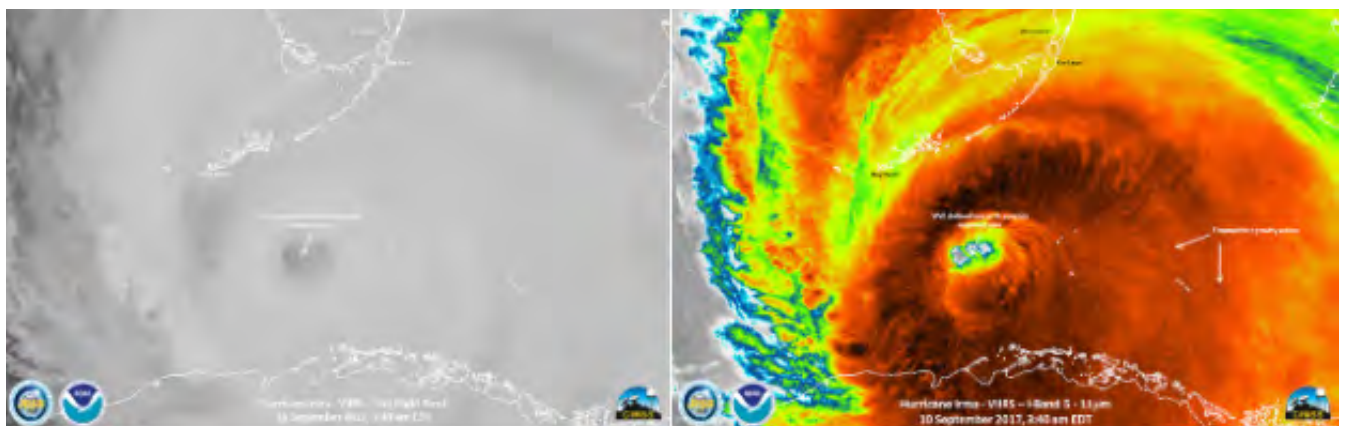
## Irma

The next major storm, Irma, made landfall on September 6, 2017 with a maximum wind speed of 155 knots (kts) and 914 millibars (mb) central pressure. Even before landfall, Irma was already setting records; she was the strongest hurricane ever recorded in the Atlantic basin. As life-threatening winds and rain ripped

through the Caribbean, many islands in Irma's path found that they were no match for the monstrous Category 5 (the highest the scale goes) storm. Irma knocked the tiny Caribbean Island of Barbuda into rubble and left it almost inhabitable as 90 percent of the structures were demolished<sup>2</sup>.



Total loss of light on the island of Barbuda on 10 September 2017. NHC Tropical Cyclone Report, Cangialosi et al., March 9, 2018.

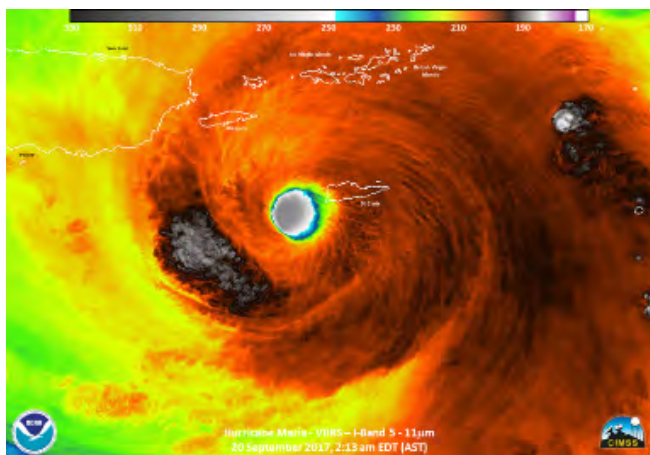


Hurricane Irma, Image credit, NOAA/CIMSS, NHC Tropical Cyclone Report, Cangialosi et al., March 9, 2018.

On the U.S. coast, Irma made landfall near Cudjoe Key on September 10, 2017 in the lower Florida Keys as a Category 4 hurricane with a maximum wind speed of 115 kts and minimum pressure of 931 mb.

## Maria

The next major hurricane, Maria, followed a few weeks later. On September 20, 2017, Maria made landfall near Yabucoa Harbor in Puerto Rico after passing just to the west of St. Croix. The powerful Category 4 storm plowed across the island with sustained winds of 155 mph, and heavy rains and flash floods destroyed homes, roads, and bridges. In the aftermath of the storm, electricity was cut off to almost 100 percent of the island. Other effects from the storm included food and water shortages, water-related disease outbreaks, and closures of vital services such as hospitals due to extensive damages.



## WHEN DISASTER STRIKES: LEVERAGING CAPABILITIES OF ENVIRONMENTAL SATELLITE SENSORS

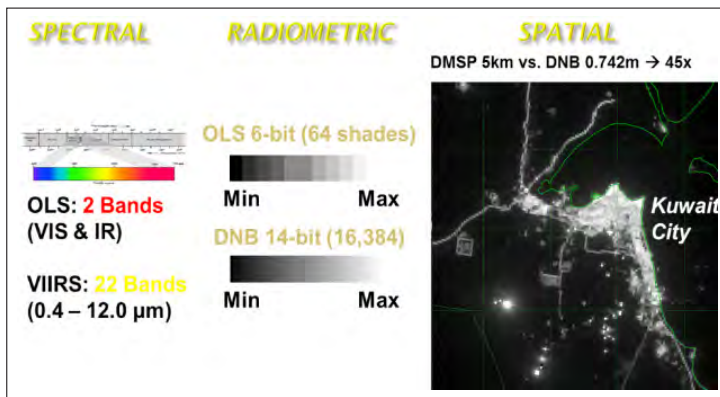
Each of the major hurricanes were observed from both geostationary and polar-orbiting weather satellites prior to land fall. Data from both sets of satellites are extensively used by numerical forecast models to help forecasters predict the path the hurricane will take as well as the intensity of these storms. After the storms had passed, images from the GOES-16 satellite as well as the Suomi NPP satellite were both used to

help observe the locations of flooding, aiding emergency responders in their response to the affected areas.

The Visible Infrared Imaging Radiometer Suite (VIIRS) instrument on Suomi NPP, as well as the newest polar orbiting satellite, NOAA-20, has a unique channel to detect radiant emissions coming from various sources including cities, industrial lights, gas flares and fires. This instrument was able to further help in the response to these disasters. The Day Night Band (DNB) on VIIRS was pioneered in the 1960s by the U.S. Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS). The OLS, a low light imager, collected visible and thermal infrared data to observe weather systems and clouds under moonlit conditions. The introduction of the DNB in 2011 shifted the paradigm in low-light visible imaging with marked advancements over the heritage DMSP/OLS capability, such as increased spatial resolution and higher radiometric capabilities. In addition, calibrated nighttime visible measurements—the process of converting the DNB sensor output signal (in digital numbers) to physical units of radiance, using traceable calibration sources—were pioneered on the DNB.

Unlike the OLS instruments, VIIRS has onboard calibration devices for all bands to ensure the accuracy and stability of the measurements while on orbit.

When disaster strikes, agencies from the United States as well as their partners from other responding nations, mobilize personnel and resources to help assess and assist with pressing



issues in some of the hardest hit areas, and also implement disaster relief programs. During the hurricane season of 2017, both NOAA and NASA utilized this unique instrument to provide information to disaster response agencies, such as the Federal Emergency Management Agency as well as the Department of Defense and the Department of Energy.

## JPSS RESPONSE

As part of a JPSS Program risk reduction project, the cooperative institutes for Research in the Atmosphere (CIRA) and Meteorological Satellite Studies (CIMSS) provided imagery from the DNB of “interesting meteorological events and other significant events” to the JPSS Program. Because the DNB can see city lights as well as meteorological (and non-meteorological) phenomena, researchers can observe variations in urban lighting and identify deviations from the norm, for example as illustrated in the images to the right, missing city lights may be an indication that major power outages have occurred.

Imagery (right) from the Suomi NPP VIIRS DNB (0.7  $\mu\text{m}$ ), captured before (August 23, 2017) and after (August 30, 2017) Hurricane Harvey’s landfall, shows changes in city light illumination associated with power outages.

This imagery was provided to FEMA initially by the JPSS program to help with assessment of where power outages were occurring. Requests for the imagery also from other stakeholders including the U.S. Army National Guard, Department of Energy (Oak Ridge National Lab) and U.S. Army South, and the Geospatial information officers at the FEMA National Response Coordination Center after it being seen at FEMA.

Along with the imagery were DNB comparisons, whereby the DNB was mapped and scaled the same way from image to image. In addition, the imagery was annotated with information on power outages as well as areas of cloud cover (so they would not mistake obscured lights for new outages). A brief written summary describing the scene and what was contained was also provided. The summary explained



Hurricane Harvey: Imagery courtesy of William Straka, SSE/CIMSS at the University of Wisconsin-Madison.

what could and could not be seen, as well as limitations such as lunar or cloud contamination. Along with this, a “slider” webpage displaying “before” and “after” images was developed. This enabled comparisons between past and present scenes as stakeholders could easily transition from one to the other via the interactive slider.

In the case of Irma, losses in the U.S. were estimated at \$50 Billion, making the storm the 5th costliest in U.S. history. According to the U.S. Energy Information Administration (EIA) and various media outlets, Irma left millions of Florida’s residents in the dark. The Sun Sentinel, for example, cited that roughly 65 percent of the state (6.5 million residents) lost power after Hurricane Irma, which correlated with satellite imagery from the VIIRS DNB (next page) of a well-lit Florida prior to Irma to an almost blacked out state in Irma’s aftermath. Several stakeholder groups used the imagery to track improvements as utility companies began to restore electricity.



Satellite images of South Florida as seen by Suomi NPP on May 11, 2017 (before) and on September 12, 2017 (after) Hurricane Irma's landfall. [twitter.com/NOAASatellites](https://twitter.com/NOAASatellites).



Before-and-after images of Puerto Rico show loss of electric light after Hurricane Maria hit the island. Credit: NOAA/CIMSS.

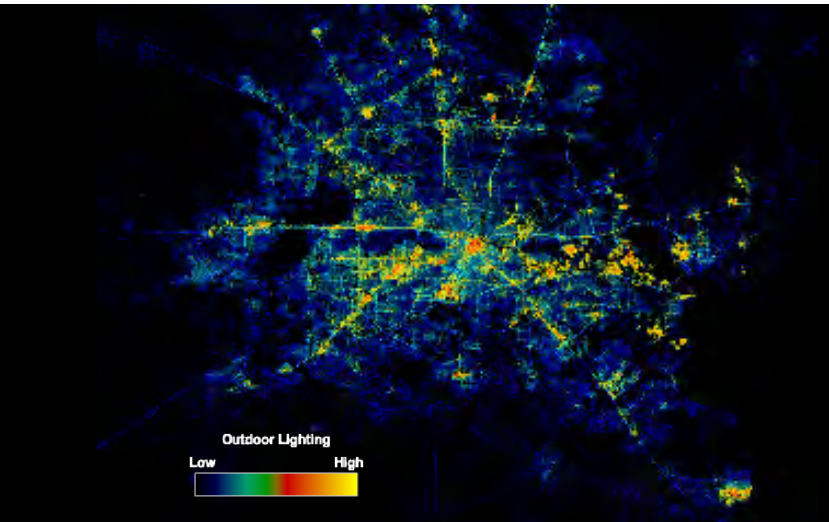
Puerto Rico presented challenges from the very beginning given its antiquated infrastructure which was in need of repair even before hurricane Maria knocked it offline. As a result, U.S. agencies such as the Federal Emergency Management Agency (FEMA) relied heavily on remotely sensed data to help coordinate their activities, which included deploying resources prior to, during and in the aftermath of the hurricanes. VIIRS imagery (such as that shown in the second image above) revealed power outages from space, and helped to monitor the post-storm recovery of power.

## NASA DISASTER RESPONSE

Another federal agency that played an important role in helping local communities during the hurricanes was the NASA Earth Science Disasters Program ([disasters.nasa.gov/home](https://disasters.nasa.gov/home)). The Program provides remote sensing support to agencies, including the National Guard, FEMA,

and the Department of Homeland Security (DHS). The Program actively engages these agencies to assess their needs and determine where NASA products and techniques can provide additional information to support situational awareness, incident response, and emergency management and recovery teams.



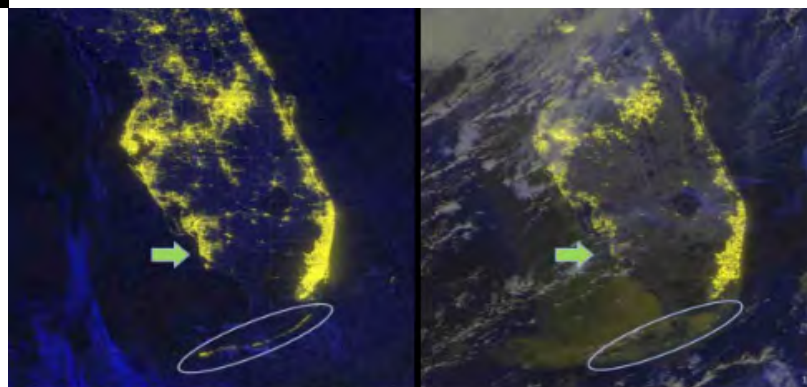


NASA Black Marble HD product helps track Power Outages in Houston, TX—Post-Harvey.

In the case of Hurricane Harvey, the National Guard requested products they could use to support situational awareness, particularly for the communities impacted after Harvey made landfall. The NASA team worked with interagency remote-sensing specialists to help them understand the NASA and partner-derived products designed to capture the extent of coastal surge and inland riverine flooding throughout the areas impacted by Harvey’s landfall and torrential, record-setting rains.

The same units that assisted in the response efforts for Harvey also supported the Guard units on the ground in Florida post-Irma. The team’s efforts, which focused on post-event

assessments, included coordinated activities with agency partners across South Florida and post-event products derived from multiple satellites. The value of this type of product is the ease of which it allows the end-user to interpret and make decisions. Analysts are able to quickly learn how to interpret the RGB and then adapt the information to their needs. Products provided to the National Guard were incorporated into their situational awareness briefings and used to assess conditions in support of response efforts.



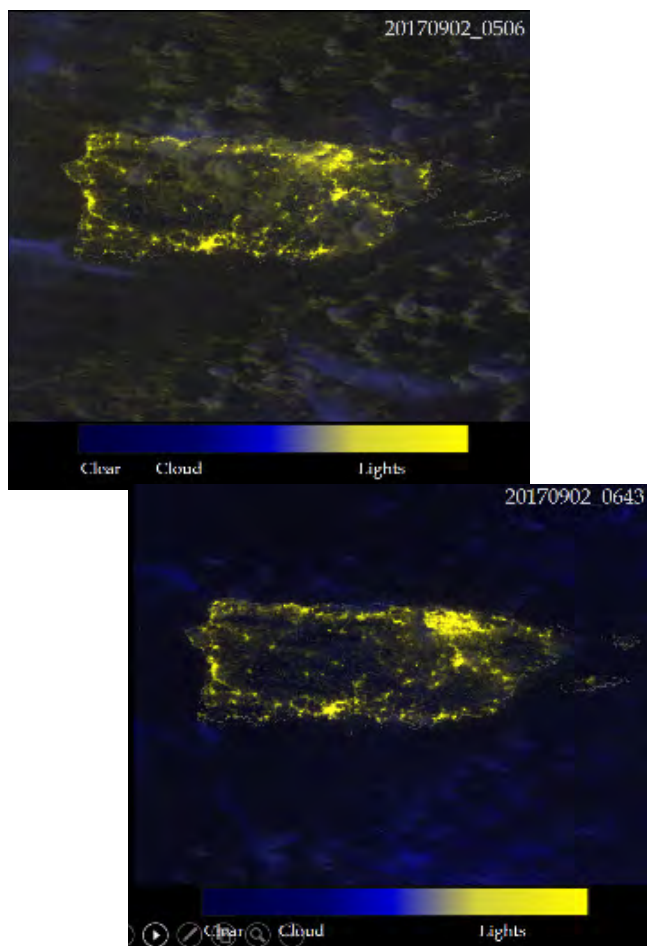
While quantitative products from the Black Marble and Black Marble HD are helpful for mapping change, they are also supplemented by false-color composites of nighttime lights and cloud cover through combination of the DNB with the infrared brightness temperatures, using a blue-yellow coloration pioneered by the Naval Research Laboratory and adopted for use with NOAA/National Weather Service partners through JPSS funding to NASA’s Short-term Prediction Research and Transition (SPoRT) Center. Detailed cloud assessments and situational awareness provide additional value to the interpretation of “percent of normal” products. For example, during hurricane Harvey there were days in which clouds obstructed the VIIRS view of surface features. Similar issues were experienced during hurricane Irma. As illustrated in the images above, which were generated prior to (left), and after (right) Irma’s landfall, the presence or absence of light is not as evident in the VIIRS image on the right. Red/Green/Blue (RGB) imagery products help with distinguishing clouds from cloud-free areas at



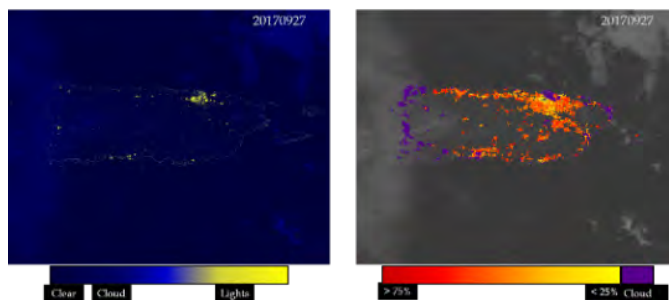
night by combining nighttime light emissions (yellows) with cloud cover inferred from their colder infrared temperatures (blues). Training was provide to the National Guard partners along with support for their Q&A to ensure use, solicit feedback, and help with inclusion in their situational awareness and decision-making efforts.

## HOW MUCH LIGHT IS MISSING?

RGB images capture the combination of nighttime emitted light and cloud cover to help interpret where changes in light could be a result of cloud obscuration. Other factors also matter, such as lunar illumination, viewing angle, aerosols, and other obstructions. This can distort the imagery, and lead to misleading interpretations. These variations are illustrated in the following images—taken the same night over Puerto Rico from two different satellite overpasses—in which similar yellow shades and some blurring of features in thin clouds make it difficult to ascertain where change has occurred.



To aid in the interpretation of the imagery and changes in light features, a team at NASA Goddard produced the NASA Black Marble product, which seeks to provide a consistent measurement of nighttime light through varying moonlight conditions. This product is further refined through spatial downscaling to a Black Marble HD product (shown on the top of page 67, an example of the Houston area following Hurricane Harvey). These products (shown in the examples below) include a pre-event average condition that can be compared with post-event scenes each night to calculate a “percent of normal” to identify areas where light emissions are reduced, but not entirely out, along with places that are fully lacking nighttime emissions. This group worked in association with team members from NASA SPoRT to get the product in front of first responders to better facilitate their ground operations. NASA SPoRT focuses on helping end users, such as FEMA and the National Guard, make effective decisions using innovative remotely sensed data products, in this case—from the NOAA-20 and Suomi NPP DNB.



## SUMMARY

The NOAA-20 and Suomi NPP DNB provide imagery during the day and at night. This low-light band has made it possible to monitor the extent of power outages from space. During the 2017 hurricane season, visible imagery from hurricanes Harvey, Irma and Maria helped agencies such as FEMA and first responders, monitor the storms from the first outage through the recovery stages. This imagery helped them determine where their equipment was needed the most, as well as to cross check against information power utility companies

were receiving from other sources. With NOAA-20 and Suomi NPP operating almost 50 minutes apart, relatively short-term changes can be identified more rapidly than was done in the past. Also, with clouds in continuous motion, an area that was previously blocked by clouds could now be clear or partly clear during a subsequent satellite pass, allowing one to view some features that would have been previously hidden. Moreover, with more observations on hand, decision makers will have more observations at hand to help figure out where to send resources.

In addition to providing information on the degree and extent of power outages, the imagery was particularly helpful in monitoring power outages in areas that lacked conventional tools. Moreover, the imagery could be tailored to suit different end-user requirements, from providing a big picture overview, to region and neighborhood monitoring from the first outage through the recovery stages. ❖

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## Footnotes

<sup>1</sup>Costliest U.S. tropical cyclones tables updated, National Hurricane Center (NHC)/NOAA, <https://www.nhc.noaa.gov/news/UpdatedCostliest.pdf>

<sup>2</sup><http://abcnews.go.com/International/hurricane-irma-destroys-90-percent-structures-vehicles-barbuda/story?id=49665358>

## Sources

Blair Shiff, and Aaron Katersky, Hurricane Irma hit Barbuda like a 'bomb,' prime minister says, ABC News, September 7, 2017, 1:05 PM ET, <http://abcnews.go.com/International/hurricane-irma-destroys-90-percent-structures-vehicles-barbuda/story?id=49665358>

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U.S. Energy Information Administration, Hurricane Irma cut power to nearly two-thirds of Florida's electricity customers, September 20, 2017. <https://www.eia.gov/todayinenergy/detail.php?id=32992>







# **POLARWATCH, A NEW NOAA PROGRAM TO IMPROVE OCEAN REMOTE SENSING DATA ACCESS**

The information in this article is based, in part, on the April 16, 2018 JPSS science seminar presented by Cara Wilson, Environmental Research Division, Southwest Fisheries Science Center, Monterey, CA. It features work being done by Dale Robinson, Deputy Node Manager; Jennifer Patterson Sevadjian, Operations Manager; and Sinead Farrell, Project Scientist.



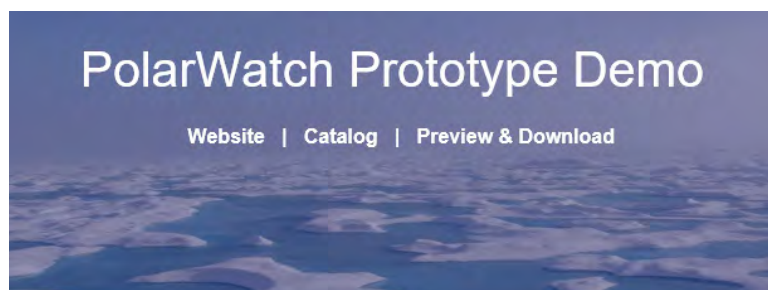
A view of the Southern Ocean from Antarctica's coast (above). Obtained from blog post "NOAA on the front lines in fascinating, foreboding Antarctica," by Vice Admiral Michael S. Devany and Dr. Richard W. Spinrad. Retrieved from [www.noaa.gov/news/blog-noaa-on-front-lines-in-fascinating-foreboding-antarctica](http://www.noaa.gov/news/blog-noaa-on-front-lines-in-fascinating-foreboding-antarctica). Left: Sea ice in the Bering Sea. Credit: J. London, NOAA's Arctic Action Plan, Supporting the National Strategy for the Arctic Region.

## MONITORING THE POLES

The Joint Polar Satellite System (JPSS) provides global observations that help us predict and prepare for severe weather events. These observations are the backbone of long-range, seven-day weather forecasts, as well as short-range forecasts. Beyond forecasting, JPSS satellites also play a critical role in detecting and monitoring environmental hazards, such as forest fires, floods, and blooms of harmful algae that can contaminate shellfish and kill fish and marine mammals. Satellites also monitor changes and provide data that can help improve future predictions. A key contribution of JPSS satellites is their ability to monitor remote regions like the Arctic and Antarctica, where a scarcity of conventional observations prevails. Why is this important? Because the satellite observations bridge critical data gaps that occur in these challenging environments. More than that, satellites provide observations of atmospheric parameters as well as the physical and biological state of the ocean that are global, consistent and long-term. Measurements of the Earth provided by satellites cannot be obtained using conventional sampling methods.

NOAA researchers use data products and imagery derived from satellites such as NOAA-20, along with its predecessor the Suomi National Polar-orbiting Partnership (Suomi NPP), to monitor sea conditions using parameters such as sea surface temperature and ocean color. Satellite data also helps researchers to observe marine life, changes in sea ice, and weather conditions as well as to track developing storms. For decades, observations of changes in the Arctic and Antarctic regions have been used to help us understand their influence on the environment at local, regional and global scales. The importance of these changes is highlighted in the 2014 NOAA Arctic Action Plan, which states that rapid environmental changes in these regions have resulted in a trend toward a much warmer and greener state of the global environment. According to the plan, these changes come with wide-ranging ramifications for resource management, the global climate system, regional commerce, and Arctic residents. NOAA's goals for the Arctic are outlined in the 2014 Action Plan and include strengthening foundational science to understand and detect Arctic climate and ecosystem changes, improving stewardship and management of ocean and coastal resources in the Arctic, sea ice forecasting, and improving weather and water forecasts and warnings. In regions such as Alaska, satellite data are used to generate forecasts that are critical in many industries, including fishing, energy, transportation and recreation. While satellite data is critical to these remote areas, it has its own challenges. Obtaining satellite data and products and distributing these quickly requires extensive satellite receiving systems and large data architectures that can be beyond the resources of the user community and can hinder the operational applications of these vital capabilities. The use of centralized antenna stations have proven critical to gathering satellite data and products from the multitude of U.S. and international polar-orbiting satellites available in the arctic regions. PolarWatch, an information portal for accessing ocean remote sensing data, was established to assist users in obtaining data derived from polar-orbiting satellites to support various applications and research in the Arctic and Antarctic.

## POLARWATCH: A GATEWAY FOR OCEAN REMOTE SENSING DATA



PolarWatch is a joint initiative between the NOAA National Environmental Satellite, Data, and Information Service (NESDIS) / Center for Satellite Applications and Research (STAR) and the NOAA National Marine Fisheries Service (NMFS) / Southwest Fisheries Science Center (SWFSC). It was created at the West Coast regional node (WCRN) of CoastWatch, which is part of the SWFSC Environmental Research Division (ERD) in California. PolarWatch builds upon and leverages the NOAA CoastWatch/OceanWatch program ([coastwatch.noaa.gov](http://coastwatch.noaa.gov)). The WCRN has a proven track record of engaging with and training users. The use of PolarWatch ERDDAP, a data access system developed by ERD, facilitates data distribution to existing and emerging Arctic and Antarctic data portals and serves as the underlying data system for the PolarWatch data discovery and access interface.

Initiated in the fall of 2016, PolarWatch ([polarwatch.noaa.gov](http://polarwatch.noaa.gov)), is a NOAA effort that advances the priorities outlined in the 2014 Plan by providing easy access to relevant data sets. The mission of PolarWatch is to deliver physical and biological ocean remote sensing data – such as surface winds, sea ice properties, ocean color, waves, temperature, salinity, and sea surface height—from multiple satellite sensors to diverse end-users, in support of broad applications in the Arctic and Antarctic.

The first year of the initiative focused on identifying potential polar ocean remote sensing datasets; evaluation of dataset accessibility; testing services, formats, polar projections; and demonstrating dataset integration and distribution. This process helped identify the information needed for ingesting new datasets

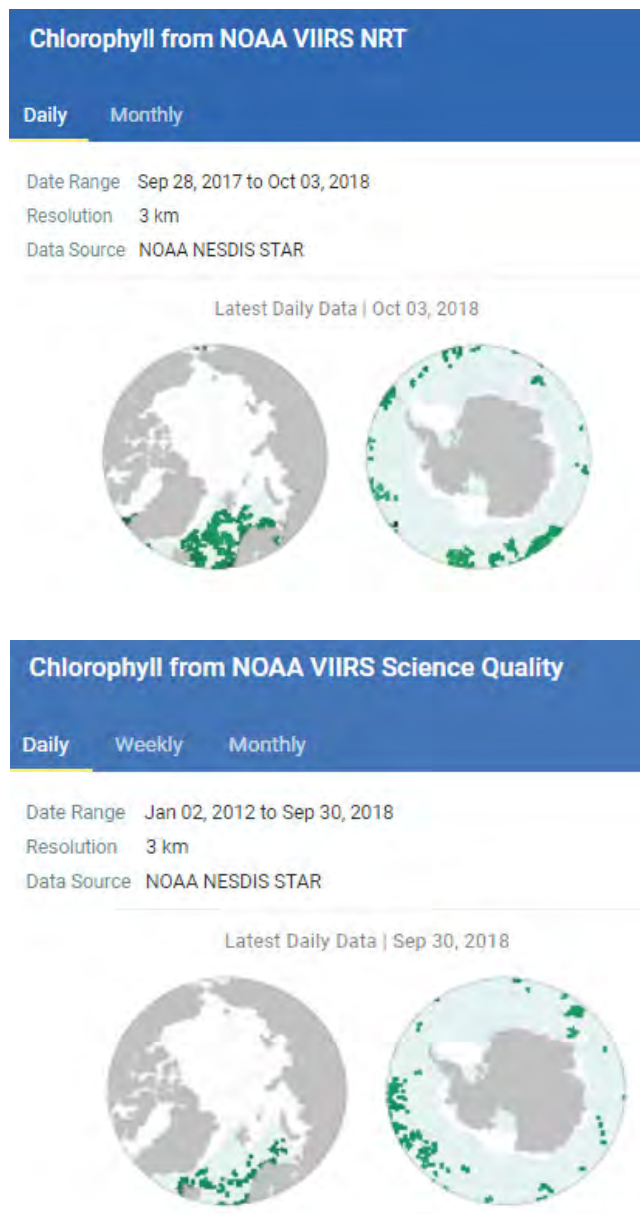
into the system. A beta version of the data distribution system and data discovery interface was released on the PolarWatch website in 2017.

## BENEFITS

Some oceanographic applications depend on near real time data for their analyses, while others, like fisheries and ecosystems studies, study a long time data series in order to examine patterns and document changes. Unique long-term data sets and analytical tools facilitate synthetic analyses across sites. As the Polarwatch portal aims to help distribute satellite data products to existing and emerging Arctic and Antarctic data portals, it accommodates these different needs by providing access to near real-time as well as science quality data datasets (as shown respectively in the examples to the right), which span the full temporal range of the dataset. In addition to the targeted content, the portal offers customizable features in a somewhat personalized environment, as well as development tools and tutorials to help users obtain and work with satellite data. For example, one of the downsides of creating portals with lots of data is that it can be hard for users to find the specific data they need. There is a lot of crucial information in the metadata associated with datasets, such as temporal span, spatial resolution, and geographic coverage, which can help users decided if a dataset will meet their needs. This information isn't easily visible on the traditional ERDDAP setup. One of the accomplishments of PolarWatch has been to design a system that clearly displays the relevant metadata for datasets, as well as letting users search and filter metadata attributes, so that the available data are more discoverable.

Sea ice datasets and other oceanographic satellite datasets are distributed in different places, and in different formats, making it hard for users who want to acquire and use these datasets together. As sea ice datasets have not traditionally been distributed by CoastWatch, one of the goals of PolarWatch is to entrain sea ice datasets into the suite of oceanographic datasets served by CoastWatch, making PolarWatch a “one-stop” shop for polar satellite

data. Many of the sea ice datasets are in polar stereographic map projection, and one of the hurdles PolarWatch has been dealing with is creating infrastructure to serve these datasets on ERDDAP, which is designed to handle dates in geographic coordinates.



Many of the ice datasets are distributed in a near-real time (NRT) fashion, and getting access to long time series of these data can be more difficult. One of the goals of PolarWatch is to distribute the complete time series of various sea ice records, which ideally will be done by working with data providers to distribute the dataset of distributed THREDDS so that they can be seamlessly integrated in PolarWatch.

## ACCESS TO RESOURCES

98 matching datasets, listed in alphabetical order. PolarWatch ERDDAP

Grid DAP Data	Sub-set	Table DAP Data	Make A Graph	W M S	Source Data Files	Title	Summary	FGDC, ISO, Metadata	Background Info
	set	data	graph			* The List of All Active Datasets in this ERDDAP *			
data			graph	M		Aquarius Sea Surface Salinity, L3 SMI, Version 5, 1.0°, Global, 2011-2015, 3-Month		F I M	background
data			graph	M		Aquarius Sea Surface Salinity, L3 SMI, Version 5, 1.0°, Global, 2011-2015, 7-Day		F I M	background
data			graph	M		Aquarius Sea Surface Salinity, L3 SMI, Version 5, 1.0°, Global, 2011-2015, Daily		F I M	background
data			graph	M		Aquarius Sea Surface Salinity, L3 SMI, Version 5, 1.0°, Global, 2011-2015, Monthly		F I M	background
data			graph	M		Chlorophyll, NOAA VIIRS, Near Real-Time, Global, Level 3, 2014-present, EXPERIMENTAL, Daily		F I M	background
data			graph	M		Chlorophyll, NOAA VIIRS, Near Real-Time, Global, Level 3, 2014-present, EXPERIMENTAL, Monthly		F I M	background
data			graph	M		Chlorophyll, NOAA VIIRS, Near Real-Time, Global, Level 3, 2014-present, EXPERIMENTAL, Weekly		F I M	background
data			graph	M		Chlorophyll, NOAA VIIRS, Science Quality, Global, Level 3, 2012-present, Daily		F I M	background
data			graph	M		Chlorophyll, NOAA VIIRS, Science Quality, Global, Level 3, 2012-present, Monthly		F I M	background
data			graph	M		Chlorophyll, NOAA VIIRS, Science Quality, Global, Level 3, 2012-present, Weekly		F I M	background
data			graph	M		Chlorophyll-a, Aqua MODIS, NPP, L3SMI, Global, 4km, Science Quality, 2003-present (1 Day Composite)		F I M	background
data			graph	M		Chlorophyll-a, Aqua MODIS, NPP, L3SMI, Global, 4km, Science Quality, 2003-present (8 Day Composite)		F I M	background
data			graph	M		Chlorophyll-a, Aqua MODIS, NPP, L3SMI, Global, 4km, Science Quality, 2003-present (Monthly Composite)		F I M	background

Data is distributed via the PolarWatch ERDDAP (Environmental Research Division’s Data Access Program), a server that allows you to download subsets of gridded, scientific datasets, in standardized machine-readable formats (e.g. netCDF, MATLAB, geoJSON, XML) and includes metadata that follows the standards for COARDS, Climate Forecast (CF), and Attribute Conventions for Data Discovery (ACDD). ERDDAP download formats also include images (geoTIF, PNG, KML, PDF) and various text formats. The catalogue provides data preview and access pages, including details and background information about each data product. Data downloads may be customized by area, date, parameter, and file format.

Currently, datasets available on the PolarWatch ERDDAP include ice coverage, sea surface temperature, ocean surface winds, and ocean color.

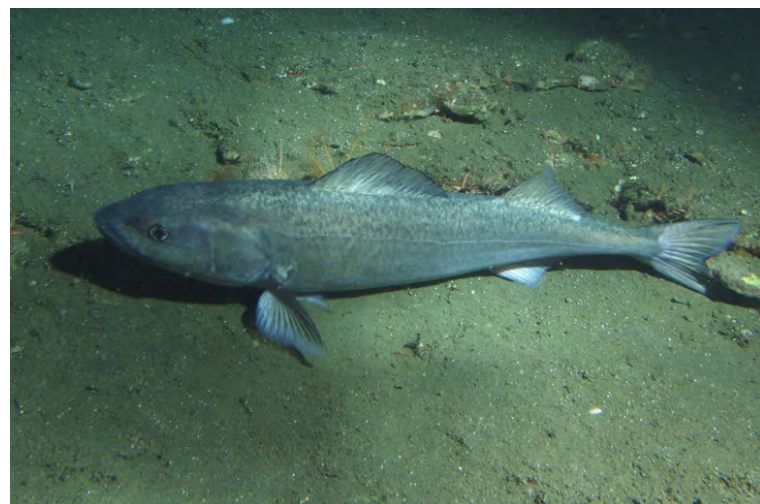
### IS POLARWATCH FOR ME?

The initial focus has been on the needs of fisheries users. The WCRN, which has been instrumental in setting up PolarWatch, has extensive experience working with fisheries users, and consequently has a good understanding of their needs for satellite data. In particular, fisheries users want to be able to access a suite of datasets, SST, including ocean color, currents, and sea ice

concentration, to understand the habitats of living marine resources. They also want to understand how these habitats are changing over time, so they want easy access to long time series of these data records.

### NOAA FISHERIES STOCK ASSESSMENT

The Alaska Fisheries Science Center (AFSC) is developing stock-specific Ecosystem-Socioeconomic Profile (ESP) reports, which will be part of the traditional stock assessment fishery evaluation (SAFE) reports. Satellite-derived datasets from PolarWatch will be a useful source for developing stock indicators for marine species such as the Alaska Sablefish.



## JUST THE TIP OF THE ICEBERG

The discovery and access interfaces for PolarWatch will be refined over the next year, and work is underway to expand the data catalog. As part of the data curation effort, targeted guidance is being developed for satellite data providers on metadata best practices (CF, ACDD) for enhanced data discovery and preparation for publishing data in netCDF format and distribution via ERDDAP and THREDDS.

There are plans in place to leverage existing collaborations with NOAA's National Centers for Environmental Information (NCEI) Arctic Team and the U.S. National Snow and Ice Data Center (NSIDC) to ensure that PolarWatch complements the existing national polar data services and portals. Initial user engagement has been targeted at NOAA Fisheries users in AFSC and AERD, with activities that include meetings, site visits and workshop presentations. These type of interactions will expand into the future to ensure that PolarWatch provides the service needed to respond to arctic challenges.

## SUMMARY

For decades now, satellite data from the Arctic and Antarctic regions have helped scientists and decision makers understand the impact changes in environmental conditions have on local, regional and global weather patterns, and the potential to affect the economies of these areas. These data and products also provide the critical tools needed to evaluate the effectiveness of changes in policies and actions being considered to mitigate these impacts. The

remote Arctic and Antarctic areas have become dependent on satellite data and products to supplement the large data sparse regions where conventional observations are not available. With the launch of NOAA-20 in late 2017 and the continued data from Suomi NPP, forecasters in these remote regions will be able to have a strong foundation of satellite data to support their operational missions.

PolarWatch is designed to deliver satellite data products, from a variety of sensors and data providers, to a variety of end-users to support broad applications in the Arctic and Antarctic. Consistent and reliable infrastructure helps to ensure easy access to large satellite datasets for numerous end-users around the world.

PolarWatch, which was built using existing CoastWatch ERDDAP datasets, has been facilitating access to near real time and long-term satellite-derived ocean data from the Arctic and Antarctic. Well into its second year of implementation, the initiative continues to expand data discovery and access, as well as evolve content, including tailored data, products and tools. Of note are sea ice datasets, which traditionally had not been distributed by CoastWatch. Two key users, the AFSC and the AERD, have already embraced the satellite data and are utilizing it in their applications. With a diverse and expanding line up of users including local, state, federal, and international communities, PolarWatch is well on the way toward achieving its long-term objective to facilitate access to current, historical, and future ocean satellite data and products to support a broad and diverse range of users in meeting their needs for decision making or assessments. ❖

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# **NEURAL NETWORK RETRIEVALS OF *KARENIA BREVIS* HARMFUL ALGAL BLOOMS IN THE WEST FLORIDA SHELF**

The information in this article is based, in part, on the May 21, 2018 JPSS science seminar presented by Sam Ahmed, NOAA CREST, City College New York (CCNY). It features work being done by Ahmed El-Habashi, NOAA CREST Optical Remote Sensing Laboratory, City College of the City University of NY, Vincent Lovko, Mote Marine Laboratories, Sarasota FL, and Drs. Richard P. Stumpf and Michelle C. Tomlinson, NOAA National Centers for Coastal Ocean Science, Silver Spring, MD.



Massive *Karenia Brevis*, Harmful Algal blooms (KB HABs) in Florida observed moving toward the beach. HABs like this “red tide” off the Floridian coast can cause illness and death in humans and animals.

Harmful algal blooms (HABs) occur when colonies of algae grow explosively and produce toxins that kill fish and pose a health hazard to humans and animals. HAB events can have an adverse effect on tourist economies as they tend to result in alerts and warnings, which can lead to beach closures. In the United States, an estimated \$100 million or more is lost annually as a result of HABs.



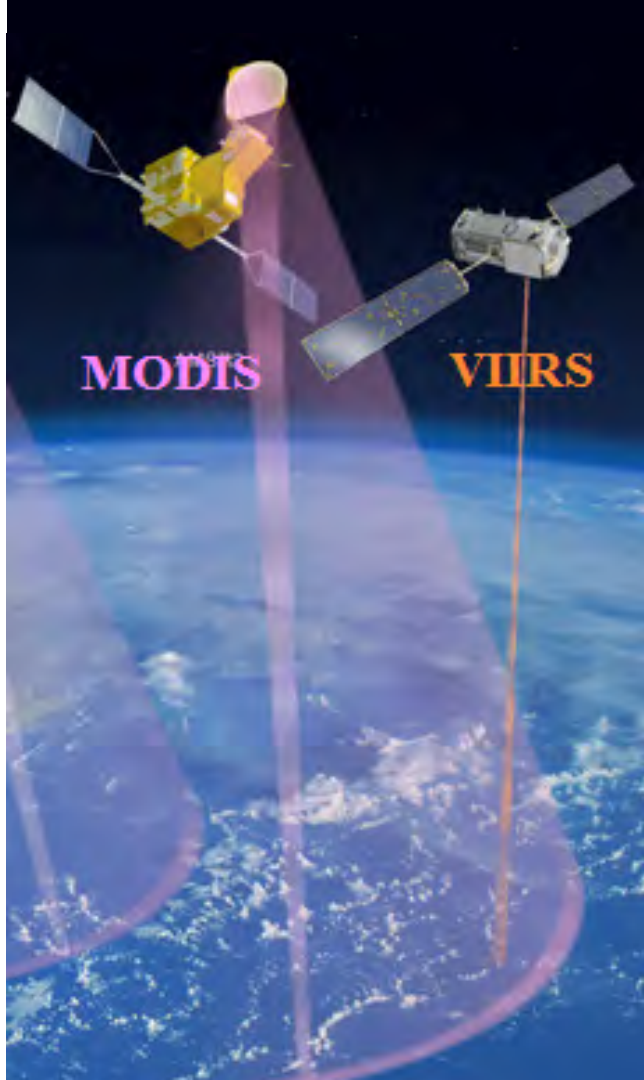
Single celled *Karenia brevis* (NOAA).

There are approximately 5,000 species of phytoplankton, but only 300 or so can cause color change. *Karenia Brevis* (KB), a species that is known to cause color change, is

especially prevalent in the West Florida Shelf (WFS). Recent blooms from the species, have had adverse impacts on human health, the economy, and the environment in the region.

KB HABs in the WFS have been detected, quantified and tracked with observations from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor on the polar-orbiting Aqua satellite using the normalized fluorescence height (nFLH) and Red Band Difference (RBD) techniques which rely on measurements from the instrument’s 678 nm fluorescence channel. The Visible Infrared Imaging Radiometer Suite (VIIRS) sensor onboard the Suomi-National Polar-orbiting Partnership (Suomi NPP) and NOAA-20 satellites is a next generation sensor and successor to MODIS. However, VIIRS does not have a 678 nm chlorophyll [Chl] fluorescence channel. The lack of this channel has not been a deterrent for the scientists at the NOAA Center for Earth System

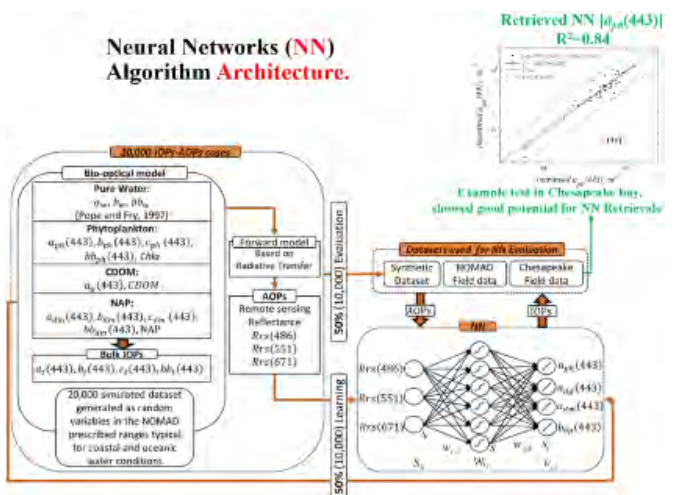




## NEURAL NETWORKS (NN) ALGORITHM ARCHITECTURE

A multilayer perceptron neural network (NN) was developed based on a bio-optical model with four components: pure water, phytoplankton, colored dissolved organic matter (CDOM), and non-algal particulates (NAP), which was used to create a simulated dataset consisting of 20,000 random variables. The NN was trained on 10,000 which were based on coastal and oceanic parameters from the NASA Bio-Optical Marine Algorithm Data set (NOMAD) to retrieve  $a_{ph(443)}$  and hence [Chl] from  $R_{rs}$  values at 486, 551 and 671 nm, bands which are available on VIIRS. The NNIt was then tested and validated on the remaining 10,000 simulated dataset and CREST field measurements in the Chesapeake Bay. It continues to be validated by the current work in the WFS.

Sciences & Remote Sensing Technologies (CREST) Optical Remote Sensing Laboratory, based at the City College of the City University of New York. They have made up for its absence by using a neural network algorithm, which makes use of Remote Sensing Reflectance ( $R_{rs}$ ) from three available visible VIIRS channels at the 486, 551, and 671 nm bands to retrieve  $a_{ph(443)}$  and hence [Chl]. These bands are also less impacted by atmospheric correction uncertainties. This feature article describes these efforts to retrieve absorption coefficients of phytoplankton at 443 nm ( $a_{ph(443)}$ ) using this customized NN approach. For this particular technique, the scientists are only interested in the  $a_{ph(443)}$  as it can be converted to equivalent chlorophyll-a concentrations [Chla] using an empirical approach based on in situ measurements in the WFS. With the extension of HAB monitoring capabilities to VIIRS, NOAA can continue to support local authorities in their reporting and forecasting of beach conditions, including health warnings, etc.



Flowchart of Bio-Optical model and the Forward Model simulations, and Architecture of VIIRS NN, one-hidden layer multilayer perceptron (MLP), trained with 10,000 set of  $R_{rs}$  and related IOPs.

Thus, the NN algorithm is used to retrieve  $a_{ph(443)}$  from VIIRS images and  $R_{rs}$  measurements over the WFS.

To retrieve KB HABS from the  $a_{ph(443)}$  images retrieved from VIIRS observations over the WFS, filters are devised to apply to those images. To devise these filters, use is made of two known constraints associated with KB HABS in the WFS. One is a low backscatter at 551 nm, manifested as a maximum permissible value of  $R_{rs}(551) \leq R_{rs}(551)_{max}$ . The other is a minimum permissible [Chla] min threshold value,

and hence an equivalent minimum permissible value:  $a_{ph}(443)_{min} \leq a_{ph}(443)$ . Based on these, two filter processes are devised and applied to delineate and quantify KB. Using the following procedures, VIIRS Rrs (486, 551, 671) are entered to the NN to obtain estimates and images of  $a_{ph}(443)$  (which is approximately proportional to  $[Chla]$ ) in the WFS. Then, in a second critical step, limiting criteria are applied to the images to filter out values of  $a_{ph}(443)$  which are known to be incompatible with KB HABS in the WFS; i.e.  $a_{ph}(443)_{min} \leq a_{ph}(443)$  and  $Rrs(551) \leq Rrs(551)_{max}$ . Following the application of these two filter processes, the residual image displays, in the figure below for VIIRS and MODIS retrievals, shows only those  $a_{ph}(443)$  values that are compatible with both criteria for KB HABS following application of the two filter constraints.

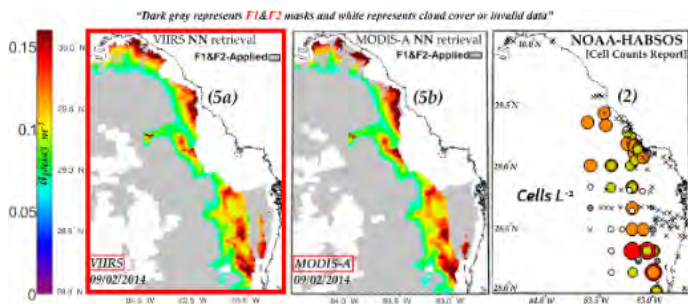
minutes–15 minutes of satellite overpass) KB cell counts collected by the Florida Fish and Wildlife Conservation Commission (FWC) over the 2012–2016 period.

Statistics of comparison for retrieval algorithms and their successful retrievals against in-situ observations (2012–2016). Higher NN retrieval accuracy may be due to use of longer wavelengths that are less impacted by atmospheric correction inadequacies.

Comparative analyses showed that when the window between in situ observations and satellite overpass measurements was reduced from 100 minutes to 15 minutes, retrieval accuracies greatly improved with increased correlations and reduced errors.

Comparisons against in-situ match-ups with HPLC measurements were also carried out for VIIRS retrievals obtained with the NASA Ocean Color product for chlorophyll-a (Ocx), Generalized Inherent Optical Property model (GIOP), Red Green chlorophyll-a Index  $[Chla]$  retrievals for WFS (RGCI), and Quasi-Analytical Algorithm version 5 (QAA\_5). It was found that GIOP and QAA algorithms exhibited negative values or no retrievals in many instances. When the negative values were excluded, 68 valid matchups remained for the 100-minute overpass window. When

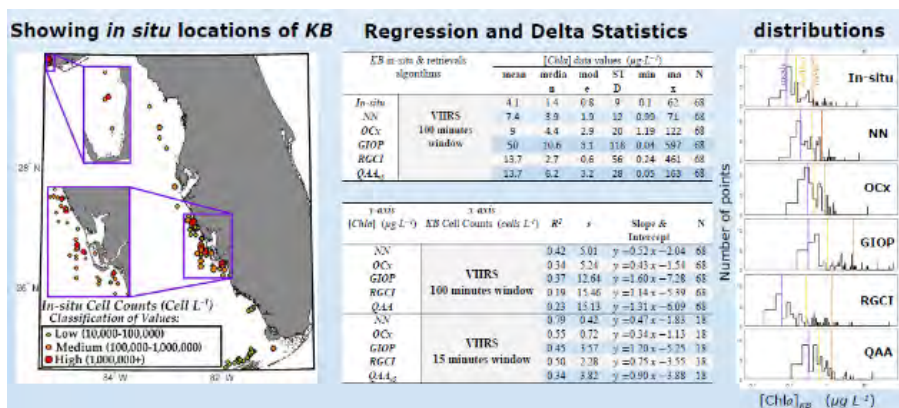
the overlap observation window was reduced to 15 minutes, 18 valid matchups remained, after excluding negative values associated with GIOP and QAA. These showed the NN technique to generally give the highest retrieval accuracies, both in terms of correlation with in-situ measurements as well as with the smallest error magnitudes.



Figures show the extent of KB blooms on September 2, 2014 after combined filters F1 and F2 are applied to VIIRS (left) and MODIS (middle).

## COMPARISONS WITH OTHER RETRIEVAL TECHNIQUES

To evaluate the accuracy of VIIRS retrievals using NN, they were compared against other satellite retrievals obtained using other techniques, including nFLH, as well as all available near-coincident (within 100



# NEURAL NETWORK RETRIEVALS VS. IN SITU MEASUREMENTS

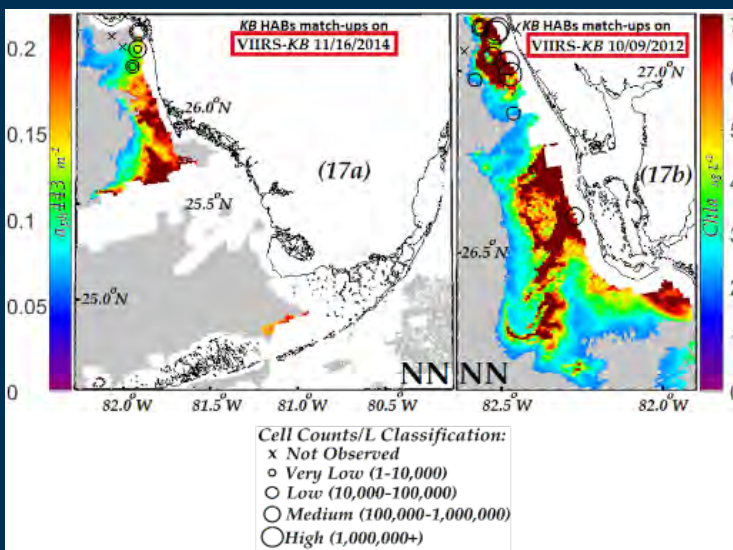
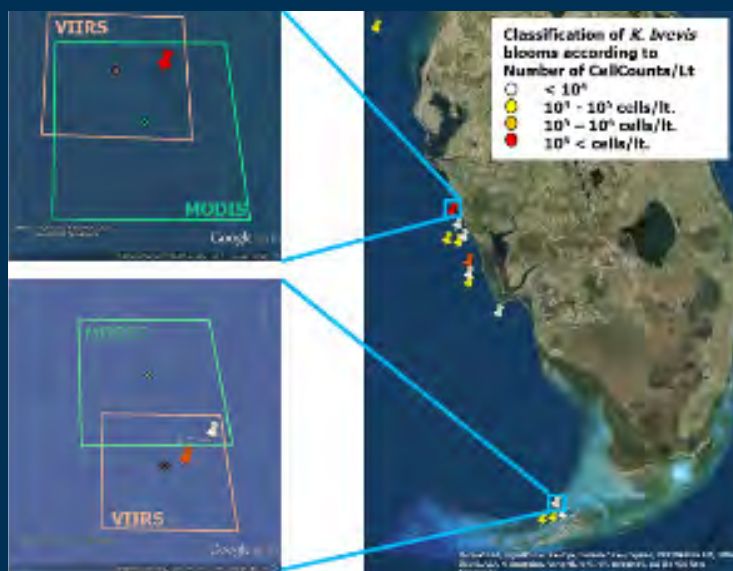
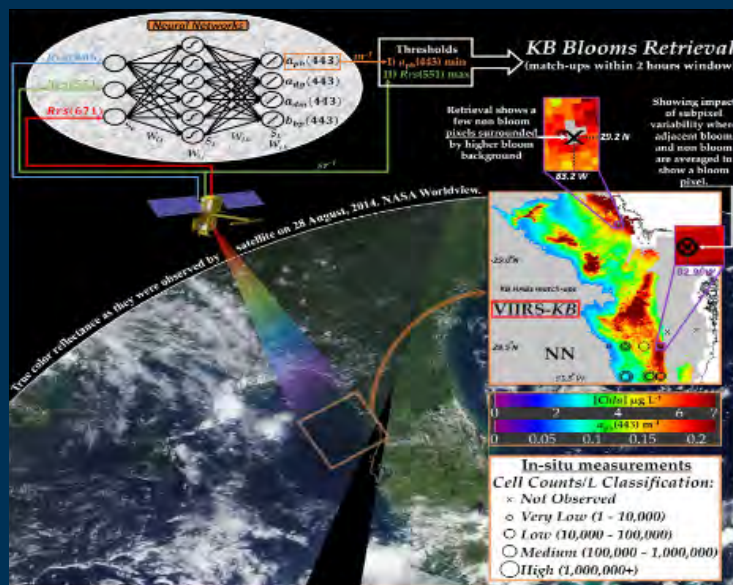
## Non-bloom-bloom conditions: August 28, 2014

VIIRS-NN KB HABs retrievals were compared against in situ measurements during a August 28, 2014 bloom event. Shown in the illustration to the right (top) are KB compatible values derived from the application of filter processes F1 and F2 to VIIRS NN  $a_{ph}(443)$ . The map inset shows the retrievals overlaid with cell counts for this date. White areas represent cloud cover or invalid data. There are a total of 20 matchups in that day.

It should be noted, that on this day, the adjacent pixel variability and averaging effect of intra-pixel variability non-bloom-bloom conditions erroneously indicated a bloom event. The image to the right (middle; for the same event) gives the location of 15 minutes coincident field data showing VIIRS and MODIS pixels. It was noted that while no in situ bloom was measured at the surface at that date, there was one below the surface almost at the same location. It was concluded that sub-pixel variations were the most likely source, as they are indistinguishable when pixel averaging takes place. According to the researchers, proximity to the edge of the bloom as well as changes taking place in the time window between in situ collections and second passes could have attributed to the ambiguities.

## In-shore blooms

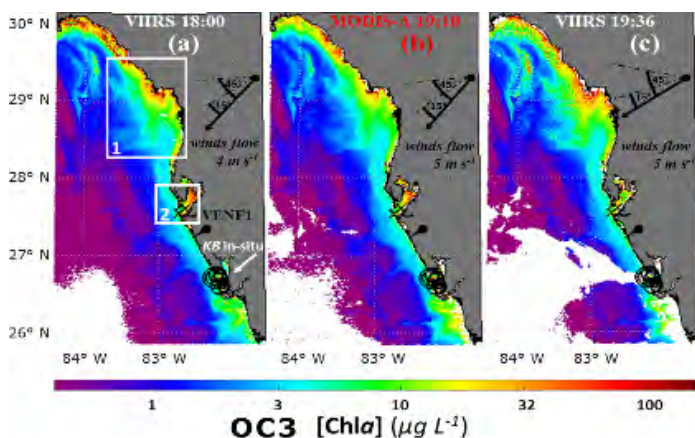
The figures on the right (bottom) show blooms near the coast on November 16, 2014 (left) and both near and offshore areas on October 9, 2012 (right). There were 12 matchups for October 9, and no false positives or negatives. The November 16 case was interesting because the retrieval was close to the



coast, and yet there were no false positives or negatives. Coastal waters as well as their surrounding atmospheric conditions tend to be complex, thus estimations of the water contents in these areas are quite difficult to obtain with high accuracy.

### Variations in bloom observed in consecutive satellite images

Shown below are consecutive satellite images of region 1 showing changes in bloom using retrieved OC3 [Chla]. The bloom, as delineated by the [Chla] color contour in the images, appears, qualitatively, to increase in concentration and expand in the southwest direction over the 96-minute interval between the consecutive overlapping VIIRS-MODIS-VIIRS images.



Consecutive satellite images on November 3, 2014.

### Field Measurements

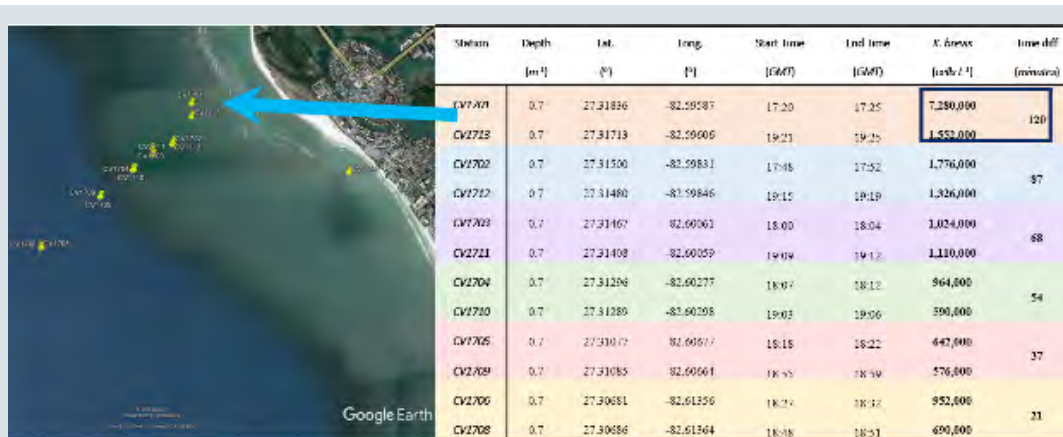
In situ field measurements lend credence to the satellite imagery of the temporal changes, intrapixel variations, and patchiness associated

with blooms in the WFS. These measurements were taken on an outgoing leg of a transect and repeated on the return leg, at stations at subpixel distances apart (generally 300m) off Lido Key, near Sarasota, Florida, and the HPLC samples analyzed at Mote Marine Laboratories.

The consecutive satellite images and the field measurement observations clearly indicate that the significantly increased bloom retrieval accuracy that occurs by shortening of the overlap time window between observation and in situ measurement matchups from 100 to 15 min is due to temporal changes in the observed bloom. A key point to consider when it comes to KB HABS satellite retrievals, and indeed, probably for any Ocean Color satellite retrievals.

### SUMMARY

Satellite ocean color imagery derived from [Chl] provides key information that is used in many ocean application including the detection of algal blooms. HAB events can adversely impact human health, the economy, and the environment. In the United States, revenues well over \$100 million are lost annually due to HABs. Of concern is the KB HAB, which is dominant in the WFS. In the past it's been detected using the 678 nm MODIS-A fluorescence band for retrievals using nFLH and RBD techniques. Although VIIRS, which extends and improves upon a series of measurements initiated by MODIS, lacks a fluorescence channel, the use of NN retrievals of aph443 from VIIRS show great potential for detecting and quantifying KB HABs in the WFS.



Transect of outward and return legs of field measurements.

While detailed comparisons with in-situ measurements are planned, factors affecting false positives and negatives remain to be

investigated. Results to date with the VIIRS NN technique remain promising. ❖

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El-habashi, A., Duran, C.M., Lovko, V., Tomlinson, M.C., Stumpf, R.P., Ahmed, S., (2017) "Satellite retrievals of *Karenia brevis* harmful algal blooms in the West Florida shelf using neural networks and impacts of temporal variabilities," *J. Appl. Remote Sens.* 11(3), 032408, doi: 10.1117/1.JRS.11.032408.

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# ENHANCING NCEP OPERATIONAL MODELS WITH SATELLITE-DERIVED OCEAN COLOR FIELDS

The information in this article is based, in part, on the June 25, 2018 JPSS science seminar presented by Avichal Mehra and Vladimir Krasnopolsky NOAA/NWS/NCEP/EMC. It features work being done by Drs. Avichal Mehra<sup>1</sup>, Hae-Cheol Kim, IMSG, James Cummings, IMSG, Eric Bayler, NOAA/NESDIS/STAR, Paul DiGiacomo, NOAA/NESDIS/STAR, and David Behringer, EMC



Ocean Color fields can help researchers identify areas in the Ocean with favorable or unfavorable conditions for fish. A school of yellow-tailed goatfish. Photo Credit: Dr. Dwayne Meadows, NOAA/NMFS/OPR. <https://www.photolib.noaa.gov/htmls/reef0653.htm>.

Ocean Color (OC) is an important parameter that provides a wealth of information on ocean states. This information is used in research, as well as in various applications including ecosystem monitoring, fisheries, and resource management. While other in situ instruments, such as ships, moorings, gliders, do not have the capabilities to provide a global synoptic view of OC observations, satellite-derived OC data provide the only means to quantify short- and long-term changes in the global ocean biosphere, as well as on regional ocean scales. Ocean color also helps scientists analyze and predict ocean biophysical processes, as well as establish a linkage to ocean ecological forecasts. Accurate predictions of biogeochemical (BGC) ocean states are made possible by ecosystem models with OC data assimilation (DA) capability. Ocean color data, such as chlorophyll-a concentration (Chl-a), are mainly used in determination of ocean primary productivity and water quality, initialization

and validation of bio-optical and ecosystems models, optimization of fishing conditions, and detection of algal blooms, among other applications. For this reason, Chl-a concentration is a key parameter derived from the ocean color measurements. In addition to enabling accurate predictions of the ocean environment, continuous satellite-derived OC measurements are essential to monitoring the health of the oceans. As a result, they must be exploited for analyzing and predicting ocean bio-physical processes, as well as for establishing a linkage to ocean ecological forecasts.

A key long-term goal for the U.S. National Weather Service (NWS) National Centers for Environmental Prediction (NCEP) Environmental Modeling Center (EMC) is integrating biogeochemical variables within NOAA's operational physical ocean models, implementing, as appropriate, the assimilation of relevant observations for an enhanced spectrum and accuracy of forecasts. To support this goal,



scientists at EMC have been exploring operational integration/assimilation of ocean color fields (chlorophyll,  $K_{dPAR}$ , and  $K_{d490}$ ) from the Joint Polar Satellite System (JPSS) Visible Infrared Imaging Radiometer Suite (VIIRS) into the NOAA's global operational ocean and coupled model (Real-Time Ocean Forecast System) at various temporal and spatial scales.

Numerical modeling of, and data assimilation techniques for environmental and biogeochemical parameters have undergone advancements that have enabled the state of primary environmental and biogeochemical variables to closely represent reality more than ever before. However, the assimilation of biological parameters is much more challenging and its development has lagged far behind that of physical variables such as temperature, salinity, and sea surface height—whose datasets are more readily available for assimilation through various platforms.

This feature article describes these efforts to integrate OC data into global operational ocean and coupled modeling at NCEP. More specifically, it will describe the efforts to ingest Near Real Time (NRT) and science quality (SQ) data into ocean models for physical and biological processes with the goal to improve operational ocean forecasts. It will also describe efforts to fill gaps in OC data by applying an artificial intelligence technique, neural network (NN) model; and to investigate improvements in these models by using more representative OC fields. The efforts build upon existing and to-be-built algorithms and techniques from an ongoing project using OC data in NCEP operational modeling, and another that uses NNs to fill gaps in VIIRS data, estimate future ocean color fields, and integrate gap-filled ocean color data fields into NOAA's global operational ocean models.

## INSIGHTS FROM OCEAN COLOR

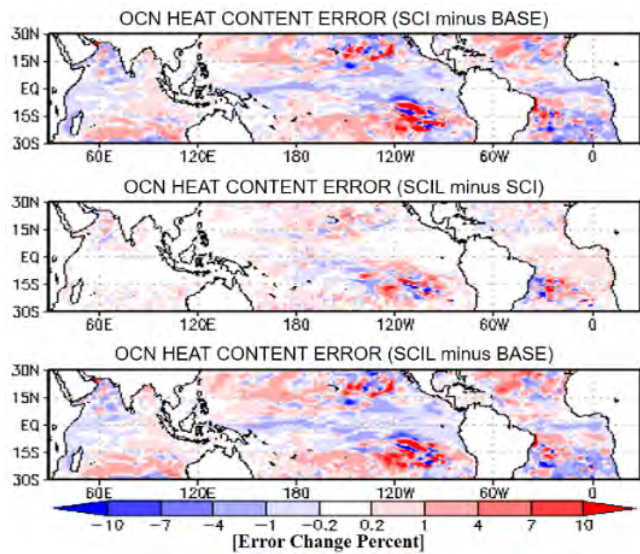
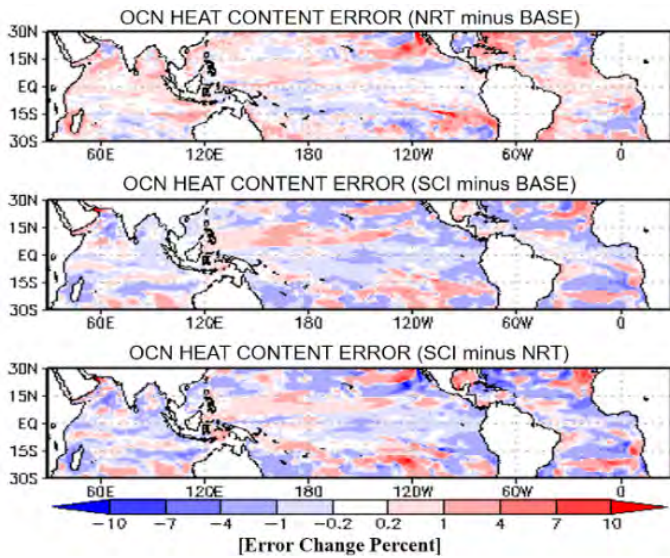
Ocean color data can provide very useful information on near-surface bio-physical feedback in terms of near-surface water column stability of the ocean, particularly the upper ocean, coupled ocean-atmosphere heat fluxes,

and coupled ocean-atmosphere moisture fluxes, as well as information on ocean-atmosphere biogeochemical fluxes, such as carbon, oxygen, dimethyl sulfide cycle through marine ecological processes. In fact, satellite derived OC data such as Chl-a, the diffuse attenuation coefficients at 490 nm ( $K_{d490}$ ), and for photosynthetically available radiation ( $K_{dPAR}$ ) have been, by far, the most easily accessible and most frequently used products for providing up-to-date information on marine primary producers (phytoplankton) and their photosynthetic activity (primary production), which are critical to an understanding of the dependent oceanic food webs in a region and the biogeochemical cycles relevant to global processes. However, limitations in observations, such as two-dimensional surface fields with limited temporal resolutions, can make it challenging to get a full grasp of the physical/biogeochemical states of oceans on a global scale.

## USE OF OCEAN COLOR IN OCEAN MODELS

In the NCEP modeling applications, two time scales are particularly relevant: seasonal to interannual and subseasonal to seasonal. For seasonal scales, the NCEP scientists focused on coupled systems, employing the Modular Ocean Model version4 (MOM4) core of NOAA's operational seasonal-interannual Global Ocean Data Assimilation System (GODAS; Behringer, 2007), the ocean component of NOAA's operational Coupled Forecast System (CFS), and examined the differences in model response to different ocean color inputs. They also investigated model improvements by incorporating two-way coupling to account for biological variability in the climate system, changes in circulation and atmospheric feedbacks.

For the subseasonal to seasonal, they focused on the Real-Time Ocean Forecast System (RTOFS), NOAA's global operational ocean modeling system based on HYbrid Coordinate Ocean Model (HYCOM) with eddy-resolving resolution and Navy Coupled Ocean Data Assimilation (NCODA) system.



## EXPERIMENT ON SEASONAL TIME SCALES

The first set of experiments had three OC ocean model runs. BASE used four-year monthly climatological data from the NASA Sea-viewing Wide Field-of-view Sensor (SeaWiFS); SCI used VIIRS science-quality; and NRT used VIIRS NRT. The NCEP Global Ocean Data Assimilation System (GODAS) ocean analyses served as observations, and all were based on four-year ocean model runs from 2012–2015.

They found that for seasonal scales, VIIRS science-quality Chl-a significantly outperforms Near Real-Time (NRT) VIIRS and BASE (using SeaWiFS 4 year climatology) in ocean model simulations. Additional conclusions included the impact of 14-day latency for VIIRS Science-quality data, which they determined to be of little significance.

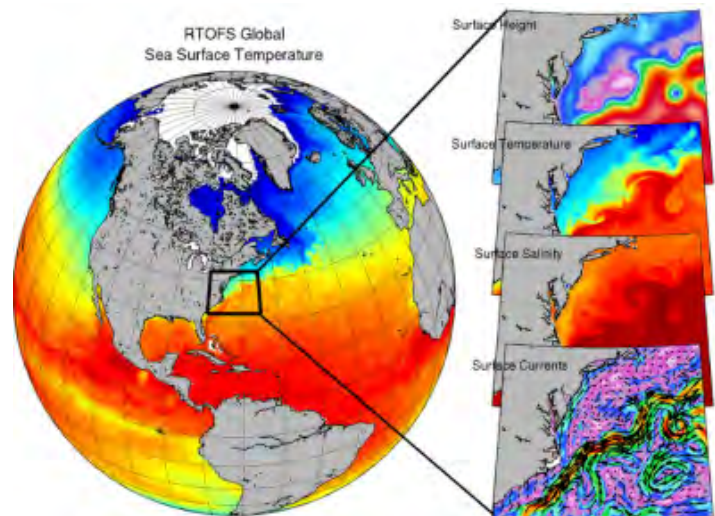
## IMPACT OF LATENCY ON OCEAN COLOR MODELING

The second set of experiments studied the impacts of latency in the availability of OC data. Like in their previous experiment, the scientists used three OC ocean model runs, BASE, SCI and SCIL, which is the same as SCI, except for a 14-day latency of Chl-a. Once again, the NCEP Global Ocean Data Assimilation System (GODAS) ocean analyses served as observations, and all were based on four-year ocean model runs from 2012–2015 without surface relaxation of SST.

They found minimal impact of 14-day latency (SCIL vs SCI), which led them to conclude that the science quality data would give the same performance with or without a delay.

## REAL-TIME OCEAN FORECAST SYSTEM (RTOFS)

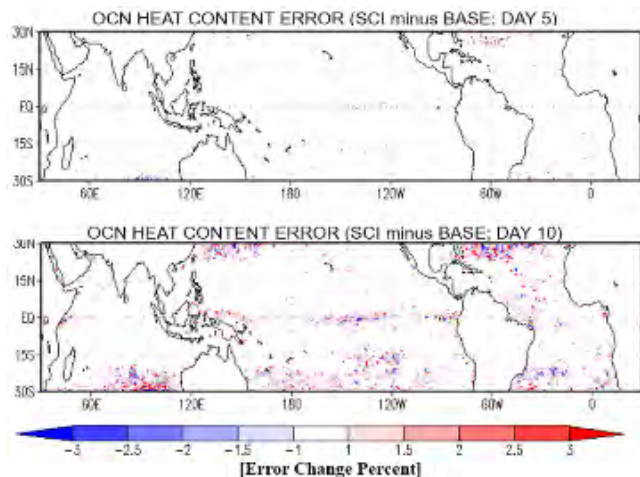
NCEP generates daily “ocean weather” forecasts from its Real-Time Ocean Forecast System (RTOFS), which uses 1/12th-degree Hybrid Coordinate Ocean Model (HYCOM) with vertical coordinates that include 41 layers, following isopycnals in the deep ocean, z-levels near the surface, and terrain-following  $\sigma$ -coordinates in coastal areas. It is initialized daily with NAVOCEANO 3DVAR data assimilation



An example of sea-surface temperature field forecasted by the operational RTOFS-Global with regional forecast of sea surface height, temperature, salinity and currents ([www.polar.ncep.noaa.gov/global](http://www.polar.ncep.noaa.gov/global)) for more details; Figure Credit: Spindler.

from NCODA (Navy's Coupled Ocean Data Assimilation), and supports the U.S. Navy's Global Data Assimilation System (GDAS) daily two-day nowcast as well as the Global Forecast System (GFS) eight-day forecasts.

## EXPERIMENT ON WEATHER TIME SCALES

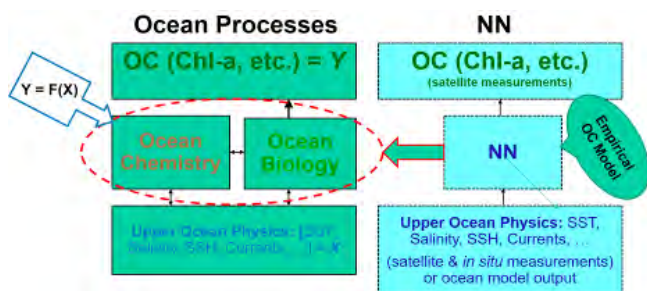


To study the impact of OC on weather time scales, the scientists conducted experiments using BASE and SCI. As in previous experiments, the GODAS ocean physics analyses served as observations, but based on 10-day ocean model runs for 2017.

For weather scales ( $\leq 10$  days), they found that VIIRS Science-quality Chl-a results were comparable to BASE for 1/12-degree ocean model simulations.

## INTRODUCTION TO NEURAL NETWORK (NN) MODEL

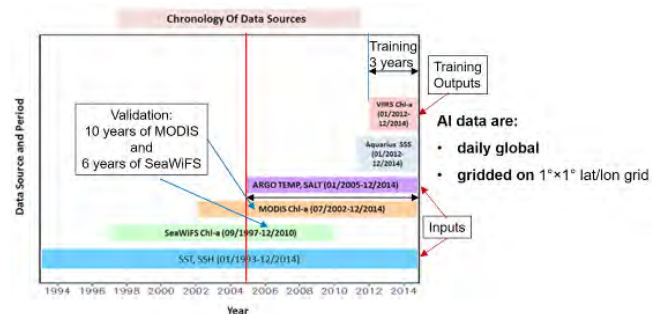
Neural Networks exploit relationships, that exist between upper-ocean physics and ocean color. Put differently, they utilize linkages between signatures of biological activity, which can be



observed from OC parameters such as Chl-a, and signatures of upper-ocean dynamics such as SST, sea-surface salinity (SSS), sea-surface height (SSH), and near-to-surface vertical profiles of oceanic state (temperature, salinity, velocity, density, etc.).

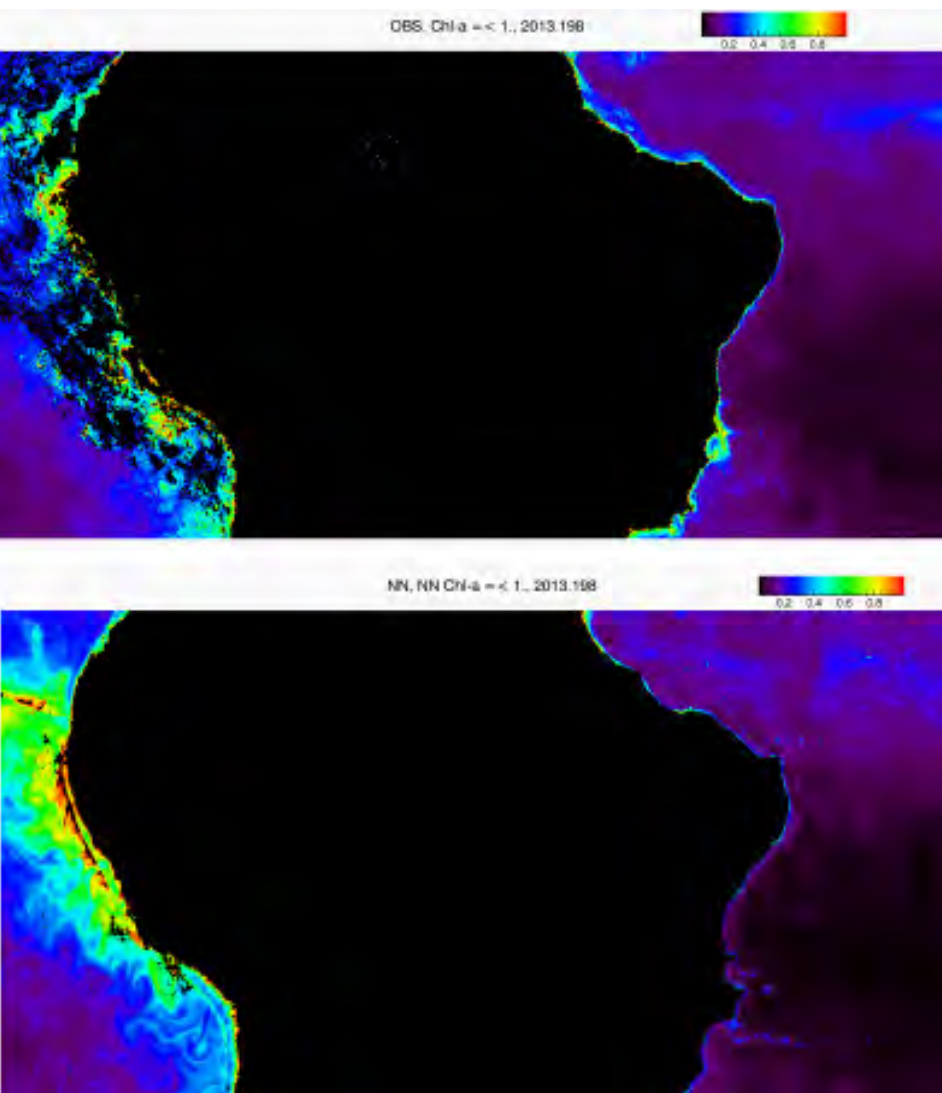
Neural Networks are accurate, fast, robust, computationally inexpensive, and flexible in that they can take multiple inputs and generate multiple outputs. Training is a complicated and time-consuming nonlinear optimization task that is done once for a particular application. The trained NN, providing accurate and fast emulations biochemical processes, is then repeatedly applied to new data.

This study employed VIIRS OC, satellite SSS/SSH/SST, and gridded vertical profiles of temperature (T) and salinity (S) from ARGO. The data sets were interpolated to the same spatial (one-degree latitude-longitude) grid and temporal resolution (daily) for 2012–2014. The NN technique covered three years, including two for training and one for testing. The NN output were assessed for: (i) bias, (ii) variability, (iii) root-mean-square error (RMSE), and (iv) cross-correlations.



Their results, as illustrated on the following page, showed that VIIRS Chl-a observations had a lot of missed data compared to the NN trained on  $1^\circ$  by  $1^\circ$  data. The NN also predicated more fine-scale parameters hidden in the gap-filled VIIRS data.

This study demonstrated that NN can be employed as a viable option for filling gaps in data as well as in fusing OC data from different satellites and creating a long-term data set of consistent OC data. This is



VIIRS OBS 1/12°x1/12° Chl-a (Top) and 1/12°x1/12° Chl-a predicted by NN trained on 1°x1° data (bottom).

especially important as instruments, processing, communications, and cloud-cover issues create gaps. The NN provides a knowledge-based approach to filling gaps through the correlation of the ocean color value to other physical parameters, e.g., temperature, salinity, and vector motion. This study also demonstrated that employing correlations with other predicted physical parameters provides the means for predicting the ocean color parameter and, thus, enables ocean color data assimilation.

## ECOSYSTEM MODELING

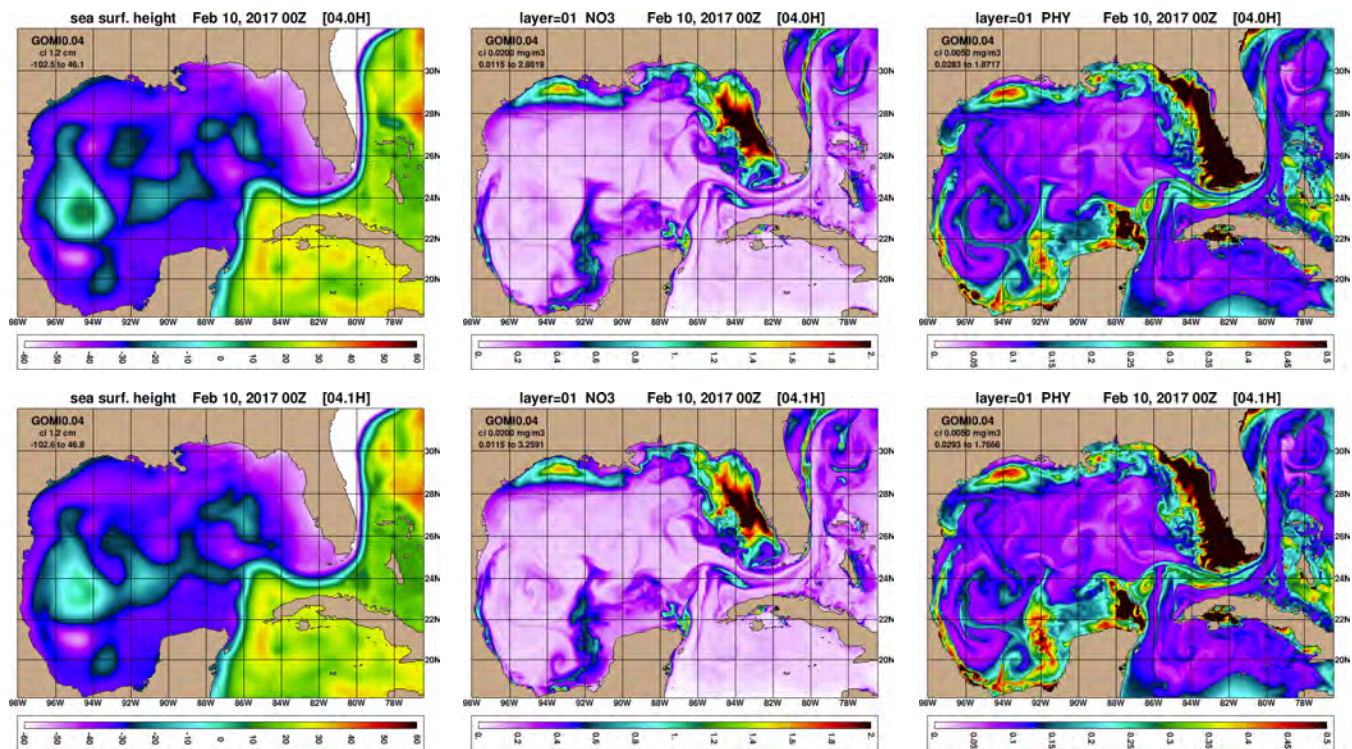
Understanding and modeling biogeochemically-physically coupled processes are foundational to ecological forecasting. But their true essence cannot be captured with incomplete, or with

a lack of, OC data in models. As a result, continuous (gap-free) satellite OC fields are essential not only for biogeochemically-physically coupled model development and initialization, but for data assimilation capability of the model. A primary objective stated in the NOAA Ecological Forecasting Roadmap (EFR) for 2015–2019 is the provision of “dependable, higher quality forecast products, derived from the successful transition of research and development into useful applications...” To support this, EMC scientists are also evaluating approaches and developing a prototype foundational global biogeochemical modeling capability for NOAA’s RTOFS to reliably provide the global modeling fields required to support the ecological forecasts of the EFR technical teams.

As VIIRS OC data provides a unique path toward ecological forecasting through biogeochemical (BGC)

analyses and forecasts, facilitating both real-time and scenario-based marine ecosystem applications, this work plans to address key linkages and gaps within the EFR infrastructure framework using the JPSS VIIRS OC data assimilation techniques and biogeochemically-physically coupled modeling frameworks.

Some activities taking place include the implementation of the assimilation of physical and biogeochemical variables (3DVAR) in RTOFS-BGC-DA. Along with this, complexities have been added into the ecosystem module to predict system responses to potential changes by drivers (natural or through ecosystem management decisions). The goal of this is to assess ecosystem dynamics as well as the effects of carbon and oxygen dynamics between the atmosphere and the ocean and subsequent changes in the acidity of the global ocean.



Comparisons between free (top) and data-assimilative (bottom) runs for sea surface height (1st column), nitrate nitrogen (2nd column), and phytoplankton nitrogen (3rd column).

## REGIONAL ASSOCIATIONS (RAs)

The Integrated Ocean Observing System (IOOS®) ([ioos.noaa.gov/about/about-us](http://ioos.noaa.gov/about/about-us)) is a national-regional partnership working to provide new tools and forecasts to improve safety, enhance the economy, and protect our environment. The U.S. IOOS is comprised of 11 regional associations (RAs), which guide development of and stakeholder input to regional observing activities. The RAs serve the nation's coastal communities, including the Great Lakes, the Caribbean and the Pacific Islands and territories. The RAs have shown considerable



interest in event-based forecasting of HAB's, hypoxia and pathogens. There is varied maturity of ecosystem forecast and products at the different RA's.

Aforementioned global biogeochemically-physically coupled ocean modeling framework with both physical and biogeochemical data assimilation capability can provide initial and boundary conditions to the inner nests maintained by regional operational systems. Therefore, targeted users within NOAA include the Ecological Forecasting Roadmap technical teams (harmful algal blooms, hypoxia, habitats), as well as those explicitly involved with numerical modeling and prediction in conjunction with the NOAA Ecological Forecasting Infrastructure and Process team. For example, the new data-assimilating NOAA West Coast Ocean Forecast System (WCOFS) is being developed with a specific objective of accommodating biogeochemical modeling and it explicitly leverages such an integration project funded by the NOS Integrated Ocean Observing System (IOOS) Program Office and the IOOS Coastal and Ocean Modeling Testbed.

## SUMMARY

OC data provides a wealth of information on ocean states. This information is used in operational forecasting, research, along with a wide variety of related applications including ecosystem monitoring and resource management. Satellite-derived OC fields are essential for assimilation in models as they enable them to address a biophysical feedback process that is particularly important to coupled ocean-atmosphere modeling. NOAA scientists have been using near real-time VIIRS and other OC fields for its operational ocean and coupled

seasonal forecast systems. Efforts by scientists from the EMC to integrate JPSS VIIRS OC data in the NCEP numerical ocean models have shown great promise in improved forecast accuracy. In addition, efforts using NN to fill data gaps and provide projected OC values needed to run the model into the future for predictions are showing even greater promise by providing continuous OC data and projected values. The NN have consistently predicated many finer scale parameters previously hidden in the gap-filled VIIRS data. ❖

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# **NOAA-CREST FIELD EXPERIMENT ACTIVITIES TO SUPPORT JPSS MISSION AND HYDROLOGICAL APPLICATIONS**

The information in this article is based, in part, on the July 16, 2018 JPSS science seminar presented by Tarendra Lakhankar, NOAA-CREST Center, The City College of New York, New York, NY. It features work being done by Peter Romanov, Jonathan Munoz, Nir Krakauer and Reza Khanbilvardi.



CCNY NOAA-CREST students and scientists taking a breather from measuring snow properties in a field site in Maine.

Snow only occurs in certain regions, yet it has far-reaching effects on weather patterns across the globe. It drives many of the essential processes that keep the planet in balance. Snow is an important part of the hydrologic cycle. Its melting helps fill reservoirs and rivers in many regions of the world, including the western United States. Snowmelt provides over 70 percent of the water supply in the western U.S., according to the National Oceanic and Atmospheric Administration/National Operational Hydrologic Remote Sensing Center (NOAA/NOHRSC)—the agency that provides comprehensive snow observations, analyses, data sets and map products for the nation. While snowmelt in spring from a bountiful snowpack brings fresh water to reservoirs, a diminished snowpack can jeopardize water supplies. In addition, snow plays a significant role in the U.S. economy via the billion dollar winter sports and tourism industries. A diminished snowpack

would have a negative impact on the sectors of the U.S. economy and society that are deeply dependent on it.

By gathering information on various snow parameters, including how snow forms, falls, and changes over time, scientists can help advance knowledge on how snow and weather interact. In addition, properties such as snow cover, depth, and wetness affect how changes in snow cover affect climate, glaciers, and water supplies around the world. Therefore, awareness of snow and its properties is essential for many, including hydrologists, water resources managers, and decision-makers.

This feature highlights the efforts of a research team from the City University of New York (CUNY) to collect details on snow characteristics using sophisticated in-situ instruments as well as those on polar-orbiting satellites, such as the next generation Visible Infrared Imaging



Radiometer Suite (VIIRS), a scanning radiometer onboard the Suomi National Polar-Orbiting Partnership (S-NPP) and the geostationary satellite NOAA-20 that collects visible and infrared imagery and radiometric measurements of the land, atmosphere, cryosphere, and oceans as part of the Joint Polar Satellite System (JPSS).

## CONSTRAINED SETTINGS

Snow measurements can be obtained using conventional methods such as ground-based weather stations at which observations of snow fall and accumulation are performed. But much snow falls on remote and inaccessible areas of the Earth's surface that are not well monitored by conventional observations. Satellite sensors, which provide higher spatial and temporal resolutions than conventional methods, have helped fill in these voids.

Microwave satellite remote sensing has shown great potential in estimating snowpack properties such as snow depth and Snow Water Equivalent (SWE) over large areas where reliable ground observations may not exist. However, other snow properties such as snow density and snow grain size, are variable in space and time and tend to impact the microwave signal scattering, which affects the accuracy of the estimating SWE based on the satellite data. Moreover, current snow radiative transfer (RT) models cannot adequately reproduce microwave emission of seasonally-evolving natural snow packs. One reason for this situation is a lack of long term in situ synchronous observations of snow pack emission and physical properties. Snow RT model development and validation, which would enable more accurate snow measurements from existing and future satellite sensors, requires these challenges to be overcome.

## MEETING THE CHALLENGE WITH FIELD EXPERIMENTS

The NOAA-Cooperative Remote Sensing Science and Technology Center (CREST), funded by the NOAA Educational Partnership Program (EPP), runs snow and soil moisture field measurements

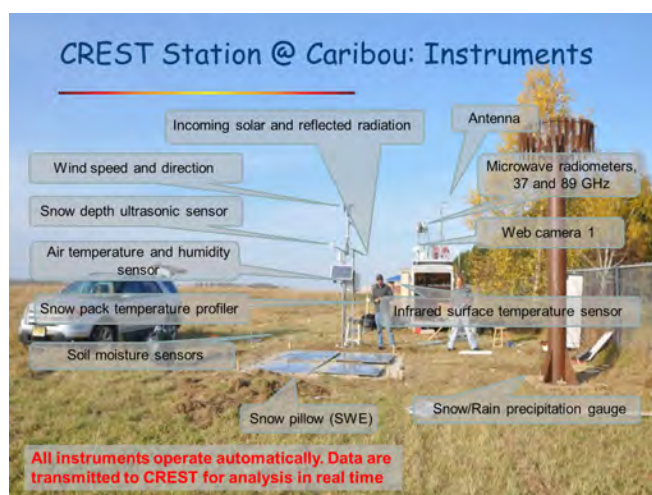
and campaigns. The CREST-Snow Analysis and Field Experiment (CREST-SAFE) campaign was motivated by the lack of long-term field observations of snowpack properties and their effect on the microwave emissions that satellite sensors see. This prompted a research team from the center to leverage field campaign methodology to study seasonal changes in the snowpack, test newly developed instrumentation for snow research, develop snow depth and snow water equivalent (SWE) retrieval techniques, and, just as importantly, offer opportunities for undergraduate and graduate students to enhance their skills, capabilities and knowledge through fieldwork training.

## CREST-SNOW ANALYSIS AND FIELD EXPERIMENT (SAFE)

Since 2010, round-the-clock measurements of snow have been collected throughout each winter at the CREST-SAFE site in Caribou, Maine. Sitting in the backyard of a National Weather Service (NWS) Weather Forecast Office (WFO), the site is equipped with several hydro-meteorological instruments ([noaacrest.org/snow](http://noaacrest.org/snow)) that began with high frequency (10.5, 19, 37 and 89 GHz) microwave radiometers and has grown to include dual polarized microwave radiometers, snow pillows, an infrared thermometer, a snow grain size, density, humidity/temperature probe and an online camera, which helps to better characterize the weather type and to identify clear and cloudy periods. Over 20 instruments installed at the station provide routine automated year-round measurements of all major physical characteristics of snowpack, as well as basic meteorological parameters. With these instruments, manual and automated snow measurements take place throughout the winter season. The observations, which show the evolution of snowpack through the



winter season and the effect of atmospheric conditions, are complemented by manual snow pit measurements to directly measure snow grain size, density, hardness, ice layers, etc., conducted 2–3 times per week. The data collected are used for snow product validation and development for sensors including VIIRS, NASA’s Moderate Resolution Imaging Spectroradiometer (MODIS), and the Japan Aerospace Exploration Agency (JAXA) Advanced Microwave Scanning Radiometer 2 (AMSR2) onboard the Global Change Observation Mission 1st—Water (GCOM-W1) satellite which is part of JPSS mission.

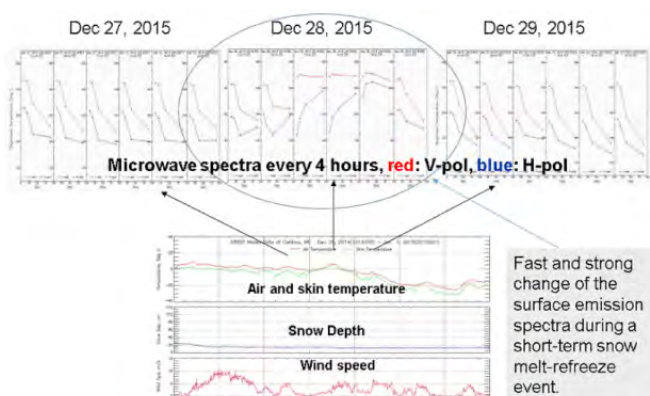


The VIIRS high resolution data help to assess variation of land surface characteristics around the station to better compare the on-the-ground observations with those of orbiting microwave sensors, which sample a large swath of surrounding land each time. The brightness temperatures at 89.0 GHz observed at the station show a strong correlation with the VIIRS and MODIS land surface temperature (LST) measurements (made at infrared wavelengths), due to a smaller penetration depth and a higher emissivity at 89.0 GHz compared to longer microwave bands. The CREST team showed that a linear regression model can be established to retrieve the LST from the microwave brightness temperature using 89 and other AMSR2 channels. This can help in use of AMSR2 retrieved snow temperature measurements to identify melting snow or snow fraction in land that is partly forested, as illustrated above in the VIIRS snow fraction image on the left.



VIIRS snow fraction: darker green areas indicate less exposure to snow cover.

## MICROWAVE SPECTRA: SNOWMELT AND REFREEZE

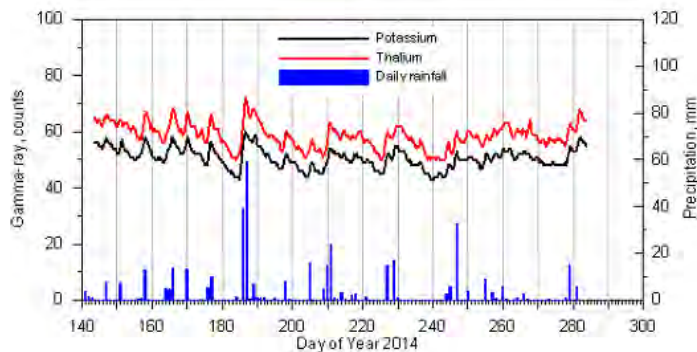
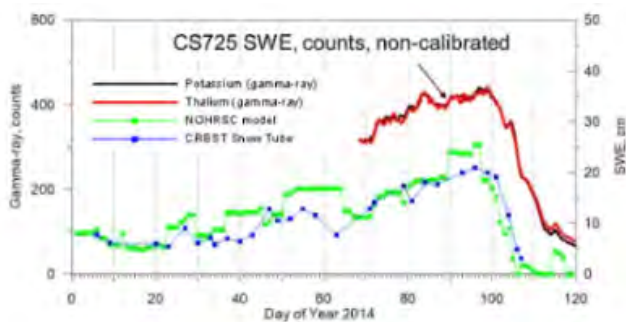


In the data shown above, snow melting and refreezing were observed on December 28, 2015, even though the snow depth stayed the same from the 27th to the 29th. This picture shows a classic example of the impact of snowpack temperature and short-term melt and refreezing on microwave emission. Three days of microwave brightness temperature plotted at a four-hour interval for four frequencies. The bottom graph shows corresponding air and snow surface temperature and fairly constant snow depth. On December 27 and December 29, 2015 the microwave emissivities show a standard pattern of decreasing with increasing frequency.

However, on December 28, 2015, with the air and surface temperatures rising above zero, the top layer of snow melted and the emissivity at 89.0 GHz rose compared to the 10.65 GHz value, only to come down as the snowpack refroze at night. This effect of snow melt on the observed microwave emissions of the surface is not addressed in current models, and if not taken into account would lead to large errors in snow depth estimation.

Next on the researchers' agendas was to get a better sense of how station passive microwave (PMW) data compared to satellite observations. To answer these questions, observations from spaceborne GCOM/AMSR2 and DMSP/SSMIS instruments were collected during passes over Caribou and matched against in situ microwave measurements. The first would determine: whether PMW data could be used as proxy for satellite data in algorithm development; the second would consider the factors that cause differences between satellite and surface observations; and the third would help determine whether combined satellite and in situ observations could be used to improve microwave retrieval algorithms.

One of the instruments CREST scientists use to try and find out the "snow-water equivalent" or SWE was the Gamma radiation sensor (CS725). This instrument obtains SWE and soil moisture measurements by monitoring the attenuation of naturally existing high-energy electromagnetic radiation—gamma rays emitted by radioactive potassium and thallium. As snow accumulates on top of the ground, the CS725 measures a decrease in the normal background radiation levels. The higher the snow water content, the greater the attenuation of the radiation.

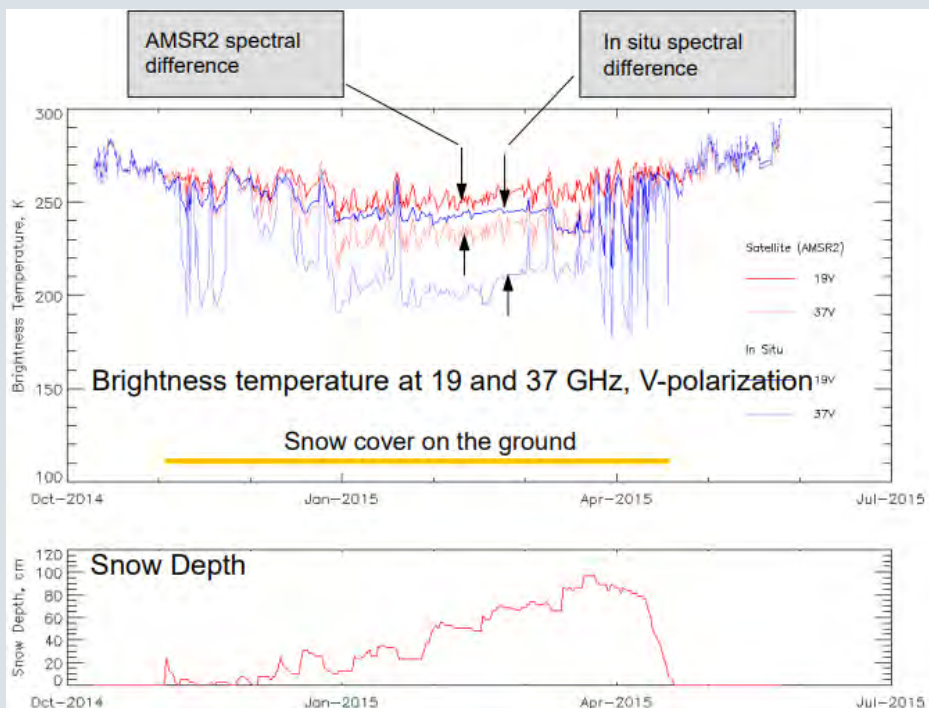


The figure above shows a strong correlation between the gamma rays and rainfall amounts (blue bars).

## IN SITU VERSUS REMOTELY SENSED DATA

The development of models linking snow radiative and physical properties is hampered by the lack of comprehensive in situ measurements of both features that would allow for testing and validating these models. Most available experimental data were obtained as part of short-term observation campaigns or individual experiments that lasted from several hours to several days. Therefore, they represent a snapshot of snow cover properties under certain environmental conditions at certain stages of the seasonal development but do not adequately characterize the full range of potential variations of snow pack features and their transition throughout the winter season from the snow cover onset to melt-off. Also, quite often, the spatial scale of observations of snow cover physical and radiative properties is incompatible. The latter particularly concerns studies where in situ observations of snow depth and snow water equivalent are matched with satellite observations of snow reflectance and emission made at larger spatial scales ranging from 1 to 50 km.

Routine observations of the snow pack emission and reflectance available with the in-situ instruments at CREST-SAFE substantially broaden the opportunities to study the snow pack radiative transfer processes and the links between the snowpack microphysical and radiative properties associated with seasonal accumulation of snow and the

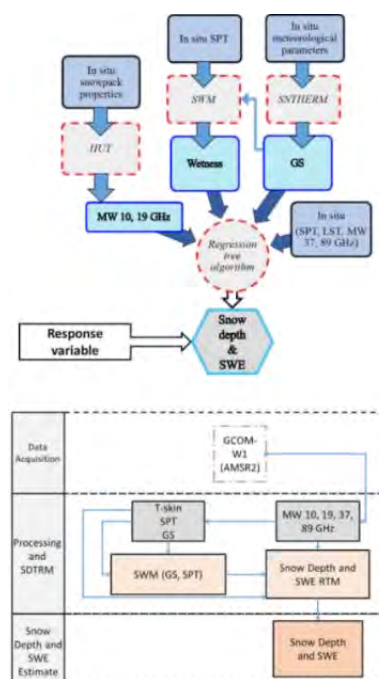


short-term changes in the snow emission due to diurnal change of the snow pack temperature and snow falls. Which also support the development of remote sensing techniques for inferring snow pack physical properties (depth, water equivalent, density, grain size, etc.) from satellite observations in the optical and microwave spectral bands. Since measurements will be taken year-round, observations with the new sensors will also be used in other research focused at the properties of the snow-free land surface. The latter includes, in particular, the development of remote sensing techniques to derive the soil moisture, reflectance and albedo of snow-free land surface, and assessing the effect of vegetation on these land surface properties.

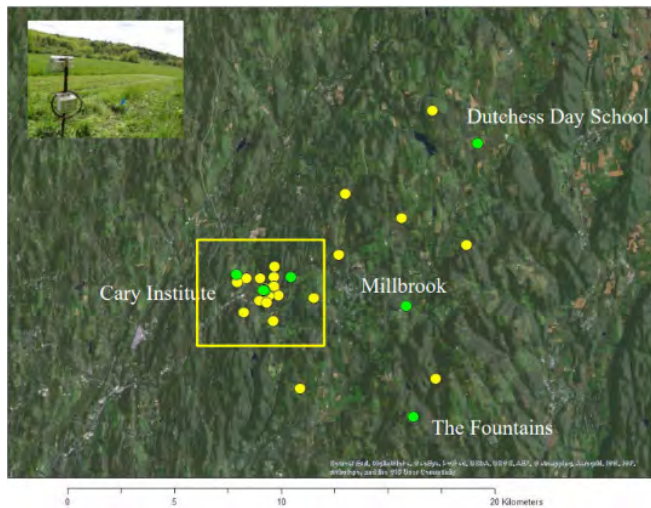
The CREST researchers found that during the snow season, larger satellite brightness temperatures (BTs) and smaller spectral gradient were due to forest cover. The largest differences occurred in the beginning and in the end of snow season, and there was close similarity over snow-free periods. Their results have led to a better understanding of station data that can be used to validate satellite-based products.

## REMOTE SENSING BASED ON CREST-SNOW PRODUCT

Current satellite snow depth retrievals are based on an empirical formula that is over 30 years old. Among other limitations, they cannot be relied upon for wet snow. This is especially a problem in the late winter to early spring seasons as air temperatures are warm, and snow contains more liquid water. As a result, part of the CREST team's work includes the development of a microwave-based snow depth retrieval model that incorporates snow wetness and varying snowpack properties using regression tree algorithms. Accurate remote sensing snow depth retrievals during all parts of the snow season are needed in order for hydrologists and decision-makers to make hydrological forecasts and issue warnings in cases such as spring floods.



## CREST-SOIL MOISTURE ADVANCED RADIOMETRIC TESTBED (SMART)

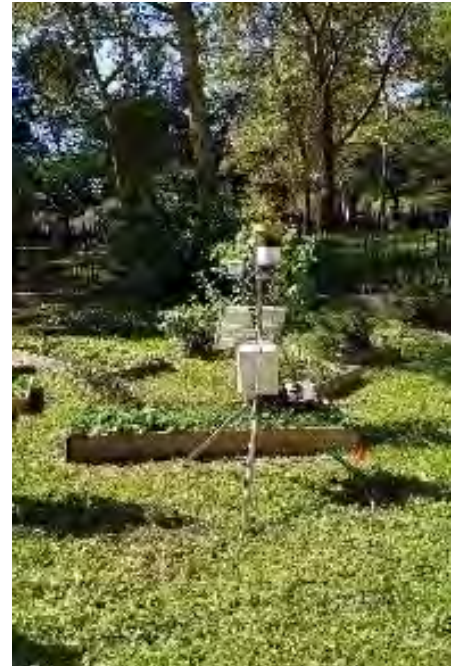


Soil moisture plays a key role in controlling the exchange of water and heat between the land surface and the atmosphere. Soil moisture is also one of the key factors in estimating drought severity. However, it is highly variable both spatially and temporally and rather difficult to measure on a large scale. In situ soil measurements are important for monitoring soil moisture variability in space and time, but are directly valid only for small areas. They are also very useful for the calibration and validation of space-borne soil moisture retrieval algorithms. As part of these efforts, the CREST research team has also deployed a Soil Moisture Advanced Radiometric Testbed (SMART) in Millbrook, NY. As permanent sites are expensive and time consuming to operate, temporary networks are also deployed so as to extend the value of the network throughout its operational life ([www.noaacrest.org/smart](http://www.noaacrest.org/smart)).

The soil moisture observation network, CREST-SMART was selected by NASA as a core validation site for its Soil Moisture Active Passive (SMAP) mission. Data from the site is also used in other research applications including the validation of the Soil Moisture Operational Products System (SMOPS) developed by the NESDIS Center for Satellite Applications and Research (STAR).

## NEW YORK CITY URBAN HYDRO- METEOROLOGICAL TESTBED (NY-UHMT)

According to the World Meteorological Organization (WMO) Guide for Urban Integrated Hydro-Meteorological, Climate and Environmental Services, extreme weather conditions, flooding and other hazards create substantial challenges in the urban environment, with densely populated cities being most vulnerable. Such scenarios were an impetus for the NOAA-CREST research team to initiate a project to create a near real time high-resolution map with early warning system to help the city administrators, including local decision-makers with their emergency management plans. New York City Urban Hydro-Meteorological Testbed (NY-uHMT) is a high-density hydro-meteorological weather network around the city. This one-of-a-kind network will monitor basic meteorological and hydrological variables to assess the variability in NYC's microclimates and their response to extreme events. Seventeen weather stations were installed across New York to monitor both meteorological features such precipitation, soil moisture, temperature and humidity, as well as the hydrological state around the densely populated NYC area to improve forecasting and prediction of environmental events, and aid emergency response and critical decision-making. In addition, the data from NY-uHMT network will be used towards the integration of ground-based in-situ observation with radar and urban-Weather Research and Forecasting (uWRF) model used to understand influence of urban heat island on urban climate, and to help validate remotely sensed urban precipitation and land surface temperature product. The testbed will also be used to improve city-scale climate modeling that can be used to study how future climate scenarios will impact different neighborhoods within the city. The framework will be an effective platform to assess the impact of various climate moderation and extreme heat mitigation strategies ([www.noaacrest.org/uHMT](http://www.noaacrest.org/uHMT)).



Weather Station at (a) Queens Botanical Garden, (b) Brooklyn Public Library - Brownsville Branch, and (c) Polo Grounds, NYCHA Property.

## PUERTO RICO FIELD EXPERIMENT

Validation helps to determine how well a satellite instrument is performing. CREST in collaboration with the Puerto Rico Water Resources and Environmental Research Institute maintains an in-situ soil moisture network in Puerto Rico. To test the performance of GCOM-W1's AMSR2 and to aid downscaling the satellite data in a complex topography, soil moisture data from the instrument has been compared to in situ data taken from ground sites in Puerto Rico (NRCS SCAN Network).

The overall results showed AMSR2 to underestimate soil moisture in Puerto Rico. Two downscaling techniques have been implemented (static and non-static physical controls), reducing the bias of the estimations. Possible reasons for the bias in the estimations include the island's heterogeneous weather, vegetation density, topography, soil types, and precipitation.

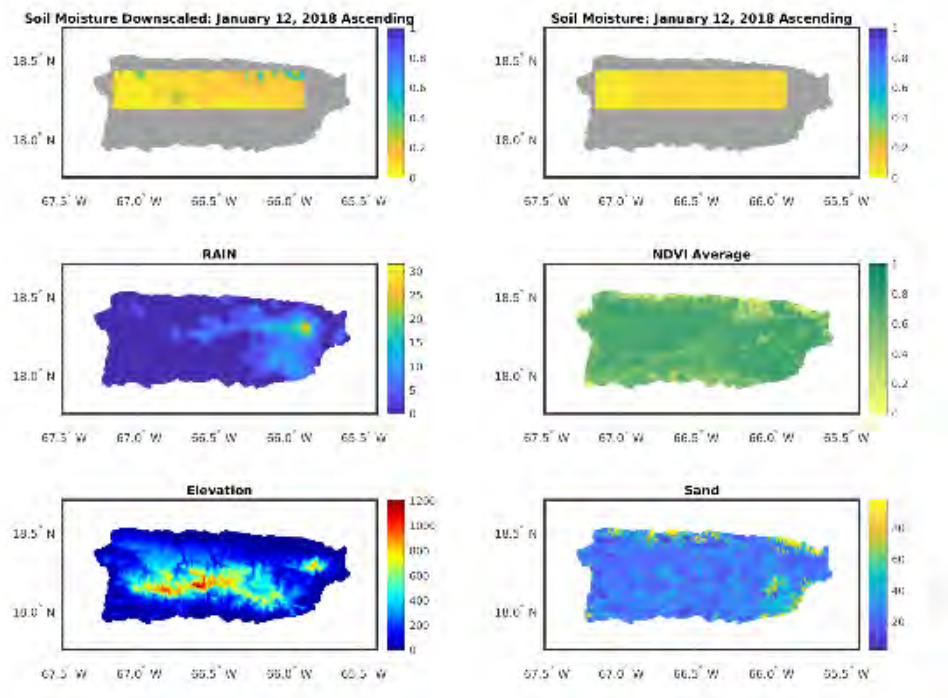


Figure: Downscaling Using Static and Non-Static Physical Controls

## SUMMARY

Snow cover and soil moisture are two important indicators of land surface conditions. Accurate knowledge of snow and soil moisture conditions is important for application in hydrology and water resources management. The estimation of snow and soil moisture over large areas is challenging and often requires a mix of *situ* sensors, remote sensing and accurate mathematical models of soil, vegetation, and snowpack physics. These long-term field campaigns add to our knowledge of snow and soil moisture microwave emission and

reflectance to develop better satellite-based techniques to derive information on snow and soil moisture. The data collected are publicly available at the NOAA-CREST website (with URLs given above). With continued funding, the maintenance and expansion of the ground observation network will extend scientific understanding of the land surface properties as snowpack, soil moisture, and vegetation evolve and enable better use to be made of data from next-generation satellite sensors. ❖

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# **TRACKING AND MONITORING THE SAHARAN AIR LAYER AND ITS POTENTIAL ENVIRONMENTAL IMPACTS WITH JPSS RESOURCES**

The information in this article is based, in part, on the August 20, 2018 JPSS science seminar presented by Arunas P. Kuciauskas, Naval Research Laboratory (NRL), Marine Meteorology Division, Monterey, CA. It includes contributions from Nadia Smith, Jason Dunion, Jordan Gerth, and Michael Folmer.



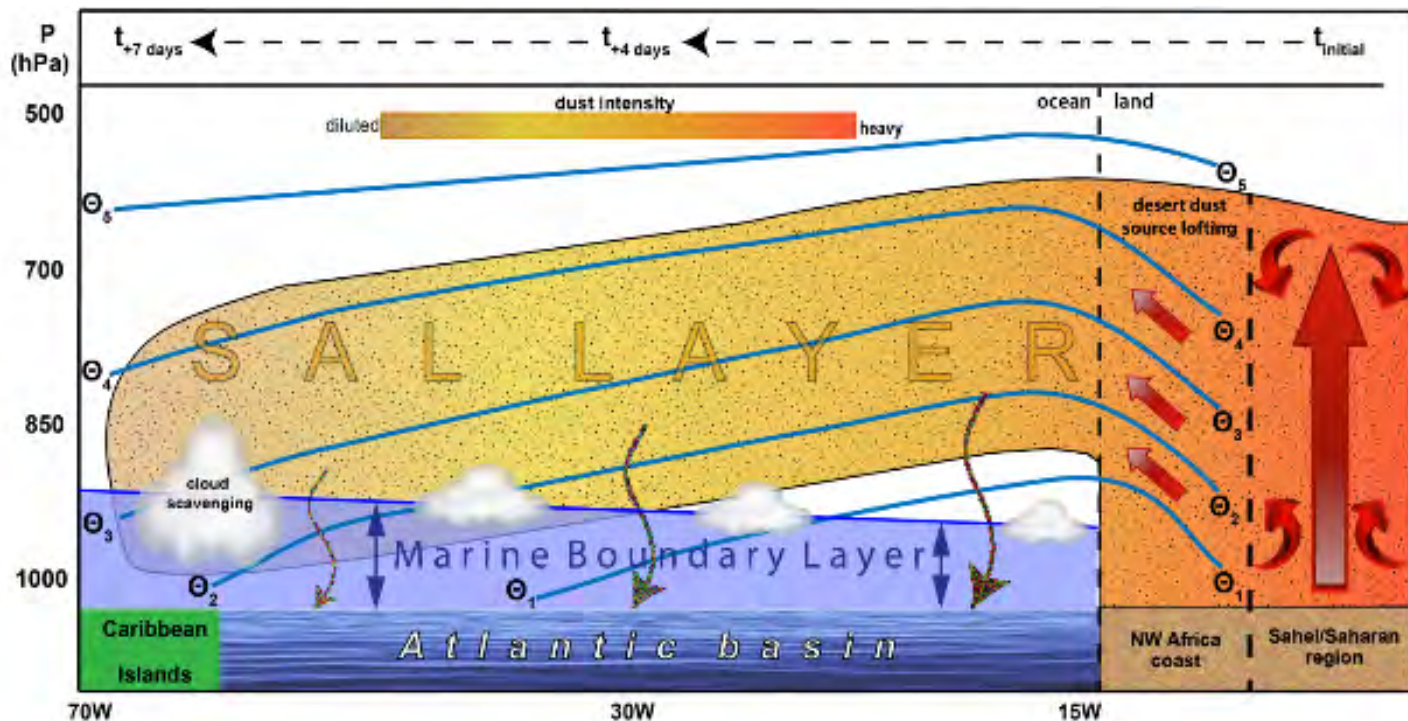
Region of Saharan Air Layer (SAL) development, particularly around the Bodele Depression.

Data from NOAA polar orbiting satellites acquire global measurements of atmospheric, terrestrial and oceanic dynamics such as water vapor, sea and land surface temperatures, clouds, rainfall, snow and ice cover, and ozone, which are used to support a broad range of environmental applications including volcanic eruption monitoring as well as severe weather events like hurricanes and blizzards; forest fire detection; global vegetation analysis; assessment of environmental hazards such as forest fires and floods; search and rescue; and many others.

The Joint Polar Satellite System (JPSS) Visible Infrared Imaging Radiometer Suite (VIIRS) sensor provides key observations of various environmental features including an elevated layer of hot, dry, and dusty air that ranges in depth from generally 500 to 850 mb levels. The elevated air mass, better known as the Saharan Air Layer (SAL), originates from the Saharan Desert in Northeast Africa mostly during the late spring season through early fall. During these seasons, the SAL contains massive amounts of microscopic dust and minerals on a journey, which takes roughly 5–7 days, from the deserts of Northeast Africa across the Atlantic Ocean (see illustration on following page). Carried by northeast trade winds and often following easterly waves, the SAL air mass travels for several thousand kilometers downwind throughout the tropical North Atlantic basin, reaching areas as far west as the Caribbean, Gulf of Mexico, Northern South America, and Southeast U.S. The SAL is the largest producer of dust globally, and according to NOAA’s Hurricane Research Division (HRD) Atlantic Oceanographic and Meteorological Laboratory (AOML), can cover an area the size of the continental U.S.



Suomi/NPP satellite images showing Saharan dust blowing from the Deserts in northern Africa and propagating westward across the tropical Atlantic basin toward the Caribbean between July 6–12, 2018. Image credit: NASA Worldview website.



The figure above, Kuciauskas, et al., BAMS 2018, depicts a vertical profile of the SAL air mass being transported via convection and turbulent mixing from its hot desert source (right side: Sahel/Saharan region) westward to the NW Africa coast, across the north tropical Atlantic basin, and finally through the Caribbean islands. The top portion describes the typical transit time of approximately 7 days. The color shading within the SAL layer represents the transition from coarse and large dust particles (red shades) to finer and more diffuse particles farther west (yellow shades). The vertical brown curved arrows depict larger dust particles settling to the surface. Isentropic contours are annotated in blue, with associated theta labels. The marine boundary layer is shown sloping upward from east to west. Cumulus clouds are prevalent throughout the maritime tropical Atlantic basin and scavenge aerosol particles from the SAL layer.

## SAL IMPACTS AND WHY WE SHOULD CARE

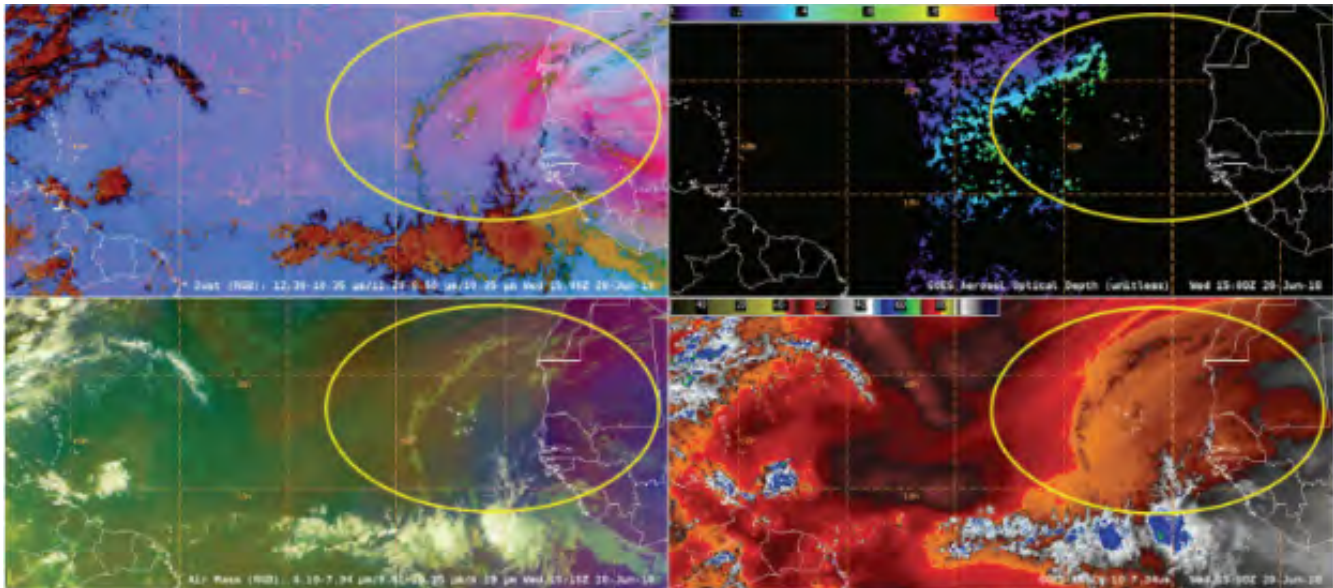
The SAL has been well studied for impacts on tropical cyclone/hurricane development. According to NOAA's HRD<sup>1</sup> the SAL's dry air can weaken tropical cyclones by creating downdrafts (sinking air) around the storm systems. The HRD further adds that by increasing the vertical wind shear in and around the storm environment, the strong winds from the SAL can induce hostile conditions that curtail tropical storm development.

The SAL is also a well-known culprit in creating hazy skies across U.S. cities in the summer months, along with lower air quality, and subsequent Ozone alerts and warnings. But, there is an upside to the hazy skies. The visiting dust clouds have been known to produce some photogenic skies with spectacular sunrise and sunset displays. Besides the picturesque skies, particle deposits from the SAL are rich

in minerals, like iron, and therefore great for soil production. However, the dust clouds also contain microorganisms and pollen which are potential sources of infectious and allergenic agents, and therefore are a major public health hazard.

## THE SAL AND THE CARIBBEAN

The Caribbean Islands, and especially Puerto Rico—known to have some of the highest asthma rates and dust related mortalities in the world—are highly susceptible to ailments associated with SAL events. The SAL air mass typically takes around five days of transit from the coast of NW Africa to the Caribbean. Due to deposits of hazardous dust onto the Caribbean population, it is important that forecasters in these regions have adequate lead time to monitor and predict SAL outbreaks and subsequently issue timely alerts of impending impacts from these dust-laden events.



An Example of a 4-panel display from AWIPS II that allows forecaster to view multiple time-synchronized products at once. In this scenario, the Dust RGB (upper left), the GOES-16 Aerosol Optical Depth product (upper right), the Air Mass RGB (lower left), and the GOES-16 7.3  $\mu\text{m}$  water vapor imagery are used to track the dust component and the dry air associated with the SAL (yellow ovals) as it advects off the west Africa coast.

## CHALLENGES IN FORECASTING SAL EVENTS

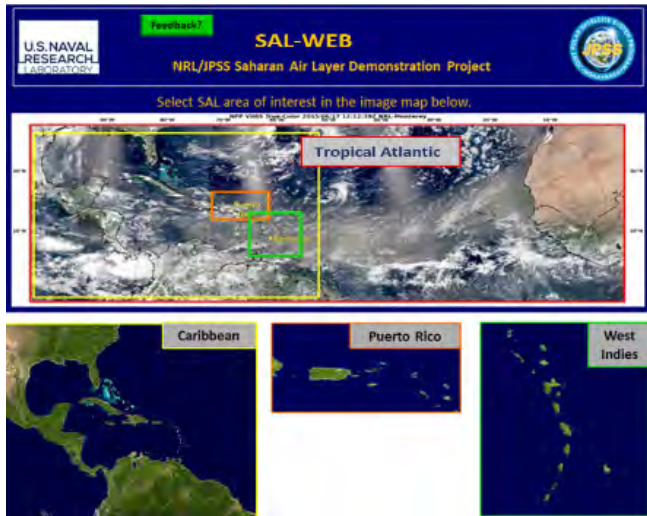
The National Weather Service (NWS) Weather Forecast Office (WFO) in San Juan, Puerto Rico (SJU) is responsible for issuing hazardous air quality warnings to local health agencies and the general public during SAL passages. They know that at some point during the spring through early autumn, SAL development will be most prevalent and will typically make its journey across the African desert, over the north Atlantic basin and into the Caribbean. To these forecasters, identifying and predicting the intensity and location of SAL events are mission critical. SAL events are challenging to detect, assess, and predict. According to the forecasters, these challenges emanate from a lack of measuring instruments over open water, resulting in sparse information within the SAL's thermodynamic structure as the system approaches their area of responsibility (AOR). Additionally, most satellite-derived products sense only bulk characteristics of the SAL structure that lack vital information regarding mineral dust concentrations and vertical profiling. Aerosol models, such as the Navy Aerosol Analysis and Prediction System (NAAPS), provide useful information for dust forecasting, but improvements in the aerosol

vertical characterization are still needed to fully resolve the thermodynamic aspect of the SAL.

Some of the products SJU forecasters have used to help them identify the extent of dusty air emanating off the coast of West Africa include standard products such as the JPSS-derived visible, infrared, natural color and true color. Additionally, the JPSS-derived Dynamic Enhancement Background Reduction Algorithm (DEBRA), the MODIS and VIIRS dust, and the GOES-16 GeoColor provides added dimensionality. However, all of the above products tend to lose some or most of the dust signature over the water due to absorption effects.

## THE NAVAL RESEARCH LABORATORY MARINE METEOROLOGY DIVISION

The Naval Research Laboratory's Marine Meteorology Division (NRL-MMD) in Monterey, CA (NRL-MMD; NRL-MRY) ([www.nrlmry.navy.mil](http://www.nrlmry.navy.mil)), conducts meteorological research and designs development programs to improve the basic understanding of the atmospheric processes and the atmosphere's interaction with the ocean, land and cryosphere. In addition, NRL-MMD 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. NRL-MMD is collocated with the Fleet Numerical Meteorology and Oceanography Center (FNMOC), to support development and upgrades of their operational numerical atmospheric forecast systems and related user products. Collocation and collaboration with FNMOC allows NRL-MMD access to the Navy's supercomputer resources.

Since 2004, NRL-MMD has been providing the global community with satellite imagery and environmental products derived from more than 38 sensors onboard a constellation of polar-orbiting and geostationary satellites. Since 2011, NRL-MMD has been supporting the SJU forecasting office with near real time web-based products, primarily datasets from the VIIRS instrument onboard the Suomi National Polar-orbiting Partnership (Suomi NPP), and more recently NOAA-20. Remotely sensed data and imagery are important sources of products generated and distributed by NRL-MMD. The products are made available via public access websites that include the SAL-WEB; [www.nrlmry.navy.mil/SAL.html](http://www.nrlmry.navy.mil/SAL.html), which is designed to help a forecaster monitor and predict these African dust events, and NexSat- "Next Generation Satellite"; [www.nrlmry.navy.mil/NEXSAT.html](http://www.nrlmry.navy.mil/NEXSAT.html), which was developed to demonstrate the capabilities of the VIIRS instrument through heritage sensors such the Advanced Very-High-Resolution Radiometer

(AVHRR) and the Moderate Resolution Imaging Spectroradiometer (MODIS).

Employing satellite datasets including those from the JPSS, along with in situ aerosol measuring instruments, and airborne dust atmospheric modeling, NRL-MMD scientists have developed basic as well as advanced processing systems for these datasets, to support NWS forecasters, (in particular, SJU) in monitoring SAL events. NRL-MMD also collaborates with the Caribbean Institute for Meteorology and Hydrology (CIMH; <http://cimh.edu.bb/>) and the Caribbean Aerosol-Health Network (CAHN) in SAL research and development. CAHN encompasses an array of international agencies working to improve understanding of the SAL's impacts on health and the environment particularly over the greater Caribbean region. A new resource and the latest addition to the NRL-MMD toolkit, is the NOAA-Unique Combined Atmospheric Processing System (NUCAPS), which has gained traction with operational forecasters given its ability to provide up to date real-time observations of the three dimensional atmosphere. NUCAPS has successfully demonstrated skill in diagnosing the 3D structure of the atmosphere, and has been found to have value in identifying cold air aloft, along with spring and summer pre-convective environments over the Central U.S. and Alaska.

## HELPING CARIBBEAN NATIONS MODEL AND PREDICT ATMOSPHERIC DUST WITH NRL RESOURCES

From a near real-time perspective, remotely sensed and in situ observations are crucial to monitoring SAL characteristics, but sparse in situ observations across oceanic basins present challenges in dust forecast modeling. NWP models specializing in dust transport are somewhat able to simulate the atmospheric dust cycle. As they can produce forecasts well in advance of a SAL event, they are ideal short-term (3-5 day) forecasting tools that can facilitate timely and quality forecasts of sand and dust storms, as well as information and

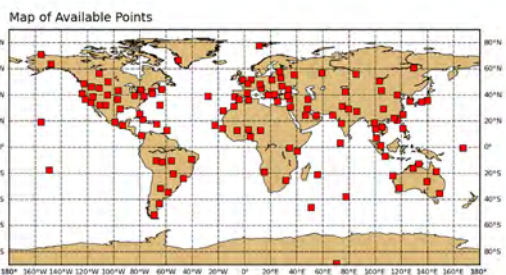
knowledge to user communities. They can also help fill the spatiotemporal gaps from sparse in situ observations. However, the requirements of SJU is that forecasters provide an adequate lead time of SAL strength and position, the current 3-5 day prediction is not adequate.

The NAAPS dust model has been run quasi-operationally at NRL-MMD since 1998, and became the world's first operational global aerosol model in 2006 with implementation at the Fleet Numerical Meteorology and Oceanography Center (FNMOC). Outputs from the NAAPS have been utilized extensively by operational forecasters in monitoring SAL outbreaks across the north tropical Atlantic basin. Besides NAAPS, the NRL-MMD also outputs data from the the Navy Global Environmental Model (NAVGENM), the NOAA Global Forecast System (GFS) Aerosol Component (NGAC) and regional models such as the Navy's Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPSTM). Included in this suite is a dust model ensemble consisting of seven quasi-operational aerosol and dust models known as the International Cooperative for Aerosol Prediction Multi-Model Ensemble (ICAP-MME), Sessions, et al., 2014. A top performer amongst other dust monitoring and prediction models, the ICAP-MME has become a valuable resource for air quality prediction throughout the Caribbean. It has helped mitigate some of the observation gaps in the data sparse tropical Atlantic Ocean that lacks sufficient repetition to actively monitor SAL events.

**NRL Monterey ICAP Multi-Model Ensemble**

This page is an official U.S. Navy site and is intended as an internal research and development website. Products should not be treated as operational forecasting tools.  
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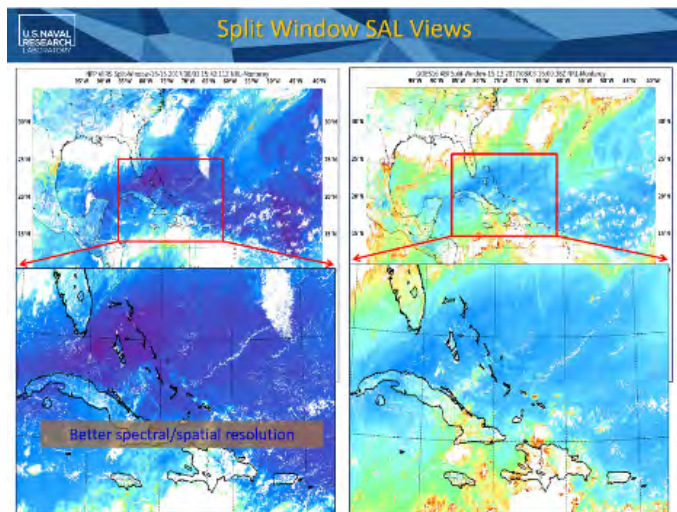
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[www.nrlmry.navy.mil/aerosol/icap.1135.php](http://www.nrlmry.navy.mil/aerosol/icap.1135.php)

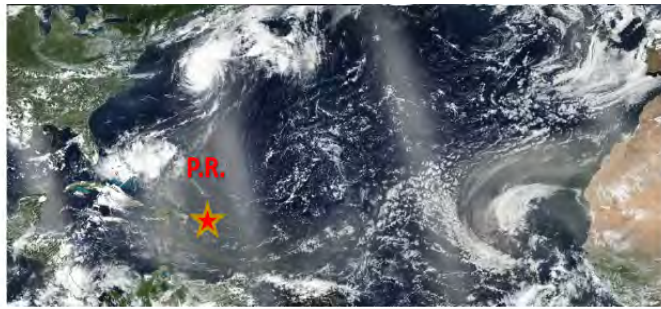
The following example shows a split-window view of a SAL event generated from concurrent passes from the VIIRS (left) and the Advanced Baseline Imager (ABI) (right) instruments on the Suomi NPP and on GOES-16 satellites respectively. These views provide basic comparisons of polar orbiting vs geostationary. In this instance, it highlights how features such as heavy dust can be tracked utilizing a simple approach that combines sensing fidelity polar-orbiting satellites with temporal refresh from geostationary satellites.

The darker blue shades in the imagery depict the approaching or leading edge of the SAL as it is about to interact with the state of Florida in early August of 2018.

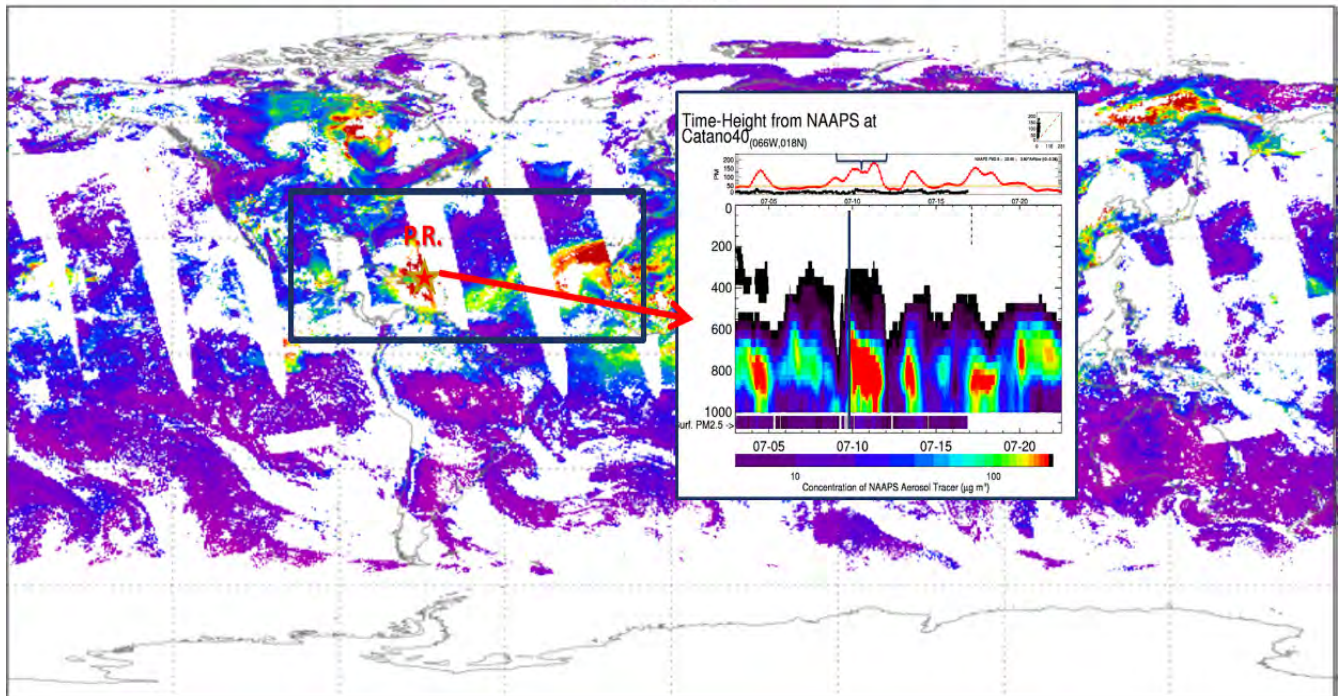


## COMPARISON OF NAAPS AND SURFACE DATA

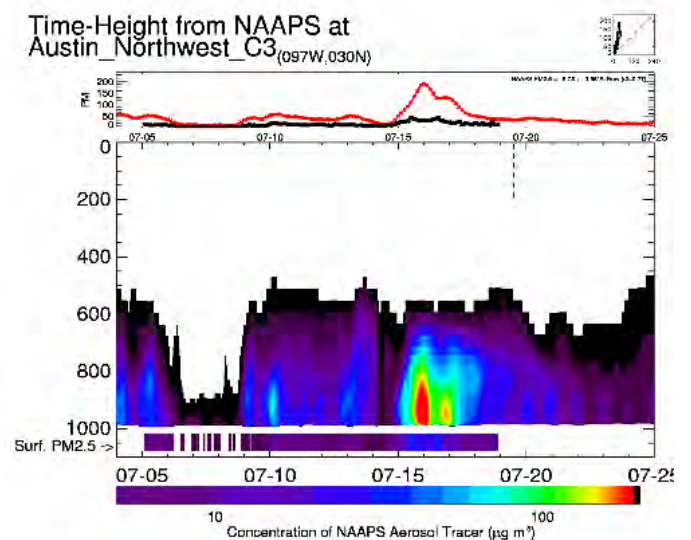
Surface particulate matter (PM) observations collected at local stations in the U.S. and Puerto Rico are provided by EPA AirNow for stations using EPA protocols. The Navy's FNMOC generates 120-hour NAAPS forecasts initiated every 6 hours. NAAPS models aerosol transport using meteorological forcing from NAVGENM. NAAPS includes explicit parameterization of sources and sinks, and NAAPS forecasts are initialized using assimilation of satellite aerosol optical depth (AOD). The following case study of a strong SAL outbreak occurred during July 7-11, 2018 helps illustrate this application.



**Suomi NPP VIIRS High Quality Aerosol Optical Thickness at 550 nm JPSS EPS**  
**11 Jul 2018**



The leading edge of the SAL is shown in the true color image (above top) as it traverses towards Puerto Rico. The impact of the SAL's leading edge is annotated by the black solid line in the VIIRS AOD figure (above bottom). This impact is signified by total PM mass concentration from dust, smoke, sea salt, and anthropogenic aerosol tracers. For this particular event, the PM counts associated with the actual AirNow measurements show almost no change in the PM measurements during the time period when the event occurred. The significance of this is that not all SAL events produce hazards as they may not necessarily translate down to the surface. Sometimes, a SAL event can impact one region and not another, as was observed with this event,



whereby, as the SAL moved further downstream and over southern Texas on July 15, the AirNow measurements, as notated by the black solid line in the bottom figure on the previous page, showed sensitivity to some additional PM.

## MEETING NEEDS WITH THE NOAA-UNIQUE COMBINED ATMOSPHERIC PROCESSING SYSTEM

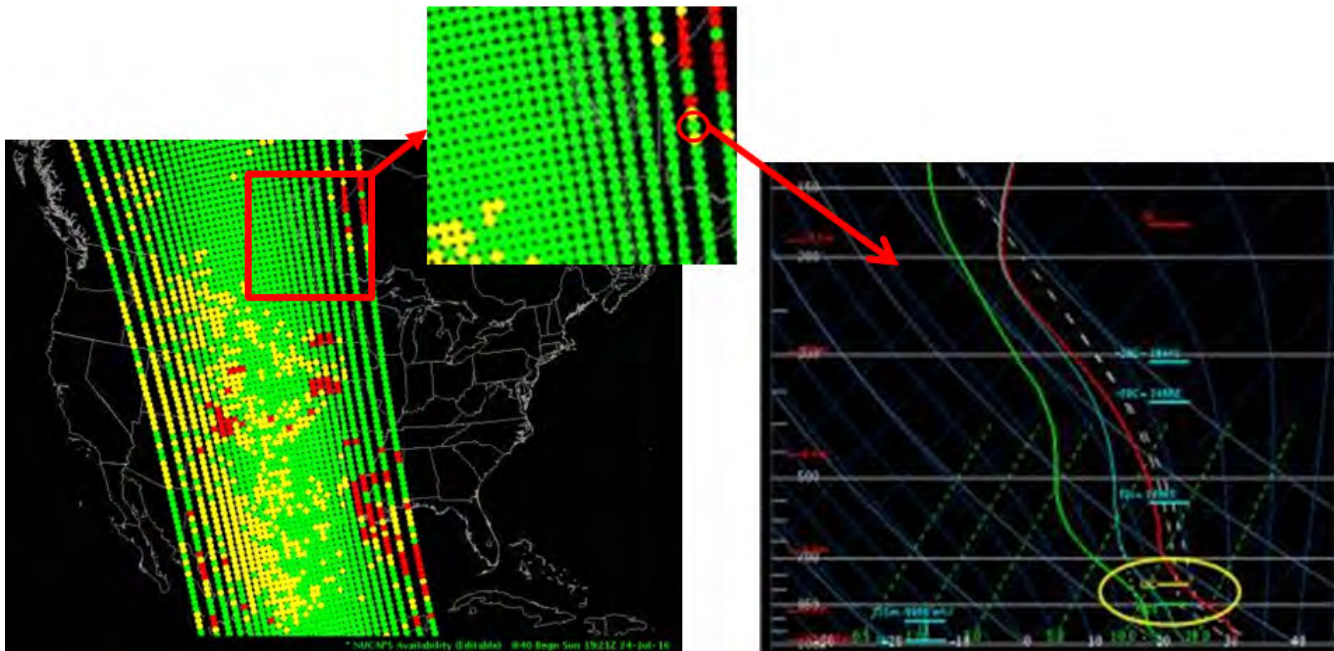
NUCAPS is an algorithm that retrieves soundings from infrared and microwave instruments onboard polar-orbiting satellites including Suomi NPP and NOAA-20. It relies on a technique called ‘cloud clearing’ to remove the effect of clouds so that atmospheric information can be obtained all the way to the surface, the region most relevant for most weather applications. NUCAPS products allow for automated modifications of soundings at lower levels and horizontal cross sections of data across wide geographic areas.

NUCAPS was one of several products recently assessed in a Atlantic SAL field campaign, which took place from mid-June through to the end of September 2018. The campaign, which focused on several forecast challenges including hurricanes and SAL, was designed to help forecasters identify which satellite

derived products or techniques (individual or combined) provided the best analysis to move the forecast decision-making process forward. In the SAL case, scientists explored the potential application of NUCAPS profiles. Results from this experiment are currently being studied.

## EXPANDING OPPORTUNITIES

NUCAPS provides information in otherwise data sparse regions, such as the open water region within the north tropical Atlantic basin. Specifically, it allows forecasters to observe thermal and moisture gradients, e.g., temperature inversions, mid-level moisture. In 2018, NRL-MMD was granted continued funding from the JPSS Proving Ground and Risk Reduction (PGRR) Program to support a three year project to demonstrate, evaluate and promote the usefulness of product sets from the NUCAPS in assessing the 3-D thermodynamic structure of the SAL air mass, particularly within the data sparse north tropical Atlantic basin. NUCAPS offers a means to measure variations in the thermal and moisture content as well as the depth of the SAL layer, which NRL researchers envision, will enable forecasters in the Caribbean to assess the size and intensity of an approaching SAL as well as get a better sense of potential impacts from its features.



Left: NUCAPS sounding locations in AWIPS. Right: NUCAPS sounding plot from the selected dot within the “zoomed panel (figures obtained from Brandt, et al., 2017).



## SUMMARY

Every summer, a dust laden air layer or SAL, lifts off the Saharan desert and travels thousands of miles across the tropical Atlantic Ocean reaching areas as far west as the Caribbean, Gulf of Mexico, Northern South America, and Southeast U.S. The nature of its impacts range from poor visibility to very unhealthy respiratory conditions such as asthma, toward the population at large.

NRL-MMD has had a long term commitment to looking at the SAL in the Caribbean and provides a suite of models to diagnose the environmental aspects of these air masses. The current 3 year NOAA-funded project will

be focusing primarily on the thermodynamic characteristics of the SAL via the nascent applications of NUCAPS.

The SAL not only impacts the greater Caribbean, but also the Gulf of Mexico, northern South America, and southern and central U.S. The NRL-MMD has been at the forefront of implementing and demonstrating the positive impact of Suomi-VIIRS during SAL events. In preparation for SAL events, NRL-MMD is currently supporting the NWS-PR with near real time web-based products, primarily from VIIRS datasets. ❖

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## Footnotes

<sup>1</sup>[www.aoml.noaa.gov/hrd/tcfaq/A17.html](http://www.aoml.noaa.gov/hrd/tcfaq/A17.html)

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# APPLICATION OF MULTISPECTRAL (RGB) IMAGERY FROM VIIRS BY OPERATIONAL FORECASTERS IN ALASKA

The information in this article is based, in part, on the September 24, 2018 JPSS science seminar presented by Kevin Fuell, NASA/Short-term Prediction, Research and Transition (SPoRT) Center, Huntsville, AL. It includes contributions from SPoRT members Andre Molthan, Frank Fontaine, Matt Smith, Kevin McGrath, Emily Berndt, Nicholas Elmer, Gary Gedlovec, and Anita Leroy, and NWS forecasters Scotty Berg, Michael Lawson, Shaun Baines, Aaron Jacobs and Edward Liske.



Source: <https://noaacoastsurvey.files.wordpress.com/2013/11/49navsig-label.jpg>

Alaska is big!! Really, really, big! With over 570,000<sup>1</sup> square miles of land, it is the largest state in the U.S. Now, Alaska's size may not seem impressive until you consider that it is larger than the next three biggest states, Texas, California, and Montana combined. When placed over a map of the continental U.S., the state of Alaska, looks roughly about 1/5 the land area of the contiguous 48 states as it extends from Florida to California through the Dakotas and into Minnesota. Yet, Alaska, which carries more coastline than the other 49 states combined, and boasts of landscapes as diverse as they are immense, is sparsely populated. What's more, the National Weather Service (NWS) operates 122 Weather Forecast Offices (WFOs) in six regions including Alaska, which has only three, Fairbanks, Juneau and Anchorage that maintain weather surveillance and have forecasting responsibility for the entire region. In addition, these WFOs provide tailored weather support to an incredibly diverse user communities from aviation (military,

commercial, cargo, and private) to a wide variety of marine users (pleasure craft, fishing fleets, Coast Guard ships, and cargo transient).

## THE VALUE OF SATELLITE DATA AND PRODUCTS

Space-based assets are extremely valuable to Alaska's weather forecast operations given that the area is data-sparse, at least for conventional observations. While most weather phenomena are not unique to Alaska the impact of this weather is intensified as rapid changes in weather may not be captured by a limited observation system. Polar-orbiting satellites are exactly what is needed. Alaska forecasters have built a robust satellite receiving capability to capture data and products from U.S. satellites and their international partners. Also, the large satellite data swaths overlap each other providing data and products from multiple satellite passes.



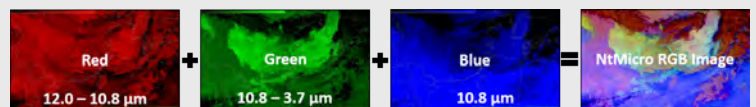
Because of their high viewing angle, geostationary weather satellites do not get a good view of high latitude areas such as Alaska. And as illustrated above on the left, they tend to generate coarse imagery. Moreover, Alaska falls on the viewing edge of geostationary satellites such as GOES, which makes imagery from polar-orbiting satellites all the more important in this region.

Polar-orbiting satellites carry multispectral imagers, such as the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument onboard the Suomi NPP and NOAA-20 satellites. VIIRS offers 5 high resolution Imagery channels (I-bands), 16 moderate resolution channels (M-bands) and a Day/Night Band (DNB) that are enabling forecasters to more efficiently diagnose short-term weather hazards such as low clouds and fog, which pose a major hazard to aviation, navigation and ground transportation. At nighttime, infrared images had difficulty with identifying low clouds from features that were similar in temperature. Low clouds, to a certain extent are similar in temperature to cold ground or snow and therefore they may not be apparent in a single longwave infrared window channel, which makes it more challenging for a forecaster to visually recognize the correct feature. Often, only the coldest clouds tend to feature prominently in longwave IR imagery. In such cases, multispectral imagery which highlight several, specific cloud or surface properties make it easier for environmental features to

be identified in satellite imagery. This ability is extremely beneficial to a forecaster. Among these techniques are applications of red-green-blue (RGB) composite imagery from the VIIRS instrument, which enable the combination of multiple cloud properties into a single imagery product, and have increased the efficiency with which various analysis and short-term forecasts of weather events can be performed.

## WHAT IS RED-GREEN-BLUE (RGB) COMPOSITE IMAGERY?

Multispectral or RGB composites are qualitative, false color images designed to highlight specific features such as low clouds and fog, dust, atmospheric moisture, convection, fire hot spots, snow and ice and volcanic ash. The 24-bit RGB image is created by combining band or band differences into each of the Red, Green, and Blue components with a defined recipe. The advantage of RGB products is the ability to look at a single image to identify a feature instead of analyzing multiple single channels. These RGB products have allowed a more efficient use of the large number of channels available from this polar-orbiting platform.



## FORECAST CHALLENGES FOR ALASKA, BUT OPPORTUNITIES FOR NASA SPORT

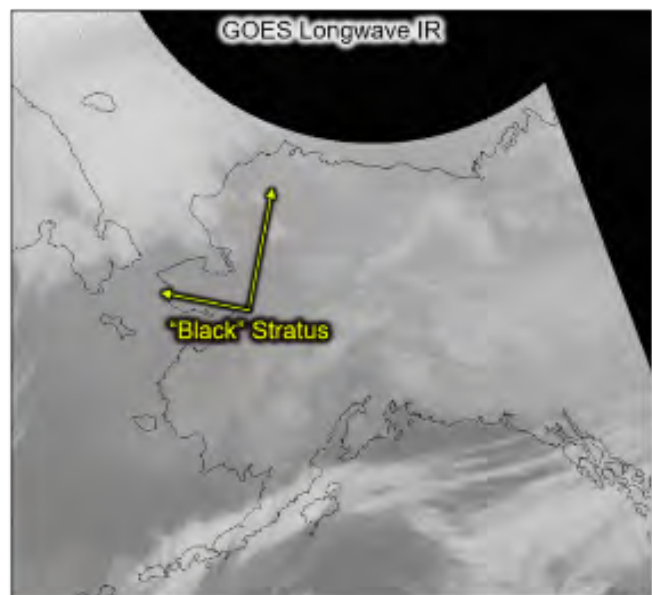
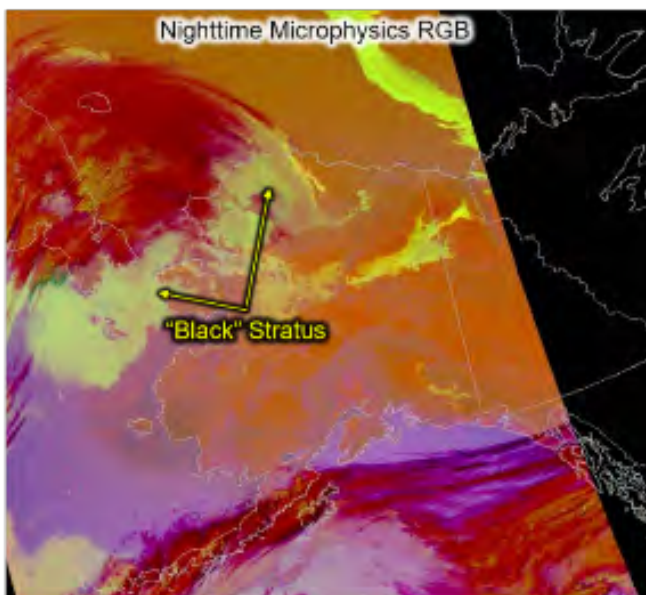
The National Aeronautics and Space Administration/Short-term Prediction Research and Transition (SPoRT) Center<sup>2</sup> has been providing RGBs to operational forecasters since 2004. Through targeted product evaluations with local forecasters, SPoRT researchers have learned values assigned to various RGBs—some being of greater value than others—can depend on the time of year. A case study on a common winter hazard, low-level clouds and fog, helps illustrate this concept.

With a limited number of roads linking communities across its big cities and scattered towns, aviation is the primary, and in most cases the only mode of transportation for Alaska’s populace. The influence of low-level clouds and fog poses a strong threat to aviation throughout Alaska, and none more so than during a typical winter in the high latitudes, characterized by short, dark days and bitter cold temperatures. RGB products emphasizing low cloud and fog detection have helped improve the content of aviation forecasts and fog advisories, allowing for improved efficiency and public safety alerts.

SPoRT started with the introduction of a series of “microphysical” RGBs that communicate the physical, thermal, and phase aspects of cloud objects within a single product. Several

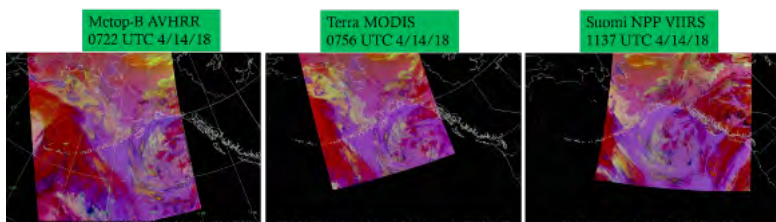
challenges were overcome to use VIIRS in combination with other polar-orbiting platforms as well as improve the consistency of the RGB across the swath area.

The Fairbanks AK Weather Forecast Office (WFO) has operationally used the Nighttime Microphysics (NtMicro) RGB from VIIRS and other platforms to identify low clouds and fog to more efficiently anticipate and warn for cloud ceiling and visibility restrictions impacting aviation and the public roadways. WFO Fairbanks has forecast responsibilities for several airport sites along the Arctic Coast of north Alaska associated with communities that include commercial oil industries. In the example below to the right, a Fairbanks forecaster was able to note the low stratus clouds over northwest AK that were moving eastward toward these airport sites. Due to the relatively similar temperature of the land surface/snow and the cloud tops at this time, the forecaster cannot easily pick out this stratus cloud feature in the GOES longwave IR imagery, but the NtMicro RGB distinguishes the low stratus in pea green coloring. Due to the limitation of seeing the stratus in traditional longwave, single-channel IR imagery, the stratus has often been referred to as “Black” Stratus. More of the low “Black Stratus” can be seen over the Bering Sea and this also allowed the forecaster to anticipate airport impacts to coastal communities in extreme northwest AK. Also note that fog features in a bright



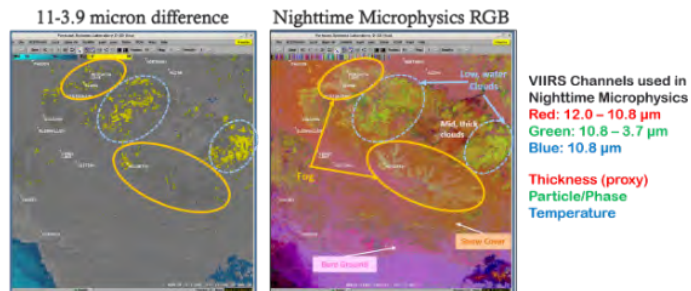
yellow-green coloring are more prominently distinguishable in northeast and southeast mainland Alaska and these features are noticeably different from the stratus. This allows the forecaster to have the added value of being able to differentiate low clouds from fog hazards (as illustrated in the bottom left image on the previous page).

Some RGBs can be created from multiple satellites and across platforms, both polar-orbiting and geostationary. But comparing RGBs across different sensors can be problematic due to imager band differences in various characteristics including central wavelength, spectral bandwidth, and spectral response function. Such differences in band characteristics can lead to inconsistent RGB coloring for the same feature and thus, impact interpretation and use in operations. To work around this challenge NASA SPoRT researchers incorporated limb and bias corrections techniques to remove effects of an increase in optical pathlength (i.e. more absorbing atmosphere between the satellite and the edge of the imager view) and improve the consistency of RGBs from various sensors on the polar-orbiting platform including AVHRR on Metop-B, the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the NASA Terra and Aqua satellites, and the VIIRS aboard the Suomi NPP (see images below).



The RGB products, like any other items being launched into the marketplace, undergo several steps prior to placement in the hands of the consumer. Before introducing a new or replacement item on the market, a developer has to ensure that it has proven its value over an existing tool. For example, the images to the right were generated from IR VIIRS pass over the southeast portion of mainland Alaska at 11:45 UTC. VIIRS resolution allows analysis of

small scale features. The image below on the left—the standard at the time—is generated using the 11- 3.9 micron difference. In it, low clouds are identified by the yellow features. On the right, the nighttime microphysics, combines the differences between the 11- 3.9 bands with physical and temperature information to help differentiate fog from low clouds. More than that, the nighttime microphysics RGB helped characterize other clouds and surface features as well.



Olive green is still in the area of McCarthy and extending to its southeast. The imagery also shows an increase in fog coverage as this feature has grown further up the valleys of this region. In addition some of the low and mid-level clouds have cleared near the Slana and Mentasta Lake area and fog can be seen in this region as well. Bright green features representing low clouds with small water droplets can be seen between these two regions as well as in Canada on the right center portion of the image. Mid-level, thick clouds in dark oranges and reds are also seen in Canada. The surface color where snow cover exists tends to have this dark orange and tan color while bare ground is more light purples and pinks.

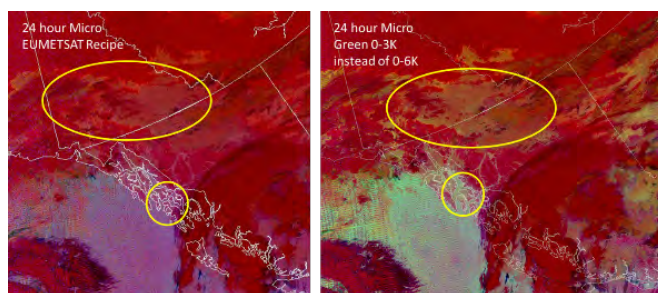
However, in the nighttime microphysics image some of the dark orange and tan colors indicating mid-level clouds is very similar to coloring of the land surface where it is cloud free. As a result the images can be difficult to read without training. To complement the RGBs, the NASA SPoRT center applies various training methods and material to help the forecasters learn how the image is formed and understand what new colors mean. These methods include targeted, applications-based training, to reach all learning styles. Among them are site visits, micro-lessons, user-based, interactive modules and quick guides. The center also has a SPoRT Applications Library—an outcome of assessments activities, feedback, and formal assessment reports—that holds one-minute examples, short videos and over 20 case examples, which forecasters can also use as reference material.

## PRODUCT IMPROVEMENTS

### 24hr Micro RGB: single product for both day and night

As its name implies, the Nighttime Microphysics, or NtMicro RGB is a nighttime only application, and its value in Alaska was dictated by the long hours of daylight in the summer or darkness in the winter. This led to the transition of the 24-Hour Microphysics, or 24hr Micro RGB. The main difference between the two products is in their use of the green channel. While the NtMicro RGB uses the 10.8-3.9 micron difference, which is the legacy “fog product” that has been employed by meteorologists for years, the 24-hr Micro RGB uses a 10.8-8.5 micron difference. The 8.5 micron channel is not sensitive to solar reflectance, while the 3.9 micron channel is influenced by both radiance and solar reflectance during the day. At night the NtMicro RGB shows more details and is considered superior to the product generated by the lower contrast of the 24hr Micro RGB. However, the NtMicro RGB is rendered unusable during the transition from darkness to daylight, while the 24hr Micro provides consistent imagery.

When it came to the 24-hour Microphysics RGB, some forecasters noted that the color contrast was low compared to the NtMicro RGB particularly in areas with low cloud objects and therefore it was challenging for them to differentiate fog from low clouds. On June 20, 2015 several aviation sites within the AJK warning area had IFR ceilings reported, and the 24hr Micro RGB depicted a uniform cloud feature across the region. The NASA SPoRT researchers adjusted the product by reducing the green component’s range from 6K to 3K.

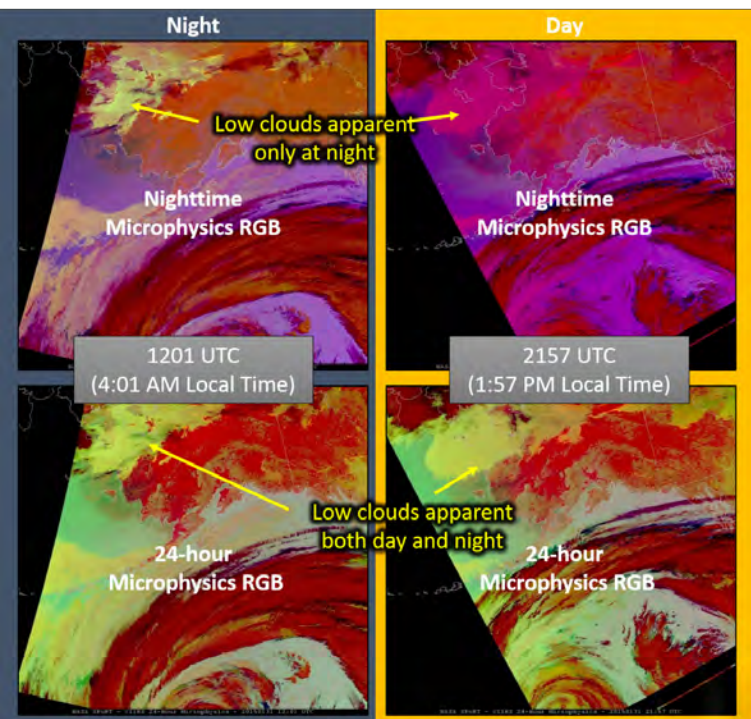


“I had better luck picking out the cloud features in the 24-hour microphysics now than I did this past winter, however the colors displayed still make it somewhat difficult to pick out where the cloud edge is compared to using regular visible satellite images or VIIRS 1.61 band.”

As shown in the case above of a daytime, low cloud event over the Juneau, Alaska WFO (AJK) area, a forecaster noted while the adjustment made it much easier to pick out cloud features, they had a preference for a another imagery product over the enhanced 24hr Micro.

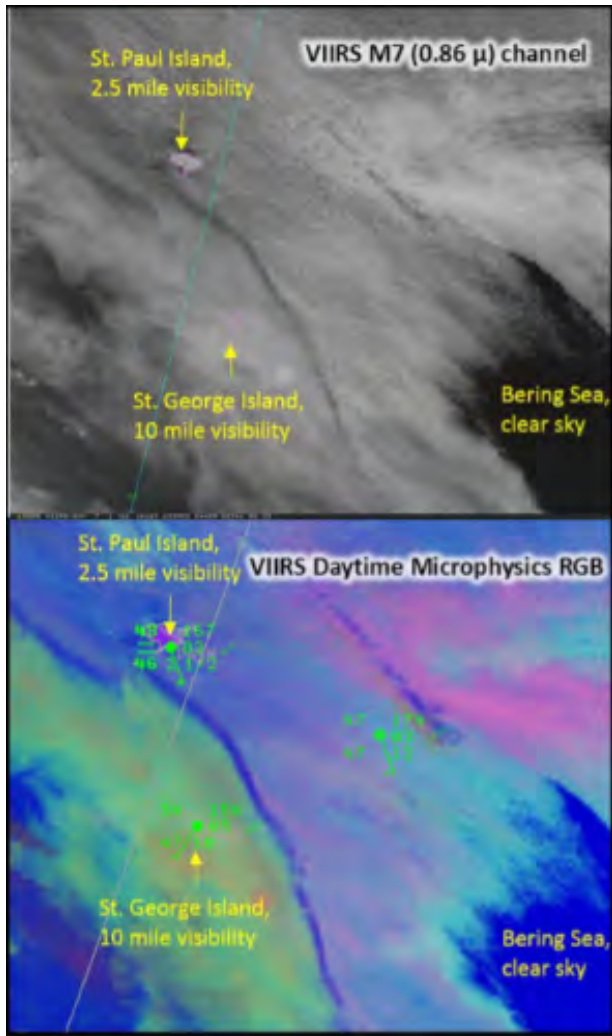
### Daytime Microphysics RGB

SPoRT has also utilized the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) recipe for RGB composites. One of these, the Daytime Microphysics (DtMicro) RGB combines bands related to various cloud properties of thickness, particle phase and size, and cloud top temperature to analyze convective clouds as well as other cloud and surface features. The product can help identify cloud types, including fog and low stratus as well as fires, snow, and contrails. In the following feedback, obtained from Michael Lawson during a July 1, 2016 assessment in Anchorage, Alaska, he notes, “the product gave great confidence in combination with model data and surface observations to continue to forecast reduced visibility over the Pribilof Islands, both in the public forecast and PASN (St. Paul) terminal aerodrome forecast (TAF).”



NtMicro RGB (top) and 24hr Micro RGB (bottom) showing views at night (left) and during the day (right).





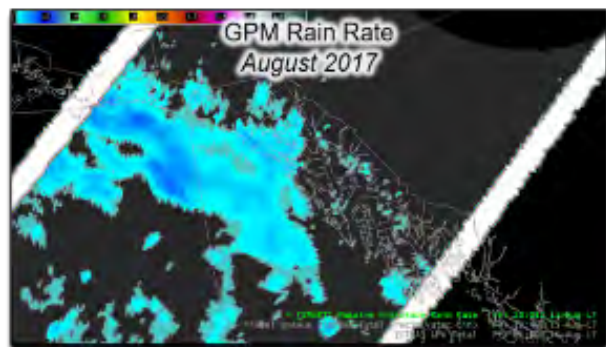
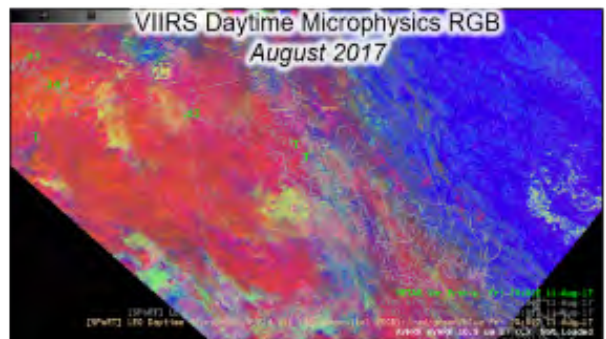
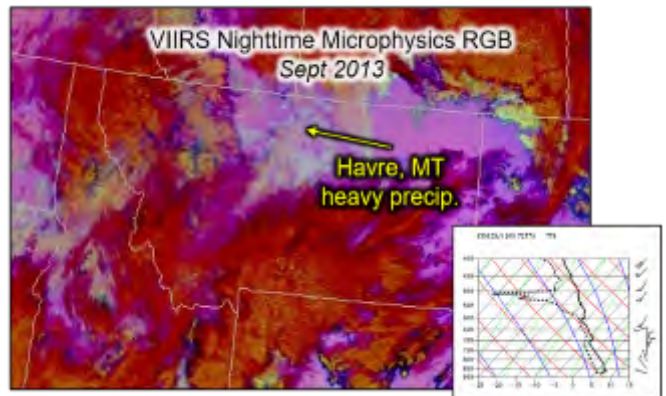
The Daytime Microphysics RGB (above) shows bright greenish clouds with some tan coloring representing thick stratus at mid-levels while the blues/pinks represent low-level stratus of varying thickness. During the assessment users noted that the daytime microphysics RGB enabled them to better see cloud types, which was extremely beneficial in the preparation and updating of TAF forecasts.

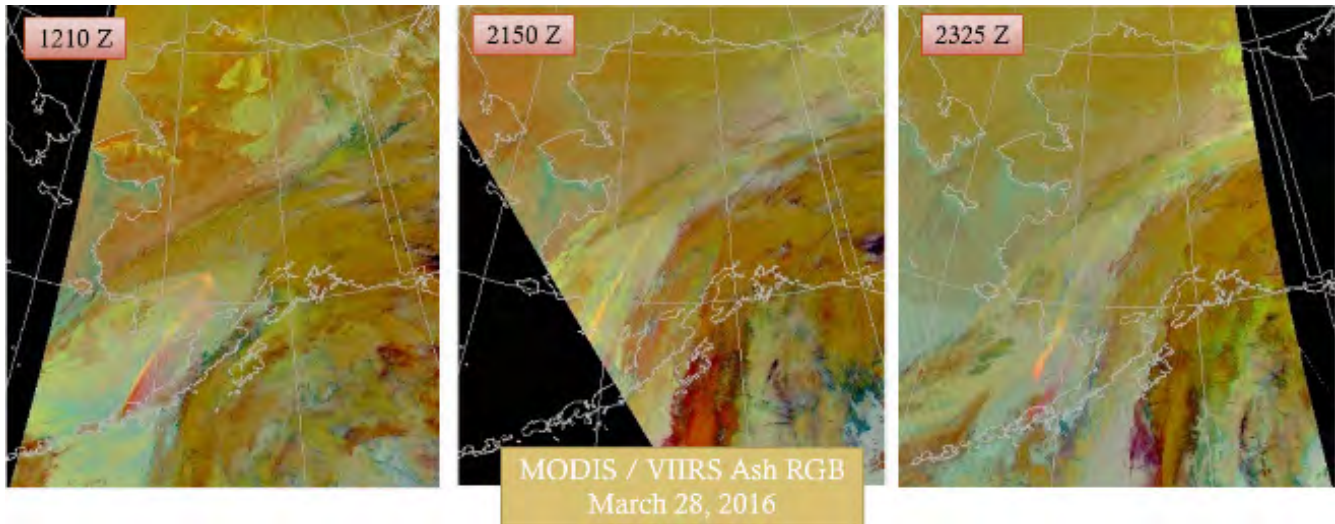
### Precipitation Events

Beyond cloud analysis the microphysical RGBs have been utilized along with other data sets to help define RGB objects and improve “cloud properties”, and also for precipitation signatures in radar-poor regions. For example, in 2012, during a precipitation event with some moderate rain, Brian Guyer, at the Albuquerque, NM (ABQ) WFO noticed some low-level precipitating clouds through signatures displayed in the NtMicro RGB, but were missed by radar beams.

Shortly after in 2013, Paul Nutter at the Great Falls, MT (TFX) WFO used the NtMicro by comparing the mixed phase signature in RGB against soundings during a heavy precipitation event in Havre, MT. More recently in 2017, Aaron Jacobs at the Juneau, AK (AJK) examined precipitation events by comparing NASA’s Global Precipitation Monitoring (GPM) satellite rain rates against signatures in the daytime microphysics RGB, to help discern the color signatures within the DtMicro RGB that are associated with precipitating cloud features.

Other unique applications of RGB products, include analysis of volcanic ash and various features in wildfires. The Ash RGB provides a consistent product both night and day to monitor ash plumes, while the Fire Temperature RGB is helping forecasters detect fire hotspots and also qualify their intensity.





## VOLCANIC ASH APPLICATIONS

RGBs have also become an important source of information for volcanic ash applications in Alaska. Ash RGB imagery is critical to identifying areas of volcanic ash at levels that can impact aircraft operations. The goal is to reduce the danger of commercial and cargo aircraft flying into volcanic ash. On March 28, 2016, the U.S. Geological Survey (USGS) issued an aviation code red for the Pavlof, one of the most active volcanos on the Alaskan Peninsula. The images above of the Ash RGB, were generated from VIIRS and MODIS channels 12-11  $\mu\text{m}$ , 11-8.7  $\mu\text{m}$ , 11  $\mu\text{m}$  in RGB (day/night) during passes over Alaska. The yellow/tan streams of color with some streaks of red represent the ash and a common by-product of volcanic eruptions, Sulfur dioxide ( $\text{SO}_2$ ) clouds emanating from the volcano.



RGB image courtesy of Curtis Seaman (CIRA).

The RGBs are also useful in locating wildfires in Alaska. In remote locations, conventional observation methods may not immediately detect wildfires. Worse still, where no ground-based observations are available, wildfires could be missed entirely. Satellites can detect heat signatures and provide imagery to forecasters that helps them to monitor surface conditions in fire-prone areas. On the bottom left is a fire color RGB generated from the Suomi NPP satellite. The bright red pixels represent the active fire perimeter, burn scars appear dark brown, while the hazy cyan color represents smoke. The Geographic Information Network Alaska at the University of Alaska Fairbanks (GINA/UAF) processes the bands for use by the NWS and other GIS users such as the U.S. Bureau of Land Management (BLM).

## SUMMARY

For over a decade, researchers at the NASA SPoRT Center have developed and delivered unique RGBs to NWS forecasters. The RGB products help forecasters to synthesize information from multiple spectral bands into a single product. This work addresses many of the forecast challenges and specific hazards identified by the NWS National Centers and WFOs in locations throughout the CONUS as well as in high latitude regions such as Alaska. as the VIIRS sensor offers more spectral detail and better spatial resolution than its predecessors. This, has

increased the efficiency with which forecasters in Alaska can do various analysis in short term forecasts. The limb and bias corrections from NASA SPoRT has led to more consistent RGB products and made the RGBs more frequently available via multiple satellite platforms.

Benefits of RGBs in forecast operations have been realized through sustained partnerships that include training and formal assessments to gather forecaster feedback, address questions, and incorporate necessary improvements. The partnerships developed through NOAA's Satellite

Proving Grounds, including the close relationship with the JPSS Program, have enabled Alaska forecasters to progressively develop skills in RGB applications, ensuring that these RGB products are now a routine part of NWS forecast operations. In Alaska SPoRT's RGB transition, research, and training efforts, has helped the NWS to serve its diverse user communities with short-term forecasts as well as improved decision support services and communication to the general public regarding such hazards such as wildfires and volcanic ash. ❖

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## Footnotes

<sup>1</sup> National Atlas of the United States at [https://nationalmap.gov/small\\_scale/](https://nationalmap.gov/small_scale/)

<sup>2</sup> <https://weather.msfc.nasa.gov/sport/>



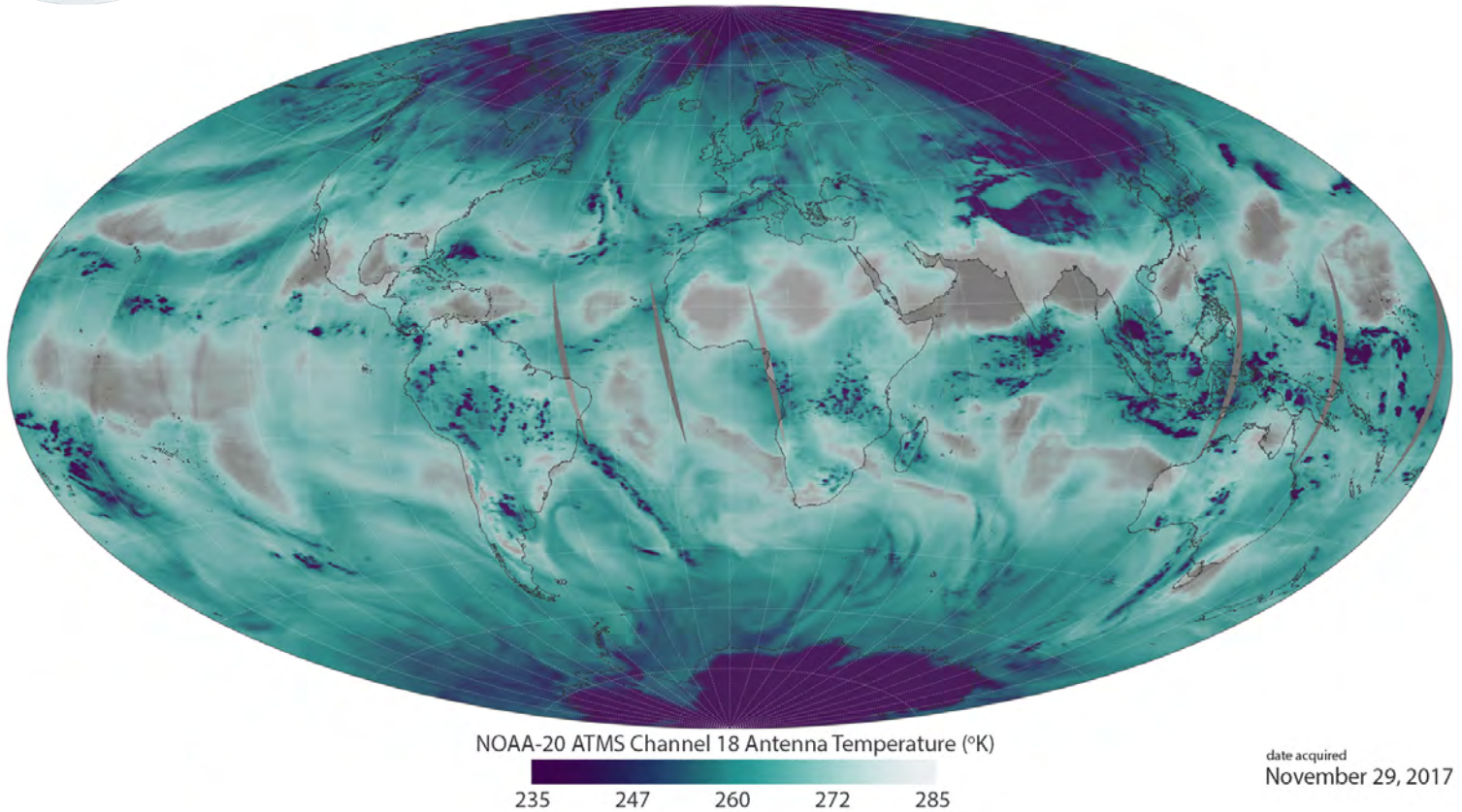


# WEB FEATURES





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.

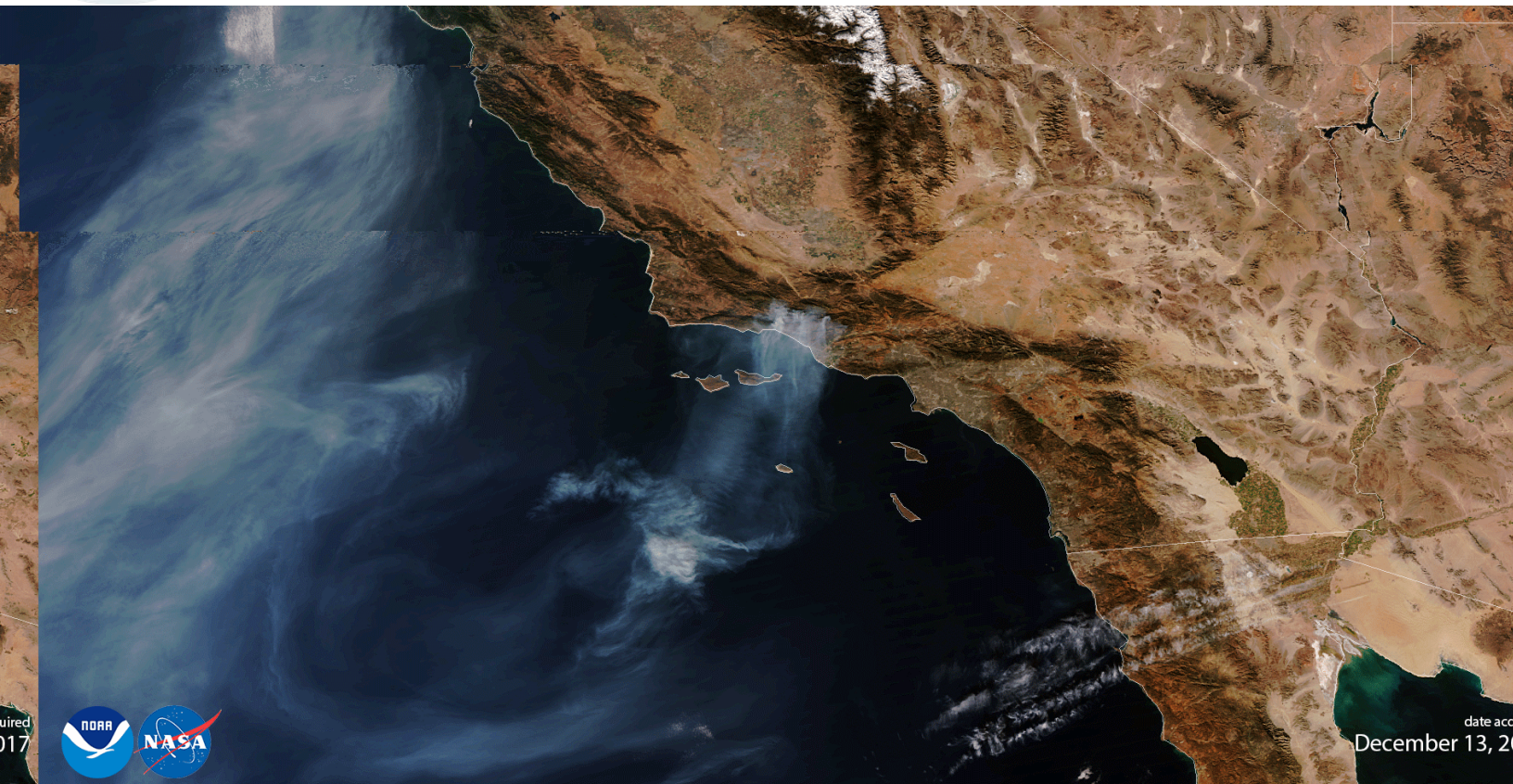
This image uses ATMS data to depict the location and abundance of water vapor (as associated with antenna temperatures) in the lower atmosphere, from the surface of the Earth to 5 kilometers altitude. Transparent/grey

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. ❖



WEB FEATURE: DECEMBER 13, 2017

## FIRST LIGHT IMAGE FROM NOAA-20'S VIIRS INSTRUMENT CAPTURES THOMAS FIRE

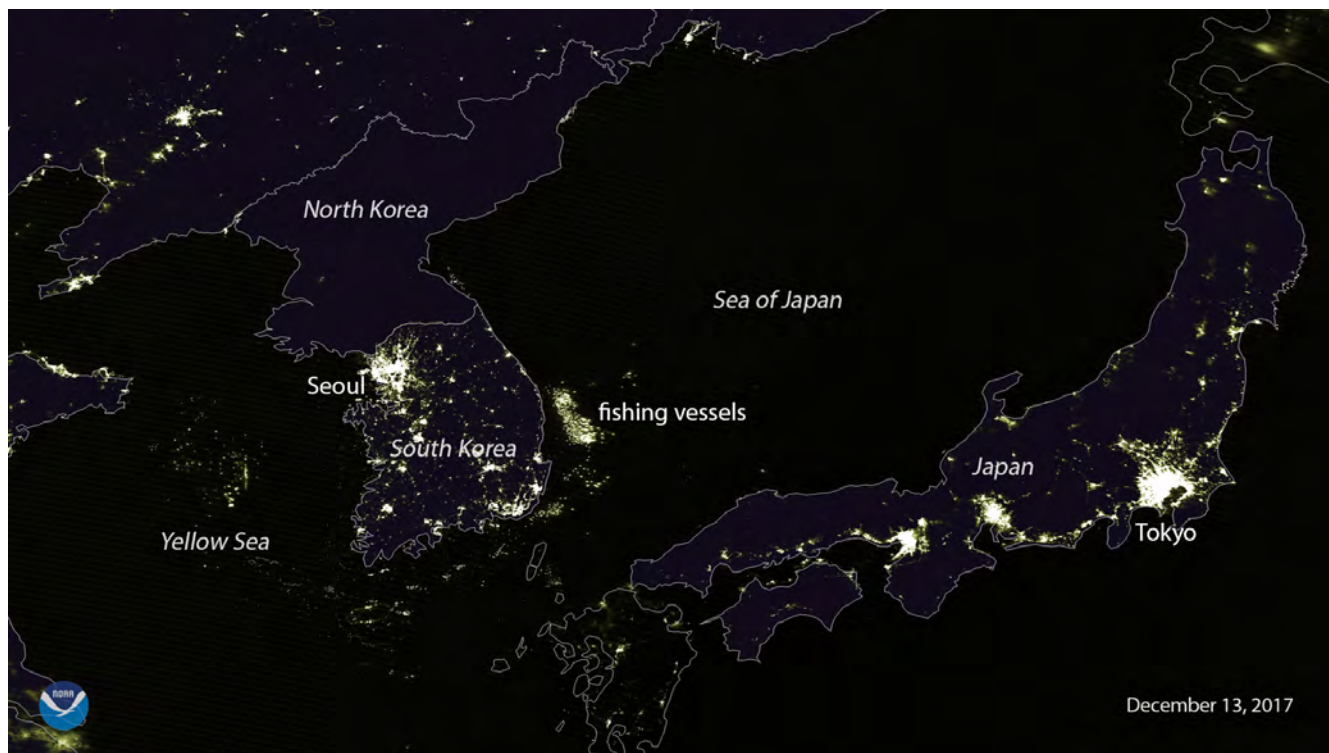


NOAA-20 VIIRS First Light Image Captures One of the Largest Wildfires in California History (Image generated by NOAA's Center for Satellite Applications and Research and the NOAA Visualization Lab).

Twenty-five days after JPSS-1 (NOAA-20) was launched into Earth orbit, NOAA-20 sent back its first Visible Infrared Imaging Radiometer Suite (VIIRS) science data on December 13, 2017, as part of a series of instrument activation and checkouts that is taking place before the satellite goes into fully operational mode. VIIRS is one of the key five instruments onboard NOAA-20 that will improve day-to-day weather forecast and environmental monitoring, while extending the record of many long-term observations of Earth's climate.

This VIIRS true color image captures the aggressive wildfires in Southern California, which forced thousands to flee their homes. As of Wednesday morning, December 13, 2017, the Thomas Fire was the fourth-largest fire in California history, and it continues to generate smoke and plumes as it enters its second week. The fire spanned more than 370 square miles and remains the strongest blaze for firefighters to battle in Ventura and Santa Barbara counties. NOAA-20 VIIRS will help monitor active fires globally for many years to come.

VIIRS is a scanning radiometer onboard Suomi NPP and JPSS satellites that produces global imagery and radiometric measurements of the land, atmosphere, cryosphere, and oceans in the visible and infrared bands with moderate spatial resolutions at 750m and 375m respectively. The operationally produced VIIRS data are widely used globally to monitor hurricanes/typhoons, measure cloud and aerosol properties, ocean color, sea and land surface temperature, ice motion and temperature, active fires, and Earth's albedo. VIIRS has 22



In this VIIRS day-night band image captured December 13, 2017, the bright lights of urban centers such as Tokyo and Seoul stand out in sharp contrast to more rural land areas and dark ocean surfaces. The glow of fishing vessels off the coast of South Korea is also clearly visible.

spectral channels covering a broad electromagnetic spectrum from 0.4 Qm (visible) to 12.5 Qm (thermal infrared). These include 14 channels measuring reflected sun-light, and seven channels measuring emitted energy from the earth. In addition, VIIRS has a day/

night band (DNB) which can measure faint night lights from human settlements, aurora, and other sources (e.g., fires). The VIIRS data are especially useful for weather forecasting in the polar-regions such as Alaska with frequent temporal coverages. The VIIRS data

support the operational production of at least 26 Environmental Data Records (EDRs) with global coverage.

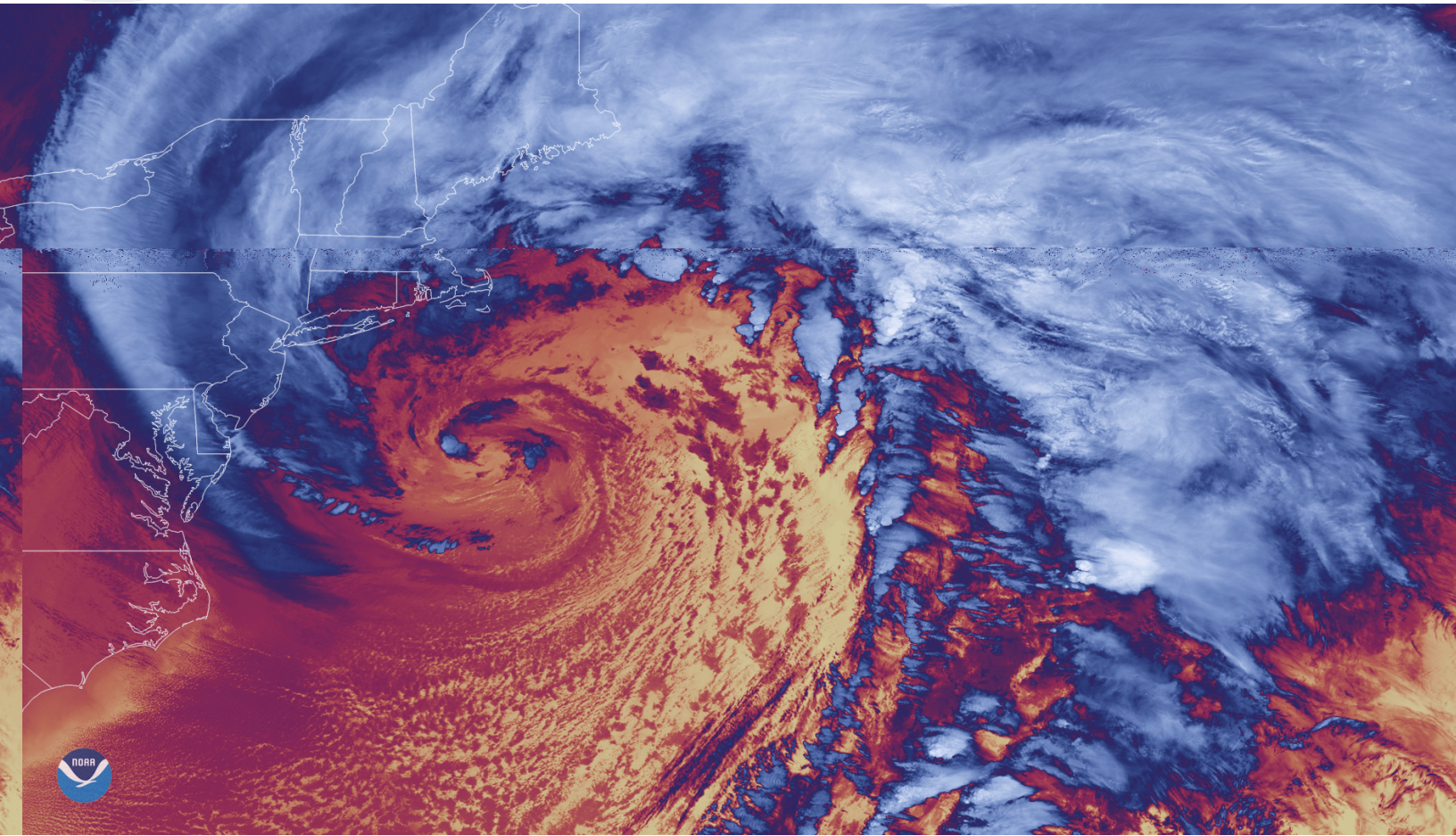
To learn more about VIIRS, see our instrument fact sheet ([www.jpss.noaa.gov/print](http://www.jpss.noaa.gov/print)). ❖





WEB FEATURE: JANUARY 5, 2018

## NOAA-20 CAPTURED DETAILED THERMAL IMAGERY OF BOMB CYCLONE



Forty-seven days after it was first launched, the NOAA-20 polar-orbiting satellite sent back its first thermal infrared images on January 4, 2018. This VIIRS thermal infrared image shows stunning detail of the powerful ‘bomb cyclone’ that struck the East Coast of North America on January 2–3, 2018. The powerful winter nor’easter delivered snow and ice, 50 to 80 mph wind gusts, and strong surf from northern Florida to Nova Scotia, Canada. Due to its rapid intensification (the barometric pressure at the center of the storm dropped

59 millibars in 24 hours), the storm ranks among the strongest ever observed along the East Coast.

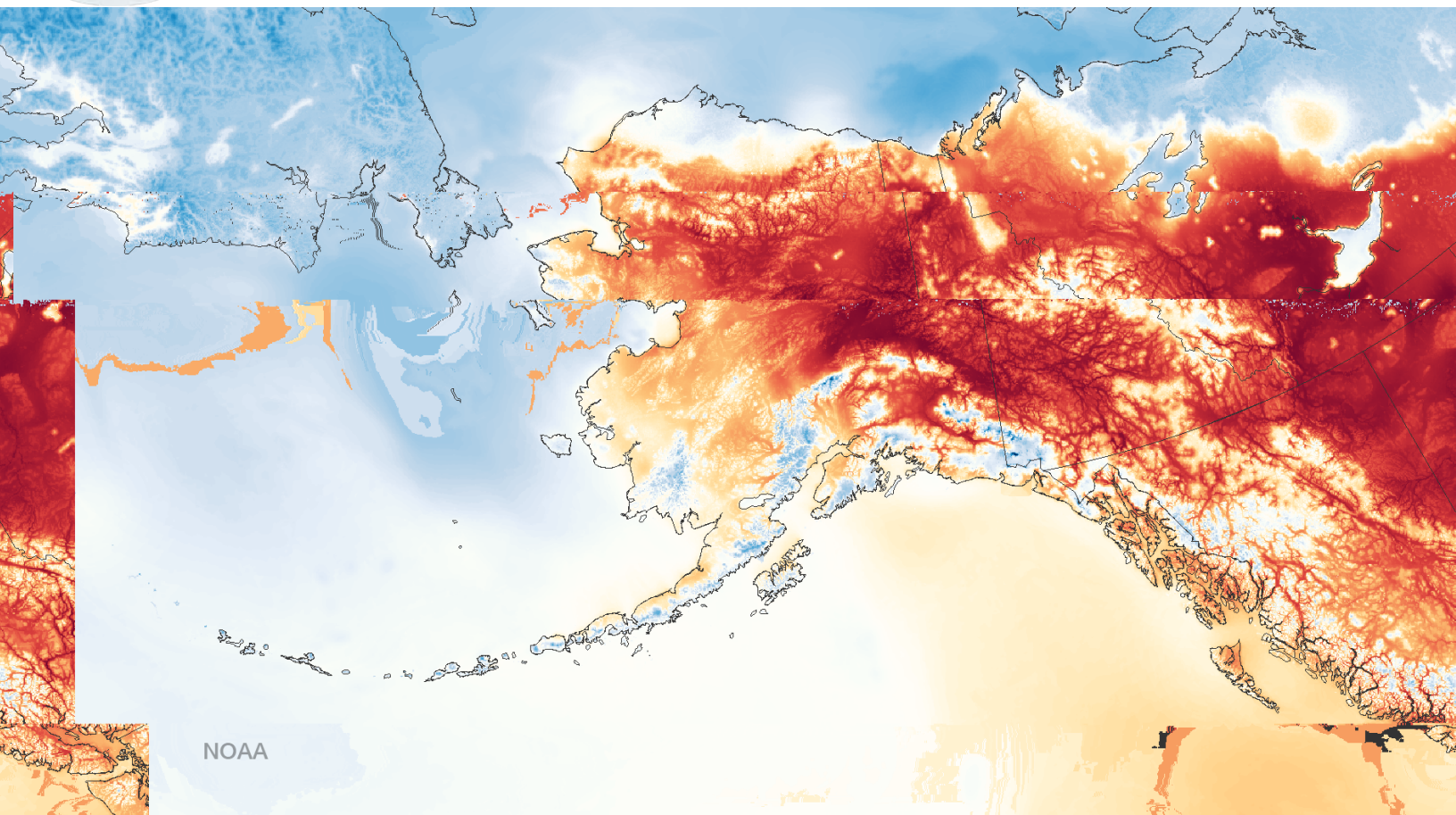
Infrared satellite imagery, which detects heat radiating off of clouds and the surface of the Earth, can help meteorologists detect certain features of the storm. This image was created from the VIIRS M15 radiometric band, which is sensitive to changes in atmospheric temperature. In this thermal infrared image, blue and white indicate the coldest sectors of the storm,

while the red and yellow shades indicate relatively warmer ocean and land surface temperatures. The whitest shades show the coldest and highest cloud-top heights, which are associated with more intense storm activity. ❖



WEB FEATURE: JANUARY 4, 2018

## HERE'S WHY POLAR-ORBITING SATELLITES ARE SO CRITICAL FOR WEATHER FORECASTING IN ALASKA



This image shows the surface air temperature from 23:00z on May 23, 2015 using NOAA's Real-time Mesoscale Analysis model (RTMA). The warmest temperatures are colored orange-red, colder colors are colored blue. The RTMA uses surface observation data from several sources, including NOAA polar-orbiting satellites, to create a highly accurate gridded analysis of past weather conditions.

With a total area of more than 660,000 square miles, Alaska is not only the largest state in the U.S.; it's the largest state in the U.S. by far! Not only is it twice the size of Texas, it's larger than Texas, California, and Montana combined! Alaska also has a diverse landscape, with mountains, valleys, coastline, and tundra, featuring dramatic changes in topography. Yet, as large and wonderful as the Alaska is, its immensity and varied landscape create certain challenges for the people who live there. Among them is forecasting the weather.

"The areas of responsibility for forecasters in Alaska's National Weather Service forecast offices are large, compared to those of other areas of the country, and topographically

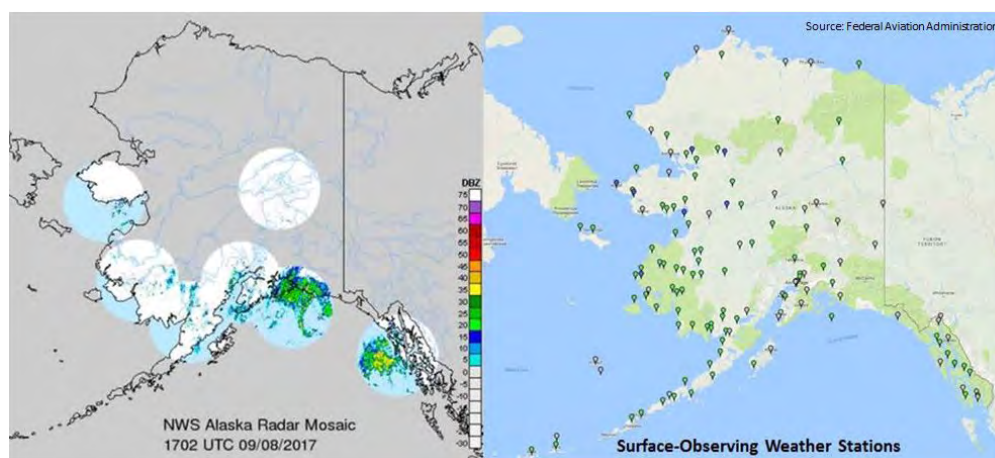
complex," said Eric Stevens, meteorologist at the Geographic Information Network of Alaska (GINA) at the University of Fairbanks and one of the JPSS Program's satellite liaisons. "The terrain can modify synoptic (aka: large)-scale weather patterns to produce highly specific local weather effects. This is important because, if you're going to forecast the weather, you first have to know what's happening now."

To get the information they need to produce accurate weather forecasts, meteorologists and forecasters in Alaska rely on the same tools their counterparts use across the lower 48: ground-level data from weather stations, radar, vertical atmospheric soundings from instruments attached to weather balloons, and imagery and

data from earth-observing satellites. What's different in Alaska, though, is that the state's size and diverse topography limit the amount of much of this data.

"In Alaska, if you want to look at the radar or balloon networks, you have a real problem with the density of observation and the limited spatial representation of these platforms," Stevens said. "Look at the radar networks in Alaska. We have seven radars, which is great to have, although six of them are oriented to track landfall-making coastal storms. In the interior of Alaska there is not much radar data."

The same can be said for the use of surface weather stations in the state. Even though they far outnumber radars in Alaska (see graphic below), large portion of Alaska's interior remain relatively uncovered.



## POLAR-ORBITERS PICK UP THE SLACK

Fortunately, Alaska's size and terrain are not impediments to one important observational tool: polar-orbiting satellites. Often called the "backbone" of global weather forecasting, polar-orbiting weather satellites provide as much as 85 percent of the data used by numerical weather models, making them vital for 3- to 7-day forecasts the world over.

In addition to the value of this data to forecast models, polar orbiting satellites are critical to meeting Alaska's short term forecast challenges. Alaska's latitude and proximity to the North Pole

result in its frequent scanning by NOAA and NASA-operated polar-orbiting satellites, as well as those operated by other space-faring nations and organizations around the world (e.g., China, EUMETSAT). More frequent scans result in more data for Alaska's meteorologists to use in developing forecasts.

To capitalize on these frequent scans, GINA has two direct broadcast antennas that track and receive data from polar-orbiting satellites. GINA also collaborates with NOAA's cooperative institutes, such as the Cooperative Institute for Meteorological Satellites Studies (CIMSS) at the University of Wisconsin. CIMSS created the algorithms that GINA uses to process (quickly!) raw satellite data into something that the meteorologists in the National Weather Service's Alaska forecast offices can use.

"Even the best satellite product does not help a forecaster or the forecast process if the imagery is available after the fact. We can get an image in front of a NWS forecaster within approximately 15 minutes of our contact with the satellite as it passes overhead. That

is pretty efficient—and that helps the NWS forecasters do their jobs." The recently launched NOAA-20 will help maintain this efficiency as both it and its predecessor—Suomi NPP—circumnavigate the Earth in the afternoon orbit. Separated in time and space by just 50 minutes, NOAA-20 will provide GINA with even more data (until Suomi NPP is no longer operational) than it's getting now.

The information presented here came from, "It's Dark in Alaska, but the Future of JPSS Is Bright," a presentation given by Eric Stevens on December 18, 2017. For more information on this presentation, see the Science Seminar page on the JPSS website.

## POSTSCRIPT: COVERING ALASKA DAY AND NIGHT

In addition to being large and possessing a challenging landscape, Alaska is also dark, particularly in the winter. (For example, the Alaskan town of Utqiagvik, formerly known as Barrow—the state’s northernmost settlement—will be shrouded in darkness for 67 days this winter.) The satellites of the JPSS constellation can be of service in Alaska during this part of the year as well.

The Visible Infrared Imaging Radiometer Suite (VIIRS) instrument aboard Suomi NPP and NOAA-20 allows the satellite to “see” during nighttime hours using the reflection of moonlight and ambient nightglow—a mix of light from starlight and zodiacal light (sunlight

scattered across the solar system by dust particles in space). The Day-Night Band (DNB) is so sensitive it can see not only the weather illuminated the moon, but also anthropogenic light (e.g., city lights), aurorae, and other sources of nighttime light (e.g., fires).

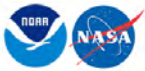
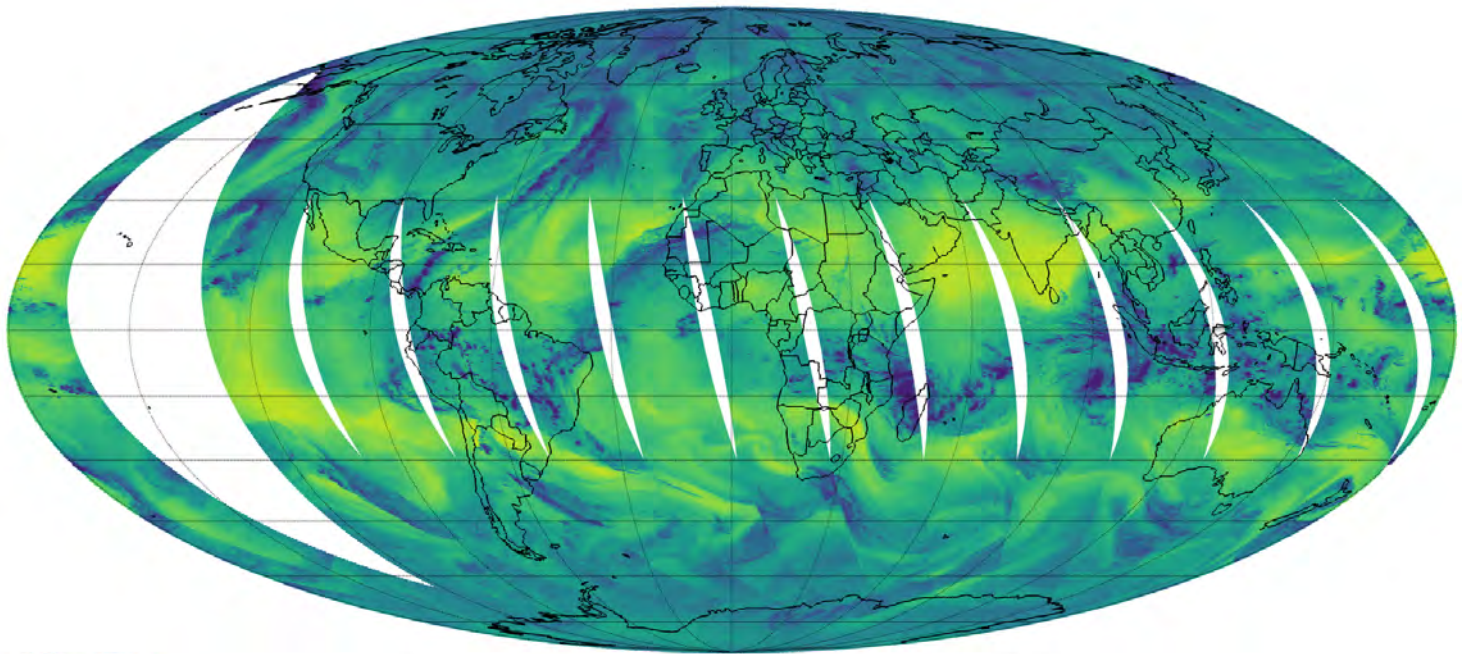
As Eric Stevens notes in a video about the importance of the Day-Night Band for weather forecasting in Alaska, “The Day-Night Band is probably the single most important piece of the VIIRS instrument to the National Weather Service in Alaska. Basically, it allows you to see visible-spectrum light at night. The instrument is so sensitive it’s like wearing night-vision goggles. DNB does not show infrared temperatures, but visible light, so if you have any sliver of moon, you can see the weather underneath the moonlight.” ❖

[Suomi NPP's VIIRS instrument captures an aurora over Alaska.](#)



WEB FEATURE: JANUARY 5, 2018

## NOAA-20 SENDS FIRST IMAGE FROM CROSS-TRACK INFRARED SOUNDER INSTRUMENT



NOAA-20 CrIS Channel 1025:  $1598.75\text{cm}^{-1}$  ( $^{\circ}\text{K}$ )

215      230      245      260      275

On January 5, 2018, 48 days after JPSS-1 (now NOAA-20) launched into Earth orbit, the satellite sent back its first Cross-track Infrared Sounder (CrIS) science data. This data is a part of a series of instrument activation and checkout tests that occur before the satellite is declared fully operational. CrIS is one of five key instruments onboard NOAA-20 that will improve day-to-day weather forecasting while extending the record of many long-term observations of Earth's climate.

CrIS provides global hyperspectral infrared observations twice daily for profiling atmospheric

temperature and water vapor, critically needed information for improving weather forecast accuracy out to seven days. CrIS also supplies information to retrieve greenhouse gases, land surface and cloud properties. CrIS measures infrared spectra in three spectral bands: the long-wave IR (LWIR) band from 650 to 1095  $\text{cm}^{-1}$ , mid-wave IR (MWIR) band from 1210 to 1750  $\text{cm}^{-1}$  and short-wave IR (SWIR) band from 2155 to 2550  $\text{cm}^{-1}$ .

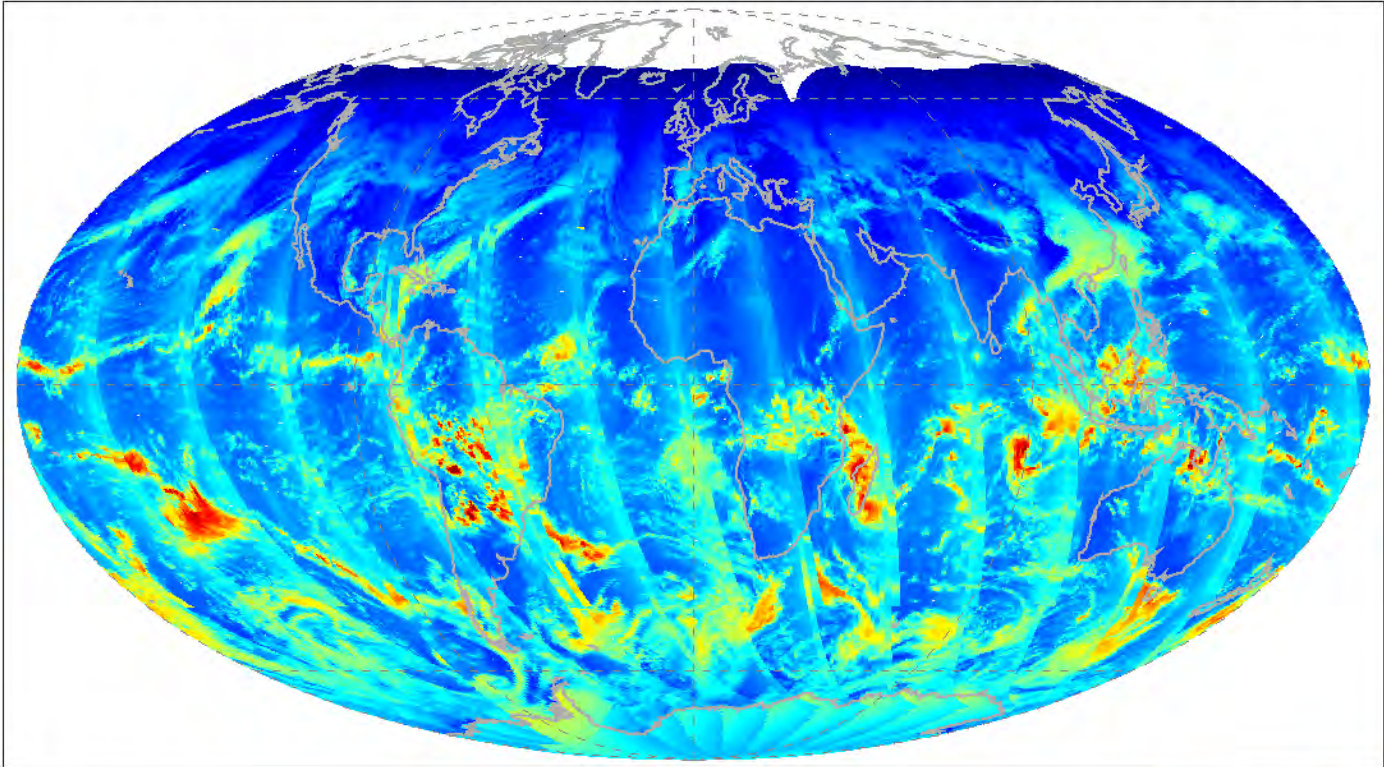
This image shows the global brightness temperature distribution at day time in one of the CrIS water vapor channels at 1598.75  $\text{cm}^{-1}$ . This channel is sensitive to water

vapor amounts around 500 hPa, and to mid- to high-level clouds. Dark blue colors in the image represent liquid water and ice clouds. Yellows indicate that the radiation is from the warm Earth's surface, or a dry layer in the middle troposphere. The image captured the blizzard striking the northeast coast of the United States on January 5, 2018. With the detailed vertical water vapor information provided by CrIS water vapor channels, weather forecasts can be better improved. ❖

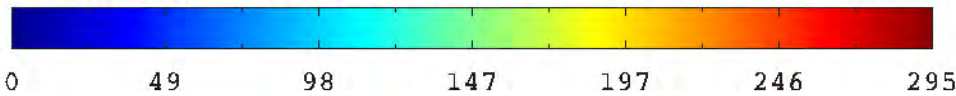


# WEB FEATURE: JANUARY 8, 2018 NOAA-20 SENDS FIRST OMPS INSTRUMENT DATA

2018/01/05 First Light NOAA-20 OMPS Nadir Mapper, 360.8nm



Radiance at 360.8nm, Watts/cm<sup>2</sup>/nm/sr

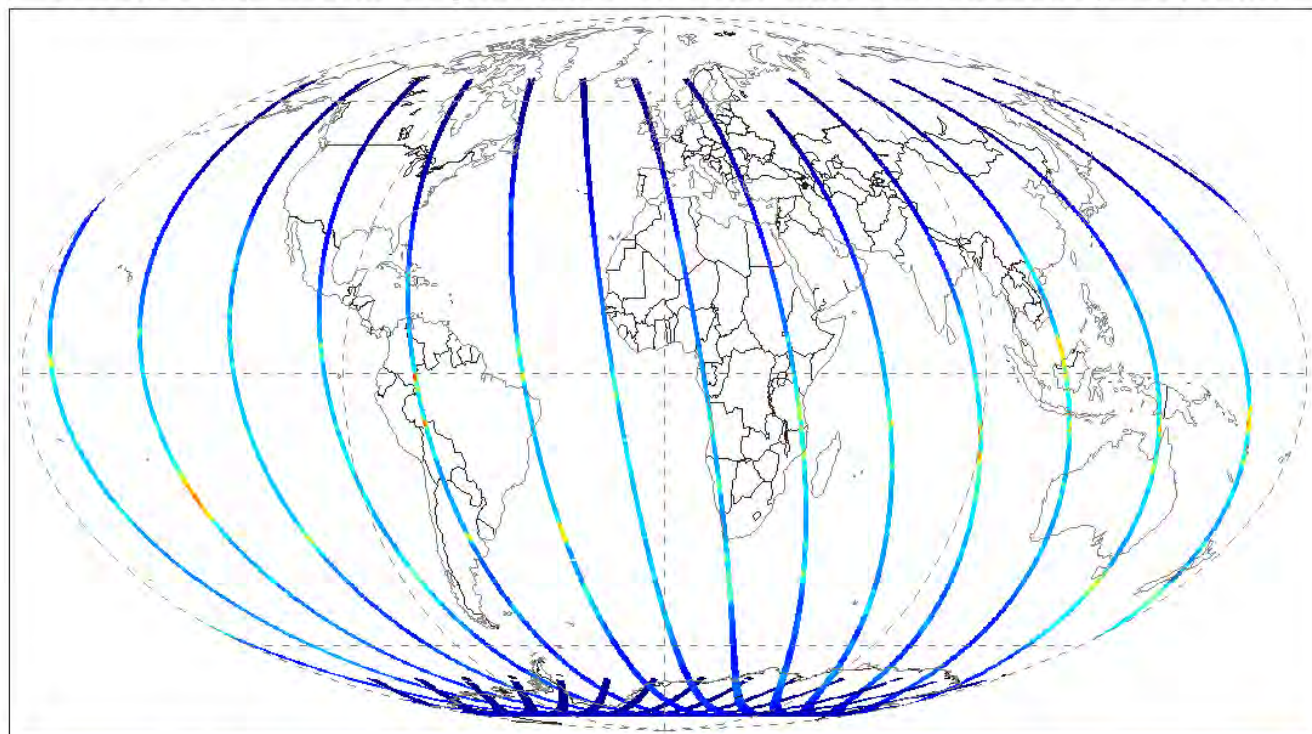


The OMPS instrument on the NOAA-20 satellite acquired its first data on January 5, 2018. The OMPS (Ozone Mapping Profiler Suite) measures the health of Earth’s ozone layer, and continues a crucial global data stream produced by current ozone monitoring systems. Measurements of ozone throughout Earth’s atmosphere are key to issuing

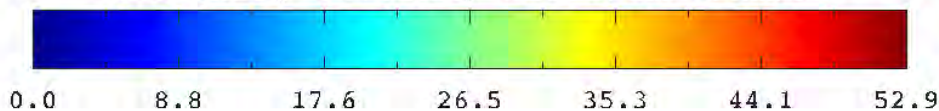
air quality warnings and creating the National Weather Service’s UV indexes.

OMPS shows us ultraviolet light that is reflected back into space from the atmosphere called “backscattering”. This first-light image shows the radiance values for the cloud reflectivity channel on the OMPS Nadir Mapper. The highest radiances are

associated with bright cloud tops. The cloud reflectivity channel is one of the five primary channels used to estimate total ozone concentration. The striping pattern is created from the slight differences in the angle of the satellite relative to the incoming energy from the sun.



Radiance, 307.5nm, Watts/cm<sup>2</sup>/nm/sr



The second image (above) shows the radiance at 307.5nm from the OMPS Nadir Profiler. This measurement is one of the 12 primary channels used to estimate the ozone at various levels in the atmosphere—closer to and farther from Earth's surface. The OMPS Nadir Profiler only makes measurements directly under the satellite's path.

Understanding the vertical structure of ozone in the atmosphere is important because ozone in the stratosphere (higher in the atmosphere) protects us from the sun's harmful ultraviolet energy while ozone in the troposphere (lower in the atmosphere) contributes to air pollution.

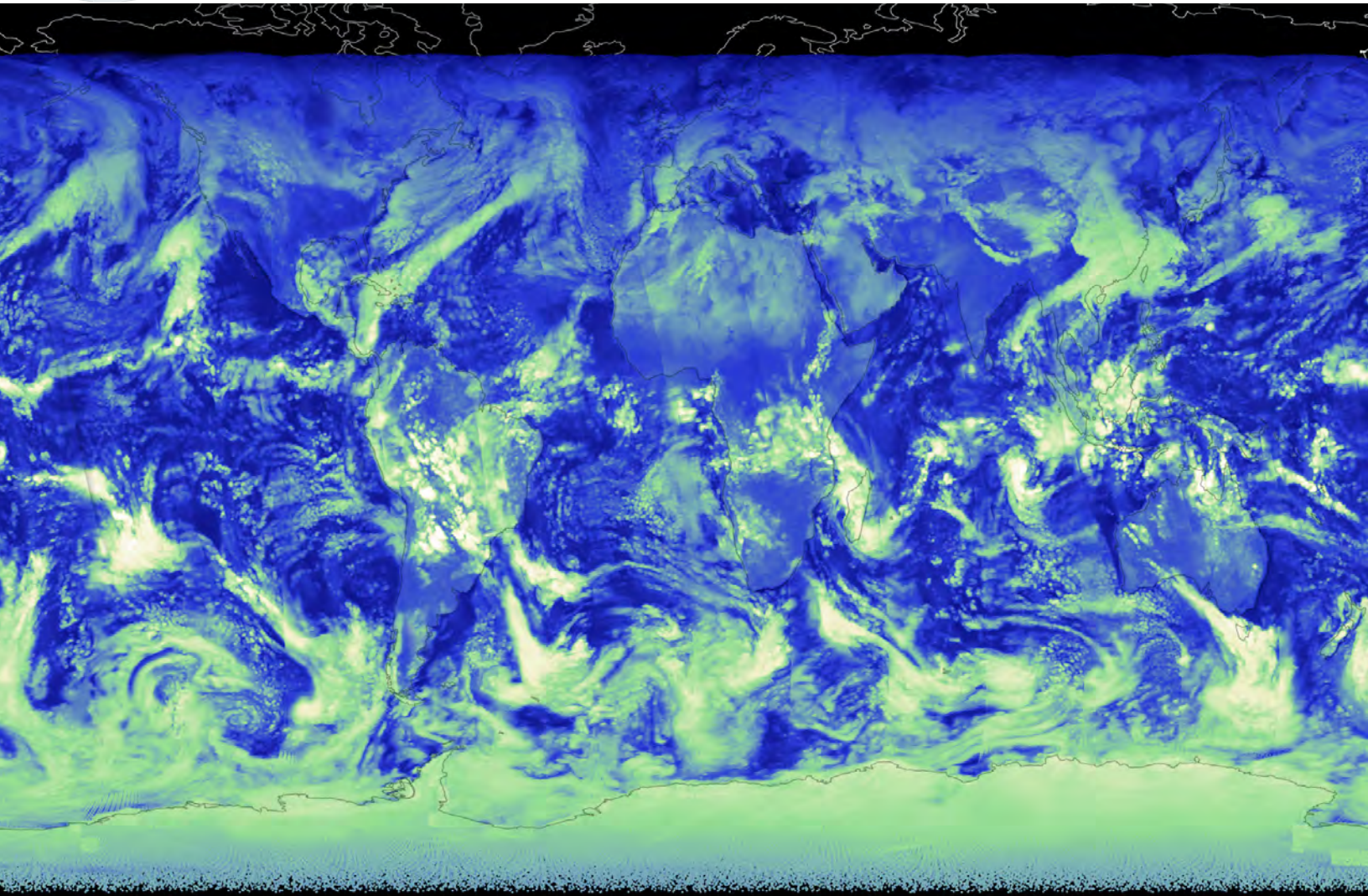
Image processing by NOAA/Center for Satellite Applications and Research.

Contributors: Trevor Beck, Chunhui Pan, NOAA/NESDIS/STAR, JSTAR OMPS SDR Team. ❖



WEB FEATURE: JANUARY 17, 2018

## THE FIRST LIGHT IMAGES FROM NOAA-20'S CERES FM6 EARTH-OBSERVING INSTRUMENT ARE HERE!



61.4 96.7 132 167.3 202.7 238 273.3 308.6 343.9 379.2 414.5 449.8 485.1 520.4 555.7 591 626.3 661.6 696.9 732.2 767.6 802.9 838.2 873.5  
Watts per square meter

In this shortwave image from CERES FM6, the white and green shades represent thick cloud cover reflecting incoming solar energy back to space. Compare that with the darker blue regions, which have no cloud cover, to get a sense for just how much clouds can affect the balance of incoming and outgoing energy on Earth. Credit: NASA.

The covers on NOAA-20's Clouds and the Earth's Radiant Energy System Flight Model 6 (CERES FM6) opened Jan. 5, allowing it to scan Earth for the first time.

CERES FM6 was launched into space aboard NOAA-20 (formerly JPSS-1) on

November 18, 2017, and is the last in a series of instruments going back to the late 1990s that measure the solar energy reflected by Earth, the heat the planet emits, and the role of clouds in that process. The instrument was built by Northrop Grumman, funded by NOAA and managed by

NASA's Langley Research Center in Hampton, Virginia, in coordination with the JPSS program.

"The successful launch of CERES FM6 and acquisition of initial data is fantastic news," said David Considine, program manager for NASA's Modeling,



In this longwave image from CERES FM6, heat energy radiated from Earth is represented by shades of yellow, red, blue and white. Bright yellow regions are the hottest and emit the most energy out to space. Dark blue and bright white regions, which represent clouds, are much colder and emit the least energy. Credit: NASA.

Analysis and Prediction program. “Its data will help us to understand the critical role that clouds play in the Earth system, and shows the value to the Nation of the NASA and NOAA collaboration leading to this achievement.”

The CERES data record extends back to 1997. Prior to CERES, the Earth Radiation Budget Experiment (ERBE) collected similar data beginning in 1984. The two NASA programs demonstrate NASA’s long-term involvement in measuring Earth’s energy

balance going back more than 30 years.

This information appears courtesy of NASA. For more information, visit their website. To learn more about the CERES instrument, visit the [JPSS website](#). ❖



WEB FEATURE: FEBRUARY 9, 2018

## FROM LAUNCH TO OPERATIONAL: AN OVERVIEW OF NOAA-20'S CHECKOUT PHASE



Approximately one hour after liftoff, when JPSS-1 separated from the upper stage of the Delta II launch vehicle and its solar array deployed, the launch of NOAA's newest polar-orbiting satellite was officially deemed a success. Mission accomplished then, right?

Not quite. Despite making it to space and orbiting on its own, JPSS-1 (now known as NOAA-20) won't be declared operational for several months after launch. So what is the satellite doing up there during the interim? It's getting checked-out by scores of engineers and scientists from NASA, NOAA, and the Joint Polar Satellite System's industry partners—Ball Aerospace, Raytheon Space and Airborne Systems, Northrop Grumman Aerospace Systems, and Harris Corporation— who will test everything from the satellite's communications systems to its scientific instruments.

This period of checks and tests—aptly referred to as the “checkout phase,” but it's also known as “post-launch testing”—began Saturday, November 18, 2017, immediately after the satellite separated from the upper stage of the Delta II and began orbiting freely in space. At this time, the Mission Operations Support Team (or MOST), a group of about 50 engineers, begins executing an orderly, round-the-clock plan for evaluating just about every piece of hardware on NOAA-20. This plan continues until the satellite is deemed ready for handover to NOAA for routine operations.

### FOUR SUB-PHASES AND ORBIT-RAISING

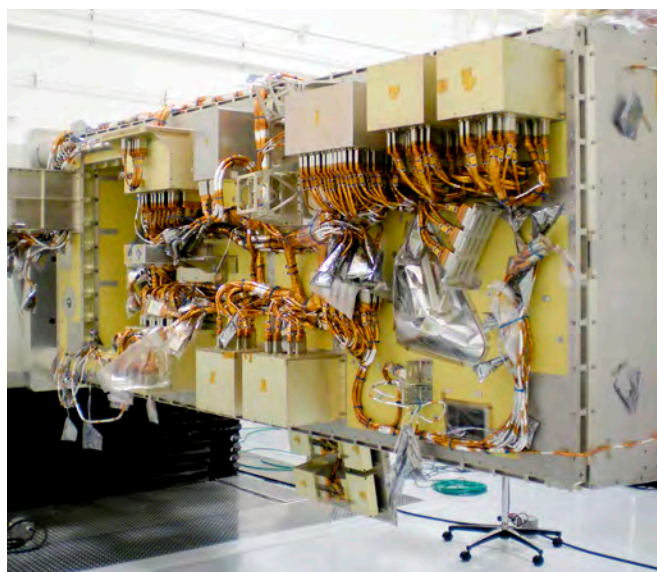
In general, the checkout phase consists of four sub-phases: spacecraft commissioning, outgassing, instrument activation and instrument performance characterization, and operational science testing. It is important to note, however, that these sub-phases do not take place in linear fashion, occurring one after the other.

Often, tests from different sub-phases take place simultaneously. For example, although instrument activation and testing activities generally take place after the commissioning of the systems on the spacecraft, some instrument testing is done in concert with spacecraft commissioning initiatives. In addition, the satellite's orbit-raising (see sidebar) typically occurs simultaneously with the early sub-phases.

## COMMISSIONING THE SPACECRAFT

The spacecraft commissioning sub-phase, which begins soon after launch, focuses on tests of the spacecraft's primary systems.

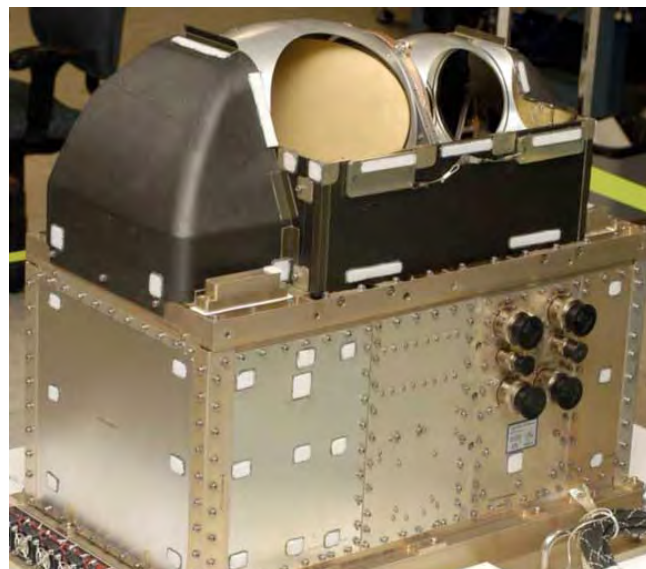
"[The spacecraft] has a number of systems that run the satellite," said Tom Wrublewski, Physical Scientist with NOAA's Joint Polar Satellite System program. "The key ones are the power system: the solar array has to deploy right after launch to recharge the batteries; the attitude control system, which keeps the satellite flying right and facing the earth; the communication system, which is composed of several antennas and transmitters that send both health and safety or housekeeping data to the operators and mission data to ground stations; and the computer/data system that monitors and controls the spacecraft in flight to make sure everything is operating smoothly."



The JPSS-1 spacecraft bus Credit: Ball Aerospace.

Also included in this sub-phase are checks of the satellite's propulsion system, which is used during orbit-raising, station-keeping and then at the end of mission to de-orbit the satellite safely into the ocean.

## ACTIVATING AND OUTGASSING THE INSTRUMENTS



Above: NOAA-20's Advanced Technology Microwave Sounder was the first instrument to be turned on and the first to send back science data.

In the second sub-phase, engineers shift their focus to NOAA-20's instruments and to get them ready for operation. As with any other electronic device, the engineers must first to turn them on to make sure they are operating as expected, and then complete an outgassing period, before opening the doors protecting their sensors. During the outgassing period, any chemical residues or water vapor from the materials used on the satellite or in the instruments evaporates into the vacuum of space.

"You try to keep everything clean on the ground, but it's very hard. The multi-layer insulation blankets used to protect the instruments hold water vapor and, when the satellite gets into space, the instruments use a series of heaters and the vacuum of space to drive them off. Instruments like VIIRS, CrIS, CERES, and OMPS that have sensitive optics that need to be protected from these contaminants, so we give them a chance to migrate away from the spacecraft during the early weeks [of checkout]."

## INSTRUMENT CHARACTERIZATION, CALIBRATION AND OPERATIONAL SCIENCE TESTING



This image of the recent fires near Santa Barbara, California, was created with data from NOAA-20's Visible Infrared Imaging Radiometer Suite Instrument.

Following activation and outgassing of the instruments, the next sub-phase pertains to their characterization, calibration and validation, which is a fancy way of saying that engineers are checking to see if the instruments are performing as expected based on pre-launch tests, and in comparison to the instruments on NOAA-20's predecessor, the NOAA-NASA Suomi NPP satellite.

"What they're doing is checking performance against the pre-launch measurements," said Wrublewski. They are making sure the instruments survived the harsh launch conditions and that there are no surprises.

Among the tests performed on the instruments during this sub-phase involve a series of maneuvers, including rolls (side-to-side movements), yaws (twisting the spacecraft left and right) and a pitch or "back flip," in which the satellite is flipped 180 degrees.

Although performed for a variety of reasons, these maneuvers are designed to give the satellites engineers and operators a better

understanding of the interactions between the instruments and the spacecraft, and how various aspects of the space environment are affecting the sensors (e.g., the amount of light reaching sensitive instrument sensors, etc).

The final sub-phase, operational science testing, involves inspecting the quality of the instrument data, or as Bryan Fafaul, project manager with the Joint Polar Satellite System Flight Project put it, "Making sure the instrument data sent back via the ground system are what you think they're supposed to be."

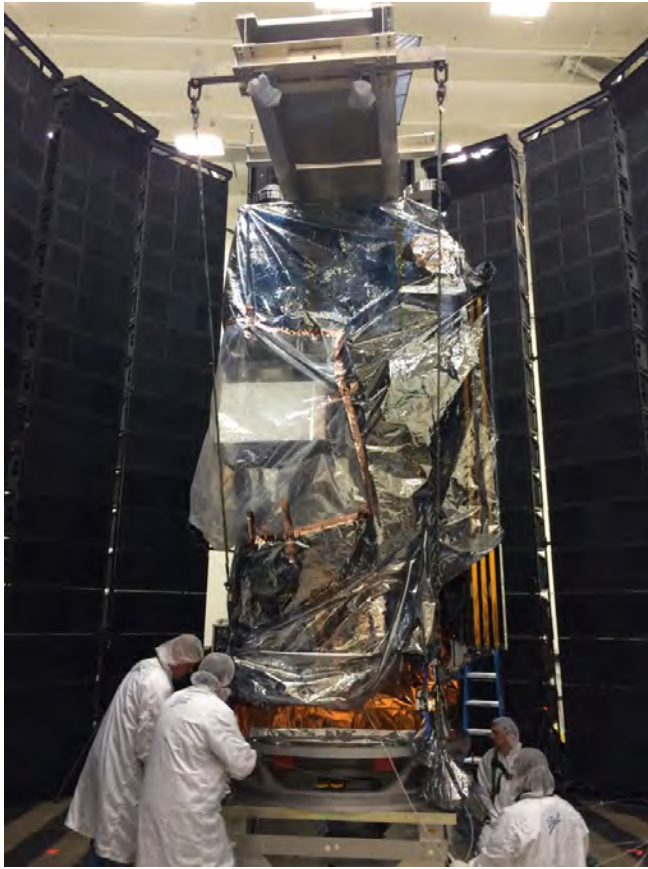
## LEARNING THINGS IS EXPECTED

There are moments during the checkout phase, however, when instrument data or something associated with a satellite subsystem doesn't behave as expected. When things don't behave as they should, this doesn't necessarily mean you have an issue, but you need to understand the anomalous behavior, said Fafaul.

"You expect to learn things after launching a satellite. It'll never be perfect because you can't test exactly for how the satellite or its instruments will behave in space while they're still on-the-ground," he said. "Once you get the satellite up there and all the systems are working, anomalies will occur."

So what happens when an anomaly occurs?

"The JPSS's Mission Systems Manager will assemble what's known as an anomaly response team—a group composed of NOAA, NASA and industry personnel with in-depth knowledge of the system or instrument," said Wrublewski. "Once assembled, the members of this team meet to discuss the issue and develop a plan to address it."



JPSS-1 (now NOAA-20) during pre-launch testing.

Once resolved, the anomaly is then documented (extensively) so the operators who will control NOAA-20 after it's declared operational will know what to do if the anomaly happens again.

## FROM CHECKOUT TO OPERATIONAL

NOAA-20's checkout phase is expected to conclude sometime in mid-February, when all of the tests associated with the four sub-phases have been completed. At that time, Vanessa Griffin, Director of NOAA's Office of Satellite and Product Operations (OSPO), and her deputies, will gather members of NASA's MOST team to go over a check list to ensure that all the requirements, including instrument performance, the documentation and manuals, procedural updates, and the training of operations personnel, have been met. If they have, NASA will then officially "hand over" NOAA-20 operations to OSPO, which manages the ingestion, processing, and distribution of NOAA satellite data and derived products to domestic and foreign users.

## THE ORBIT RAISING OF NOAA-20

NOAA-20's orbit-raising is just what it sounds like—an orbital maneuver conducted to get the satellite into its proper position, precisely 50 minutes apart from its predecessor and polar-orbiting partner Suomi NPP.

If you were under the impression that NOAA-20 was launched into its final orbit after rocketing into space aboard the Delta II, you're not wrong. This initial orbit is known as an insertion orbit, which is approximately 10 kilometers lower than the satellite's intended, operational orbit. To get the satellite where it needs to be, engineers conduct an orbit-raising sequence consisting of five burns, or maneuvers using NOAA-20's propulsion system.

The first and second orbit-raising burns, which can last as long as 30 seconds, serve as thruster checkouts and are used to adjust elements of NOAA-20's orbit. The third burn adjusts the satellite's inclination (or the angle between the satellite's orbital plane and the equator). The fourth and fifth burns are conducted to achieve a so-called "frozen" orbit, or an orbit wherein the altitude of NOAA-20 remains constant at the same point in each orbit over a long period of time, while simultaneously maintaining half-orbit separation (the aforementioned 50 minutes) with Suomi NPP.

The length of the orbit-raising process varies on several factors. In the case of NOAA-20, orbit-raising took approximately three weeks and was completed in January 2018. Another small orbit maneuver will take place before operations are handed over to NOAA. ❖



WEB FEATURE: FEBRUARY 15, 2018

## UNIQUE COLLABORATION WORKS TO EXTEND SEA ICE PREDICTION FROM DAYS TO DECADES



The US Coast Guard Cutter Healy relied on sea ice model-driven forecasts to clear a path for a fuel oil delivery to Nome, Alaska, in January 2012. NOAA's polar-orbiting satellites provide critical data to sea ice prediction models. Credit: NOAA Research.

You might say that ice runs in Elizabeth Hunke's blood.



Department of Energy scientist Elizabeth Hunke has spent more than two decades designing, creating, and improving a sea ice prediction model. Credit: Department of Energy.

The U.S. Department of Energy scientist who created the nation's premier model used by NOAA, the Navy and many scientists to predict sea ice got a taste for ice as a child.

The daughter of a Coast Guard officer, Hunke grew up around sea ice in Cordova, Alaska, where her father tended buoys in the chilly waters of Prince Edward Sound. Her father was also part of the Coast Guard ice patrol when they lived near Boston, tracking ice bergs to warn ships of lurking hazards.

For more than two decades, Hunke has worked at the Department of Energy's Los Alamos National Laboratory to design, create and improve a model used to predict sea ice extent, thickness and movement in both the Arctic and Antarctica.

## DECLINING SEA ICE, MORE SHIP TRAFFIC BOOSTS NEED FOR FORECASTS

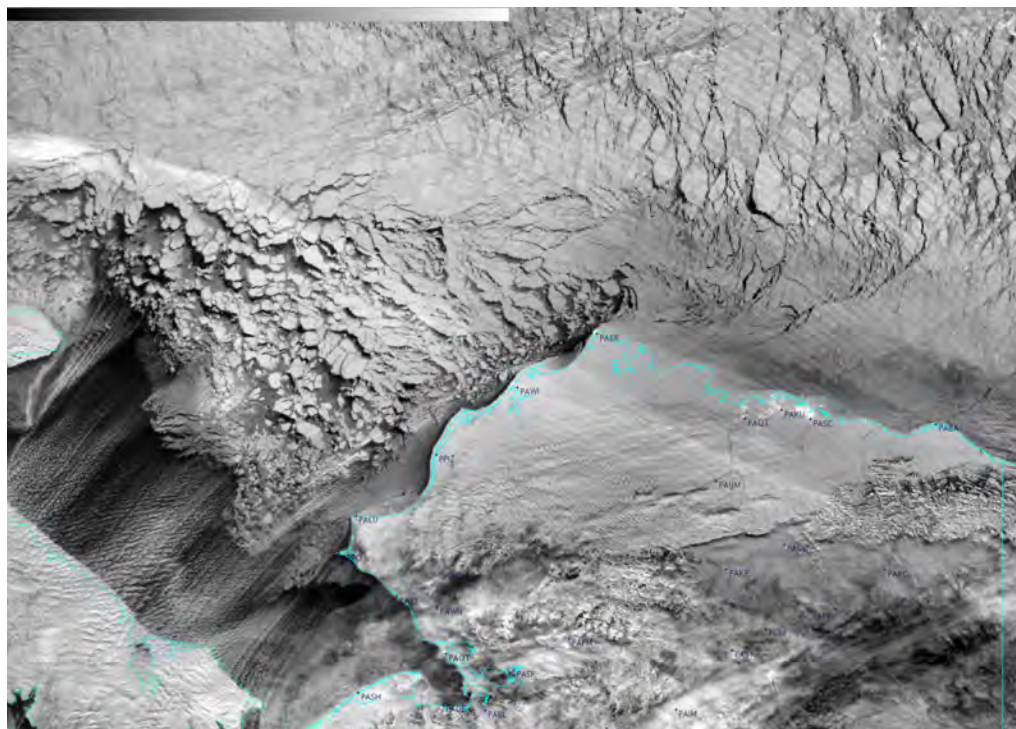
As sea ice declines more rapidly, the demand for improved prediction is increasing.

“During this period when ice is fluctuating a lot, there are many more attempts to get ships through it,” said Hunke. “This also presents more challenges for search and rescue.”

Arctic communities depend on sea ice as a platform for hunting, a roadway for transportation and a buffer for severe coastal storms. The military needs accurate prediction for today’s mission and to plan for building and operating the ships and submarines of the future. More industries working in the Arctic, including shipping, tourism and energy development, depend on sea ice forecasts.

## NEW SATELLITE DATA IMPROVE FORECASTS

Prediction and modeling advances rely on satellite observations.



This image from NOAA’s Satellite System Preparatory Project (Suomi NPP or SNPP) shows ice, snow, clouds and open ocean around Alaska on Dec 09 2014. Ships rely on such imagery to navigate the region safely. Credit: NOAA.

NOAA’s newest satellites have increased the frequency, resolution and information on sea ice used in the Los Alamos sea ice (or CICE) model, which also draws on observations from buoys, ships and aircraft. NOAA’s newest polar-orbiting satellite, NOAA-20, observes sea ice almost continually down to less than a quarter mile resolution. It uses moonlight to observe ice at night, so important in a region where it is dark a large part of the year.

The National Ice Center, operated by the Navy, Coast Guard and NOAA, uses the CICE model to help put out daily sea ice forecasts for the Arctic, Great Lakes, Chesapeake Bay, and Long Island Sound.

NOAA’s goal is to add sea ice prediction to the next generation Global Forecast System.

To learn more about sea ice prediction, efforts to enhance the CICE model and what’s in store for the future of sea ice prediction, visit NOAA’s Office of Research.

For more information on why NOAA’s polar-orbiting satellites are so important to weather forecasting and environmental monitoring in

Alaska and the Polar Regions, visit the [Joint Polar Satellite System website](#). ❖



WEB FEATURE: APRIL 16, 2018

## TWO SATELLITES, ONE ORBIT, MANY BENEFITS



Shortly after NOAA-20 (formerly JPSS-1) launched into space on November 18, 2017, it joined its predecessor—the Suomi NPP satellite—in the same polar orbit. This means that, although the two spacecraft are separated in time and space by 50 minutes, they are traveling the same path as they circle the Earth 14 times a day, each imaging the entire globe twice each day.

Why have two satellites in the same orbit?

In a word: continuity. Suomi NPP launched on October 28, 2011, which means the satellite has been orbiting the Earth for more than six years—one year beyond its design life. How long it will remain functional is anyone's guess, but the data Suomi NPP provides is too important to postpone replacing it until a problem occurs. That is why NOAA-20, which is destined to take Suomi NPP's place as NOAA's primary polar-

orbiting satellite in the afternoon orbit, launched while Suomi NPP is still operating reliably.

“We can never predict the end of life of a weather satellite, and because polar orbiting weather satellites are so critical for weather forecasts, we have to make sure we have at least one in orbit within its design life,” said Mitch Goldberg, Chief Scientist of the Joint Polar Satellite System Program. “So, having two satellites in the same orbit ensures that users will still have data for forecasting and environmental monitoring if one of the satellites experiences a partial or total failure.”

An added benefit of having two satellites in the same orbit is that, together, they will provide twice the data for forecasting the weather and monitoring the environment. It is important to note, however, that “double” does not mean “same.” As NOAA-20 and Suomi NPP orbit the



Earth, the planet spins beneath them. Therefore, although they are traveling the same path 50 minutes apart, the imagers and sensors aboard each satellite will “see” different areas of Earth’s atmosphere, land and oceans.

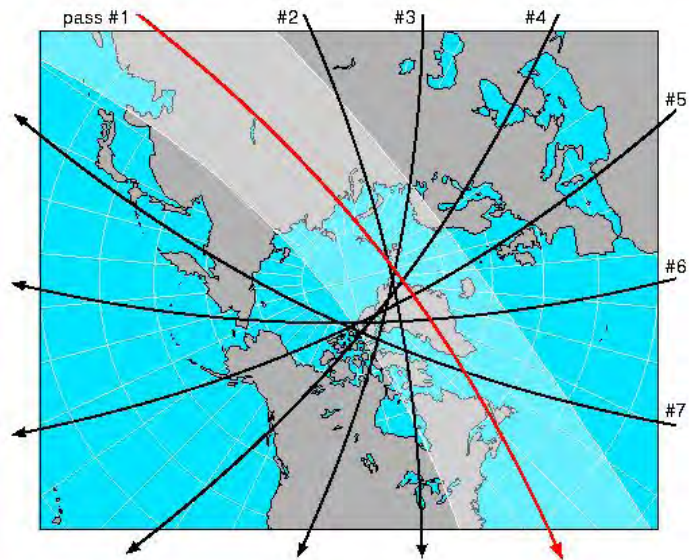
## MORE DATA, MORE OFTEN

Beyond capturing twice the data, having two satellites in the same orbit also means that this information will get to users more quickly than before. As seen in the animation above, Suomi NPP downlinks to only the JPSS ground system antenna at Svalbard, Norway (near the North Pole), while NOAA-20 downloads its data to the ground station antenna at Svalbard and the antenna at the McMurdo Station in Antarctica (near the South Pole). NOAA-20’s ability to downlink each time it passes an antenna at each pole is important, as it reduces end-to-end latency, or the time it takes the data to get from the satellite to the user. In fact, the data latency of NOAA-20 is said to be 96 minutes—a significant improvement over the 147-minute data latency of Suomi NPP.

The reduced data latency of NOAA-20 is the result of new hardware (two KA-band gimbaled antennas) not found on Suomi NPP and a more efficient ground system, which quickly ingests and processes data from both satellites. Once processed, the data are sent to the National Weather Service and NOAA’s other U.S. and international partners for assimilation into the forecast models that provide short-term and mid-range (3- to 7-day) forecasts.

## MORE COVERAGE OF ALASKA AND THE POLAR REGIONS

Nowhere is the need for timely data more pressing than in Alaska and the polar regions, where the remoteness or topography of the landscape limits the use of traditional forecasting tools, such as ground-based weather stations, radar, and sounding instruments attached to weather balloons (which are still widely in use). Even geostationary satellites such as GOES-16 cannot provide adequate coverage of the polar regions due to their position in space



This image shows the number of passes (red and black lines) Suomi NPP and NOAA-20 will make each day. The white strip refers to the width of area (or swath) each satellite will “see” on each pass.

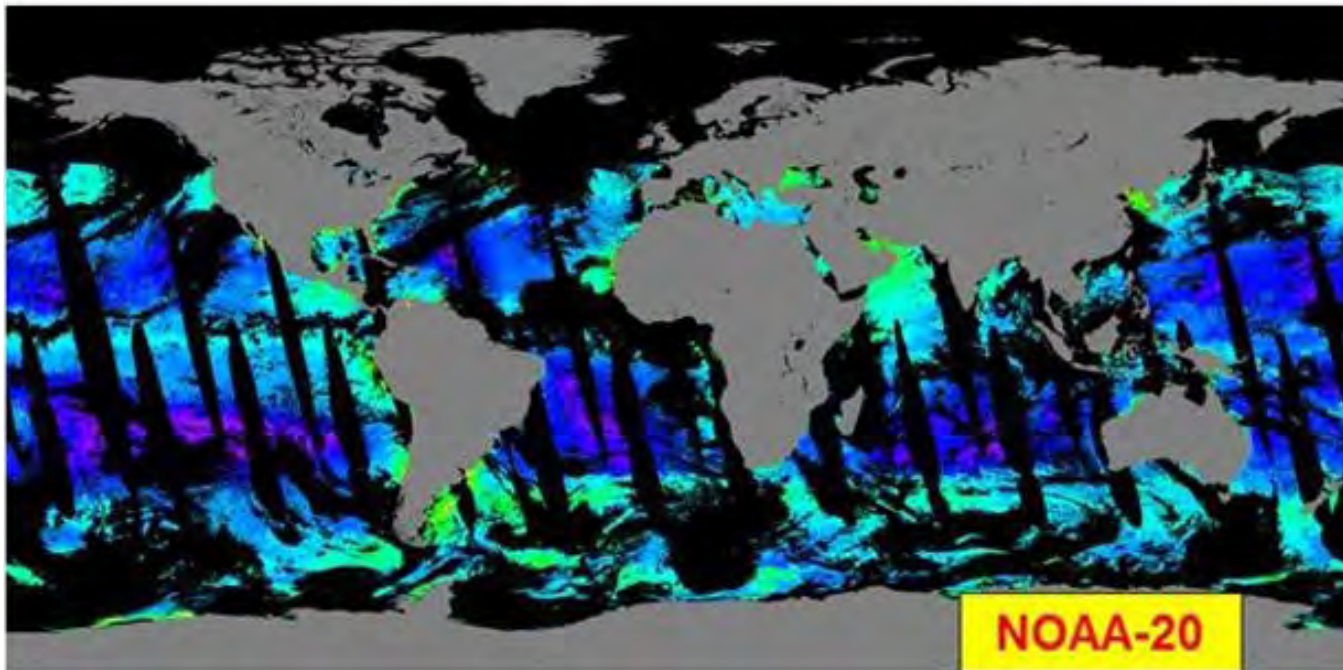
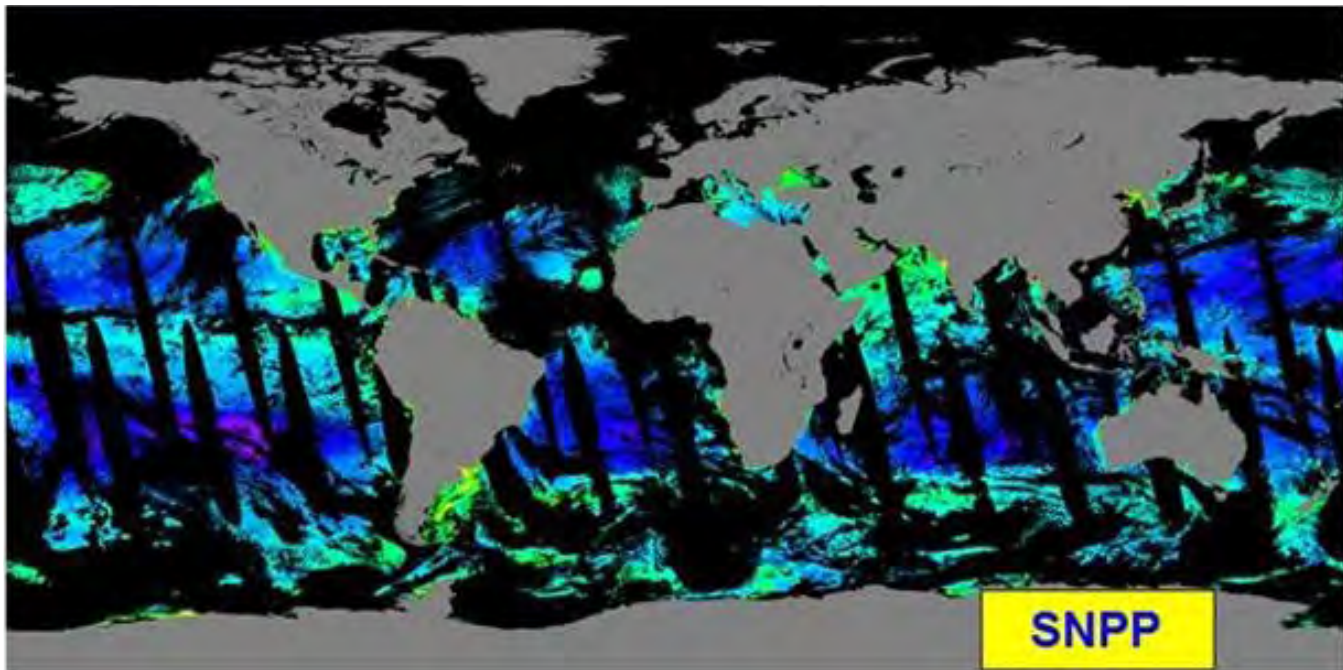
and the curvature of the Earth. Fortunately, polar-orbiting satellites can overcome these challenges. Within a given 24-hour period, NOAA-20 and Suomi NPP pass over Alaska and the polar regions several times a day.

To take advantage of these more frequent passes, the Geographic Information Network of Alaska (GINA) at the University of Alaska-Fairbanks has erected two direct broadcast antennas to receive polar satellite data and make it available even faster.

“Even the best satellite product does not help a forecaster or the forecast process if the imagery is available after the fact,” said GINA’s Eric Stevens. “We can get an image in front of a National Weather Service (NWS) forecaster within approximately 15 minutes of our contact with the satellite as it passes overhead. That is pretty efficient—and that helps NWS forecasters do their jobs.”

## GREATER ENVIRONMENTAL INTELLIGENCE

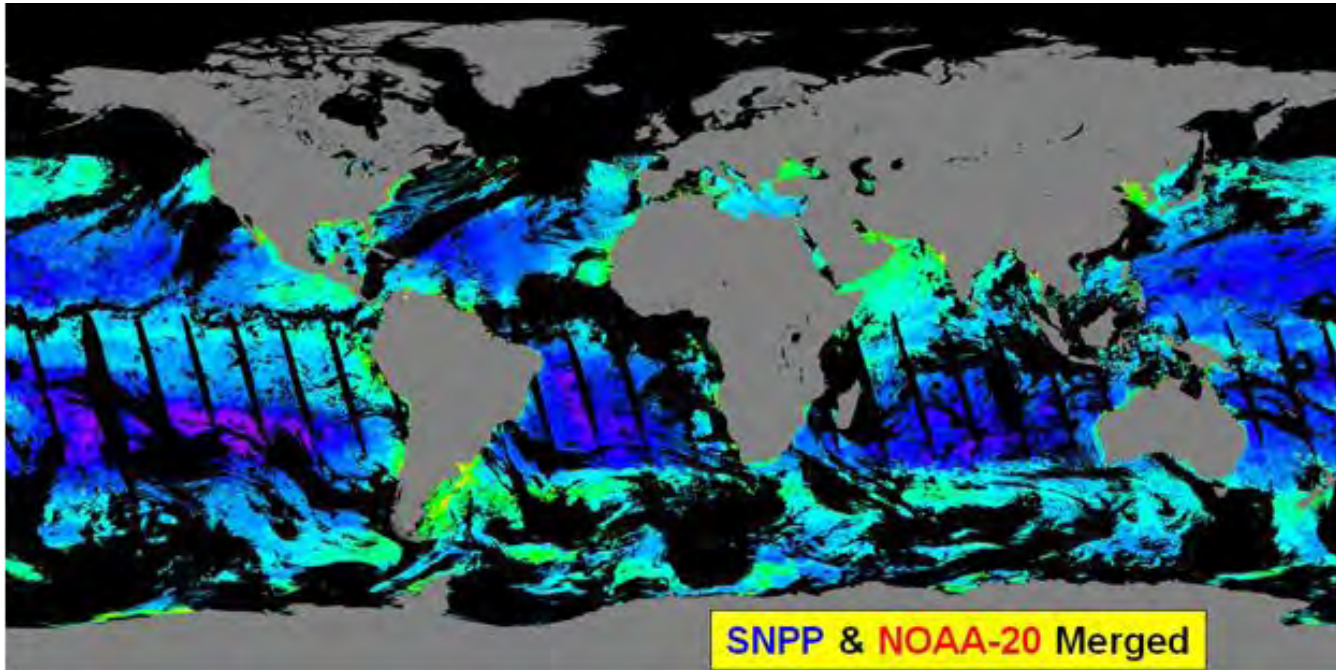
Meteorologists are not the only ones who benefit from having two satellites in the same orbit. The increased data and data products also support the ongoing efforts to monitor Earth’s ecological health. For example, the following ocean color images from Suomi NPP (top) and NOAA-20



These ocean color images from Suomi NPP (top) and NOAA-20 (bottom) show how green pigment, which is associated with algae, is contained within the surface waters of the world's oceans. Ocean color data has been instrumental in understanding global productivity, carbon cycling, fisheries habitats, and biochemical oceanography. In this imagery, areas of the ocean with lower amounts of surface chlorophyll are colored blue, and areas with higher concentrations are colored green to yellow.

(bottom) show how much green pigment (which is associated with the algae) is contained within the surface waters of the world's oceans.\* As seen here, both images show gaps in coverage, which are caused by atmospheric contamination (i.e., the interference of atmospheric particles with the imaging instrument's ability to detect the surface of the water) and the viewing angle

of the satellite. Although still present in the third image featuring data from both NOAA-20 and Suomi NPP (below), the gaps are smaller because the second satellite is looking (almost) straight down at the region the first satellite viewed at an angle. Thus, when the data from both satellites are combined, the result is a more complete assessment of ocean color.



Merging data from NOAA-20 and Suomi NPP into one image provides a more complete assessment of ocean color.

Efforts to detect and track of environmental hazards, including fires, volcanic ash clouds, sea ice and floods, also benefit from having a pair of satellites in the same orbit. For example, when fighting wildfires, emergency responders rely on NOAA’s polar satellites to understand weather conditions and identify “hot spots” with tools such as the VIIRS Fire Radiative Power Product. Such information is key when making decisions about where to deploy firefighting teams and other resources. In addition, the high spatial resolution provided by NOAA-20 and Suomi NPP enables the detection of small fires before they become larger.



Having two satellites in the same orbit provides wildland firefighters with more data to use in identifying hot spots and making decisions about the deployment of fire crews and other resources.

Similarly, the aviation industry relies on polar-orbiting spacecraft to monitor volcanic ash clouds—a serious threat to aviation safety. Following the eruption of an Icelandic volcano in 2010, there was widespread disruption to airline schedules. To help companies get back

on schedule, NOAA satellite data was used as a critical input in decisions as to how to re-reroute flights. This kept passengers out of danger and likely spared airlines from costly repairs to aircraft damaged by ash.

## TWO SATELLITES, ONE ORBIT— BOTH NOW AND IN THE FUTURE

Satellites Image Eventually, the day will come when Suomi NPP fails and is deactivated. This does not necessarily mean, however, that NOAA-20 will orbit the Earth alone. The JPSS Program is already at work on JPSS-2, and have contracts on JPSS-3 and -4. Although the payloads of these future spacecraft are the same as those in orbit now, their anticipated operational lives will be seven years, with the potential to remain operational for even longer. Moreover, these satellites will be built and launched in an overlapping fashion through 2036 to ensure operational continuity and the sustainability of the critical data flows that Suomi NPP and NOAA-20 are contributing to now. ❖

\*Ocean color data has been instrumental in understanding global productivity, carbon cycling, fisheries habitats, and biochemical oceanography. In this imagery, areas of the ocean with lower amounts of surface chlorophyll are colored blue and areas with higher concentrations are colored green to yellow.



WEB FEATURE: APRIL 19, 2018

## NOAA-20 CAPTURES DAY-NIGHT BAND IMAGES OF MOST RECENT POWER OUTAGE IN PUERTO RICO



At approximately 11:04 a.m. (EDT) on April 18, 2018, an excavator involved in an effort to remove a tower toppled by Hurricane Maria got too close to a power line and caused an electrical ground fault near Salinas, Puerto Rico. The incident resulted in an island-wide power outage. According to the Federal Emergency Management Agency (FEMA), the Puerto Rico Electric Power Authority (PREPA) said that, as of 2:00 a.m. (EDT), approximately 43% of the island's customers had their commercial power restored.

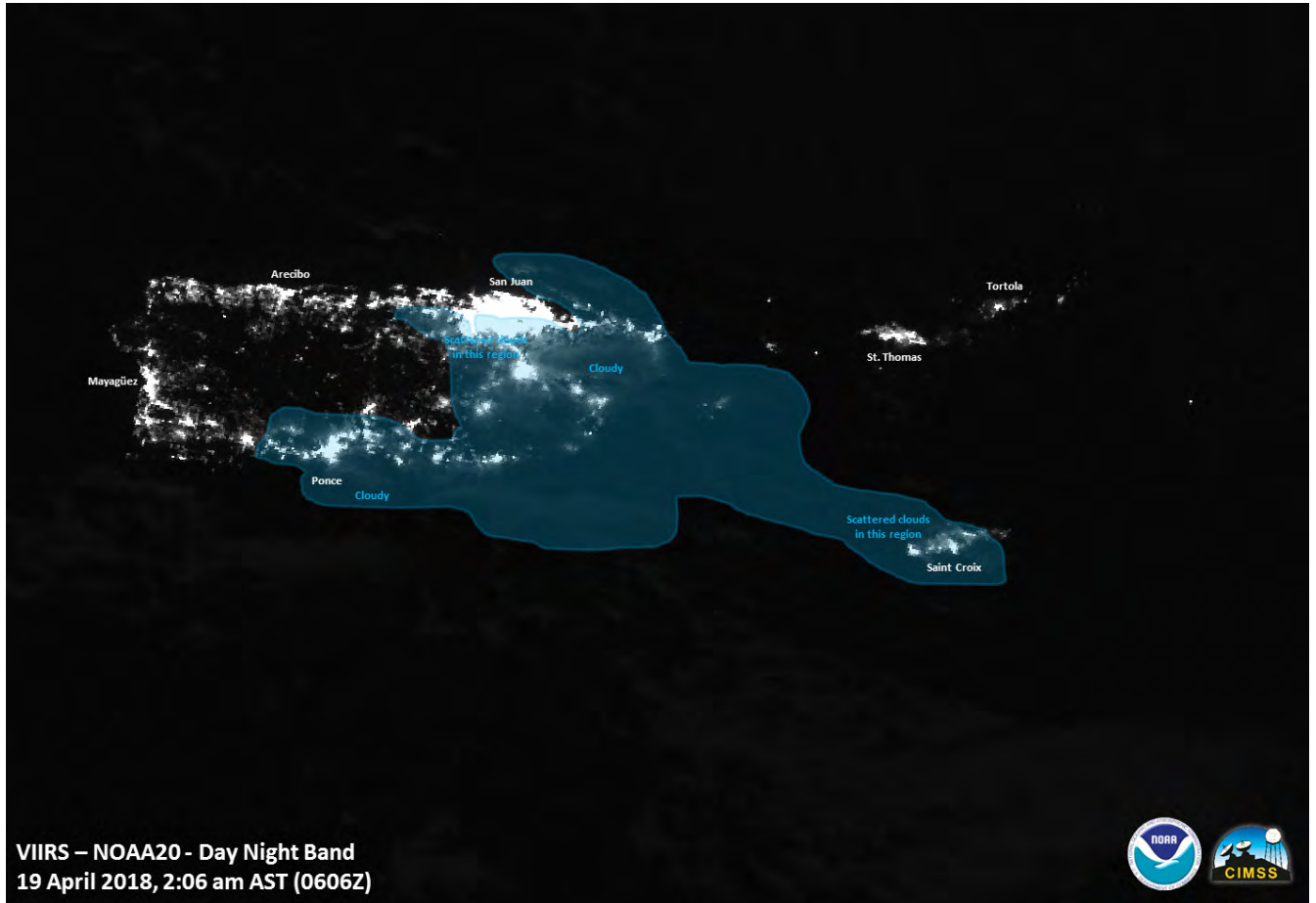
About an hour before FEMA's report, NOAA-20, the

newest NOAA polar-orbiting satellite, flew over the region with a near-nadir pass (i.e., almost directly overhead) and its Visible Infrared Imaging Radiometer Suite (VIIRS) instrument captured the following Day-Night Band image.

Although there were clouds on roughly the eastern third of the island preventing any rigorous analysis, the western roughly 2/3's of the island was relatively cloud free. As seen when comparing the Day-Night Band imagery from about a month ago (March 19, 2018 on roughly the 6-month anniversary of Maria

hitting Puerto Rico), there was a noticeable loss of light, particularly in the rural areas. However, the larger cities (such as San Juan, Arcibo, Maunabo, Mayagüez, Naguabo and Toa Baja) appeared to have power. Although some lights can be seen in the rural areas, they are likely powered by generators, meaning most of these less populated areas are without power.

To learn more about NOAA-20 and its VIIRS instrument, check out the Mission and Instruments page on our website. To see more images from VIIRS, visit our [Spotlight Images page](#). ❖



WEB FEATURE: NOVEMBER 6, 2018

but also human health. Particulate matter from wildfire smoke can penetrate deep into the lungs and cause a range of health problems, according to the Environmental Protection Agency, “from burning eyes and a runny nose to aggravated chronic heart and lung diseases.”

Wildfires and the smoke they emit are notoriously difficult to forecast. This is because there are so many variables to account for: lightning, weather, and, of course, human activity.

“In the past, it was a challenge for the atmospheric models to know where the fire was, how active it was, and how much emissions it was putting into the atmosphere,” said Andy Edman, chief of the science technology infusion division for the western region of the National Weather Service.

But a new experimental model that relies on data from the Joint Polar Satellite System’s Suomi NPP and NOAA-20 polar-orbiting satellites, as well as Terra and Aqua, has proved remarkably good at simulating the behavior of wildfire smoke.

## HOW IT WORKS

The High-Resolution Rapid Refresh Smoke model, or HRRR-Smoke, builds on NOAA’s existing HRRR weather model, which forecasts rain, wind and thunderstorms.

Central to HRRR-Smoke is an important metric called fire radiative power, or FRP. Fire radiative power is a measurement of the amount of heat released by a given fire, in megawatts, detected with the VIIRS instruments on Suomi NPP and NOAA-20. A large fire, for example, might reach about 4,000 megawatts per pixel. Calculating a fire’s heat or intensity also helps scientists pinpoint its location.

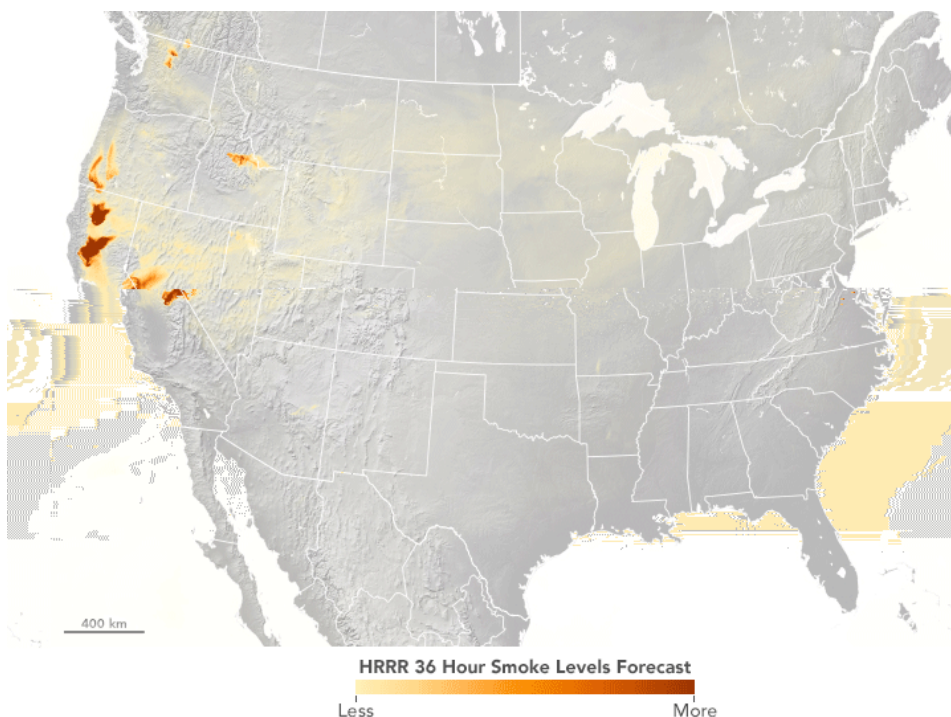
The model combines this FRP data with wind speed, rain and atmospheric temperature, along with information from vegetation maps. Sagebrush burns differently than a ponderosa pine, and the more the scientists know about what’s burning, the better the simulations.

“Grass burns fast. And a dense forest has so much biomass to burn, so it’s going to produce much more smoke than a grassland,” said Eric James, a research associate with NOAA’s Earth

Systems Research Laboratory and the Cooperative Institute for Research in Environmental Sciences at CU Boulder.

These measurements are mapped to a three-dimensional grid that extends nearly 16 miles into the atmosphere. What results is a detailed forecast of the amount of smoke produced, the direction it’s traveling and its plume height. HRRR-Smoke spits out these forecasts four times a day, extending out to 36 hours.

The forecasts are visualized as two plots: “Near-surface smoke” refers to the smoke about 26 feet from the ground, the kind responsible for burning eyes and worsening asthma. “Vertically integrated



A 36-hour HRRR-Smoke forecast from August 6 shows vertically integrated smoke moving east across the United States during the Mendocino Complex Fire. Credit: Lauren Dauphin/NASA Earth Observatory.

smoke” is all of the smoke in a vertical column, including smoke high in the Earth’s atmosphere. That’s the smoke you see at sunrise and sunset.

“Near-surface smoke is one indicator of air pollution, but the smoke could also be at much higher altitudes,” said Ravan Ahmadov, the main developer of the HRRR smoke model, and a research scientist at NOAA’s Earth Systems Research Laboratory and the Cooperative Institute for Research in Environmental Sciences at CU Boulder. “That’s important to know, because the smoke could affect visibility for aviation.”

Higher altitude smoke can also block incoming sunlight, which in turn can cool air temperatures and interfere with solar energy production.

“The key advantages of HRRR-Smoke are the high spatial resolution and the tight coupling with a weather forecast model,” Ahmadov said.

HRRR-Smoke is being used increasingly on the ground by forecasters and government agencies, but also by schools and sports teams. During California’s Ferguson fire, which burned from mid-July to mid-August, HRRR-Smoke simulations were consulted when the Department of Transportation made a decision to suspend Amtrak service and when the National Park Service closed parts of Yosemite National Park for three weeks. As fires burned south of Provo, Utah, schools opted to keep kids inside during recess and to cancel Friday night football games. In Oregon, a children’s swim coach moved outdoor swim practice to an indoor pool.

“If you have a child with asthma, you’ll know to take precautions,” Edman said. “When we can tell people that the smoke is going to move in and hang around for a day, they can take smart actions to anticipate the event.”

## THE ORIGIN STORY

The origins of HRRR-Smoke date back four years. Advances were happening simultaneously in several fields, and everything converged in the back row of a meeting in Madison, Wisconsin.

Scientists had recently developed the HRRR weather model, with its high-resolution representation of atmospheric convection. Convection describes the movement of energy from the Earth’s surface up into the atmosphere; convection that is sufficiently deep produces thunderstorms. Meanwhile, on the satellite front, scientists had zeroed in on fire radiative power from VIIRS. And atmospheric chemists were working to turn a fire’s intensity into an estimate of smoke emissions.

“All these major advancements were happening at same time,” Edman said. “When you read the history of science, I think this is not uncommon. People say, you got this, I got that, why don’t we get together and make something happen?”

The scientists acquired funding from the JPSS Satellite Proving Ground program, and they began holding meetings, running tests and working with forecasters.

Fast forward to present day, and a small team, led by Ahmadov, runs the model around the clock from a NOAA research lab in Boulder, Colorado.

The smoke forecast is a great example of the JPSS program’s “Proving Ground” initiatives, which seek to translate satellite observations into public services that ultimately affect decision making, said Mitch Goldberg, the chief program scientist for JPSS.

“Satellites are expensive, but the societal and economic benefits are huge. So we engage with the community to help them realize the benefits of our data,” Goldberg said. “Let’s say someone’s decision is simply, ‘Do I leave my house and seek shelter?’ Or you have families wanting to know if the air quality is good or bad and if they can go outside. We try to work with services, such as smoke forecasts, which would communicate that.”

## NEXT STEPS

The HRRR-Smoke model is still evolving. One limitation, Ahmadov said, is that each polar orbiting satellite passes over a single location in



the continental United States twice a day, and fires can spread and evolve rapidly during the gaps in time.

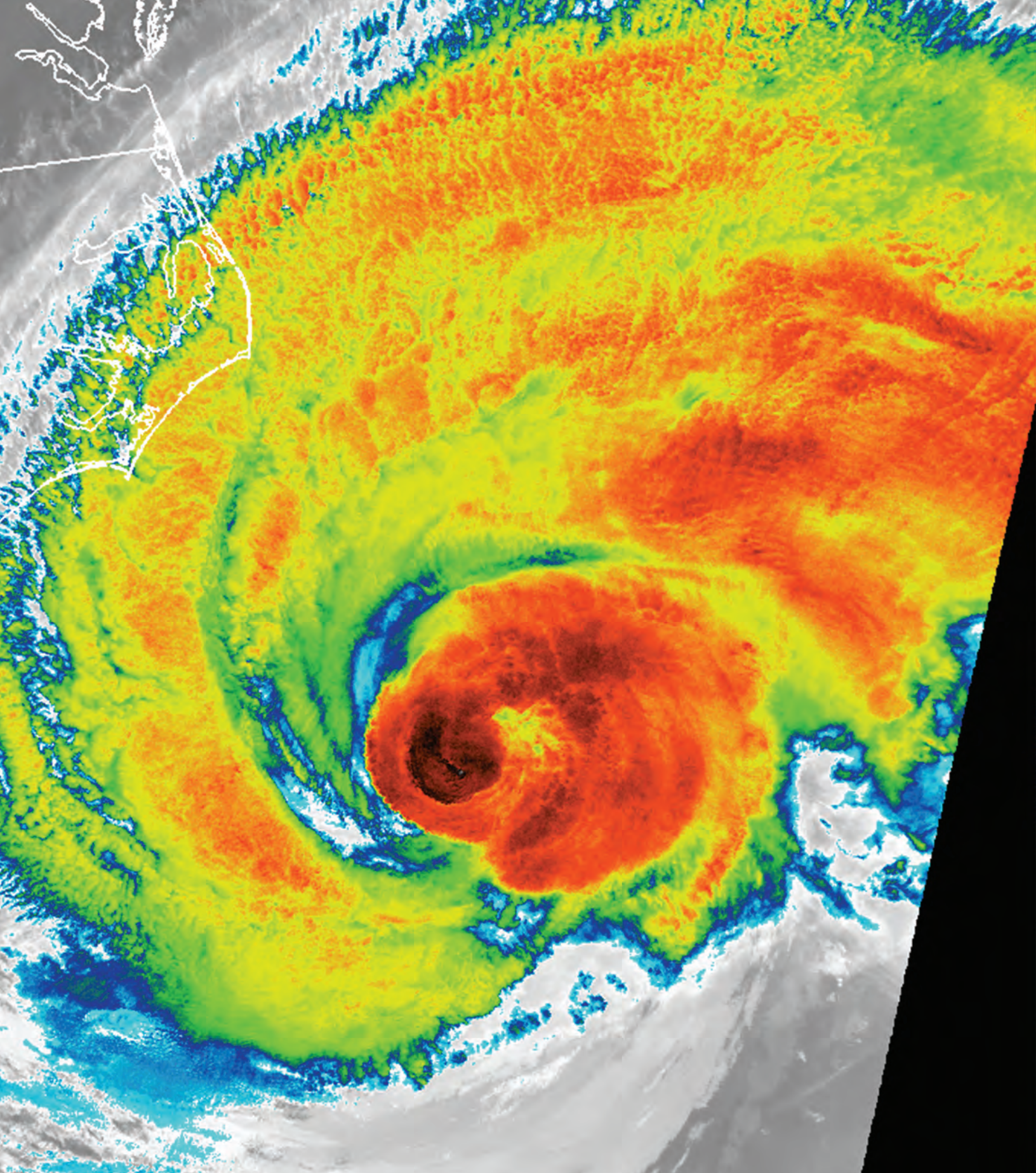
Ahmadov's ultimate goal is to add smoke to the regular HRRR model and transition it to operations at the National Weather Service. And he hopes to eventually incorporate data from geostationary satellites like GOES-16 and

GOES-17. These satellites have a lower spatial resolution but would scan the fires more often.

"In the next couple years, I think we're going to see a lot of small, incremental improvements," Edman said. "The model's not perfect, but all the components came together this year, and the forecasts were pretty darn good." ❖







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