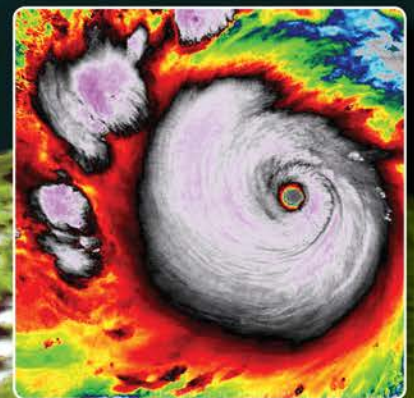
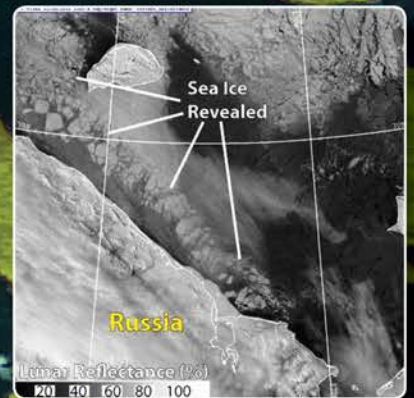
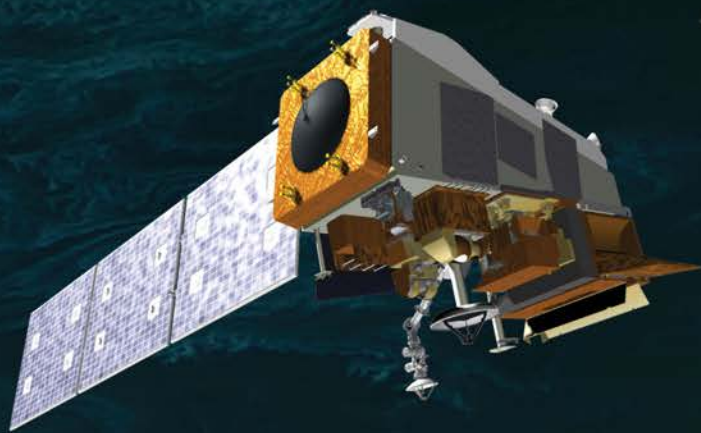


Joint Polar Satellite System Science Seminar Annual Digest 2014



Front and back cover image credits

Front and back cover: swirls of phytoplankton blooms in the Baltic Sea. Image captured by the NOAA/NASA S-NPP satellite on July 24, 2014. Credit: NOAA Environmental Visualization Laboratory.

Insets

Top: VIIRS imagery showing burn areas and smoke plume from the King Fire, CA (Sept 17, 2014). Credit: NOAA Environmental Visualization Laboratory.

Middle: VIIRS Day-Night Band (DNB) shows Arctic sea ice through clouds during nighttime. Credit: Naval Research Lab (NRL).

Bottom: VIIRS image of Super Typhoon Vongfong as it approached Japan. The image, taken on October 7, 2014, shows a highly detailed view of the eye. Credit: NOAA

Joint Polar Satellite System Science Seminar Annual Digest

2014



From the Senior Program Scientist

It is my pleasure to present to you the second Joint Polar Satellite System (JPSS) Science Seminar Annual Digest. This digest is an excellent resource for charting the progress of JPSS Program Science, and like our first digest, features a collection of articles generated from a series of monthly science seminars. It showcases the ways in which the nation's premier operational environmental satellite in polar orbit, Suomi National Polar-orbiting Partnership (Suomi NPP), continues to provide its user community with the highest quality satellite data for critical operational products and services. Suomi NPP is the first next-generation polar-orbiting satellite in the JPSS series. Its products and capabilities have become a critical input for NOAA personnel in areas such as weather forecasts, climate and ecosystem assessments, river flooding, fire and smoke forecasting and environmental monitoring of land, ocean and the cryosphere. Furthermore, JPSS data is also vital to the missions of our partner US agencies including the National Aeronautics and Space Administration (NASA), Department of Defense (DoD), United States Forest Service (USFS), United States Department of Agriculture (USDA) and Environmental Protection Agency (EPA), and international partners, particularly worldwide weather prediction centers. All of our partners have been instrumental in relaying to us the value of Suomi NPP data for their missions.



This digest is intended to demonstrate the importance of the close collaboration between developers and key users to conceptualize and develop applications that help improve the use of JPSS data to enhance key services. I would like to thank our federal staff, private sector support staff, and numerous partners whose contributions and dedicated efforts make the digests a big success.

The JPSS program is committed to ensuring that its user community continues to effectively utilize Suomi NPP's satellite imagery, soundings, and other products. The Proving Ground and Risk Reduction Program (PGRR) is entering its third year of managing projects that promote the most innovative use of the new and improved JPSS capabilities. It continues to expand its outreach efforts to ensure the successful application of Suomi NPP data and imagery. The JPSS Program utilizes a number of ways to encourage user feedback on the JPSS PGRR Program. For example, this May we organized a formal PGRR Project Review. This inaugural review gave the 40+ projects an opportunity to share their key

accomplishments, challenges, and future plans with the NOAA user community. This review helped spark innovative discussion on the use of satellite data in support of NOAA's key missions.

The JPSS PGRR also kicked off some major initiatives that seek to evaluate how best to fuse environmental data from multiple satellite, ground-based, and in-situ sources. The enhanced products from these initiatives will provide federal, state, and local decision makers the critical information needed to implement measures to safeguard lives and protect property; and support economic efficiency.

The first of these initiatives, "River Ice and Flooding," led to the development of new and innovative experimental river ice and flooding areal extent products derived from satellite imagery generated by the Visible Infrared Imaging Radiometer Suite (VIIRS) sensor onboard Suomi NPP. These products were developed by the JPSS PG in conjunction with the Community College of New York (CCNY) and George Mason University (GMU). The products were delivered to the National Weather Service (NWS) Fairbanks Weather Forecast Office (WFO) and Alaska Pacific River Forecast Center (APRFC) for operational evaluation during the 2014 spring river ice breakup season in Alaska.

The second initiative, "Fire and Smoke," began in May 2014 as an effort to understand the current use of geostationary and polar-orbiting satellite capabilities in support of fire and smoke detection and forecasting. In addition, the initiative sought to identify the current Suomi NPP and new Geostationary Operational Environmental Satellite R-Series Program (GOES-R) data and capabilities with the potential to improve support to this mission. This initiative also sought to establish methodologies and procedures for the operational demonstrations of these capabilities. JPSS is now working closely with senior leaders from the NWS Western Region, forecasters and incident meteorologists to evaluate how to fully leverage JPSS capabilities to support their fire mission. Through the initiative, the NWS High-Resolution Rapid Refresh (HRRR) Model was modified to provide smoke forecasts from existing fires. These forecasts are now available across the Western Region.

The cumulative positive impact of these two new efforts is central to the evolution of additional future initiatives.

May 1, 2014 marked another important change as Suomi NPP became NOAA's primary polar-orbiting weather satellite. Users are consistently giving it high praise on operational value. Its next generation sensors, including the VIIRS Day-Night Band (DNB) – allows improved imagery of Earth's surface and atmosphere during nighttime hours – have enabled forecasters to make improved predictions of significant weather events, including tropical cyclones such as hurricanes.

To foster additional interaction with NOAA users, the Satellite Proving Ground/User-Readiness Meeting was held in June. The overarching goal of this meeting was to determine the path for operational forecasters to achieve JPSS/GOES-R "user-readiness." Meeting participants determined that user-readiness will be achieved when operational NWS meteorologists have the skills, competencies, and ability to use JPSS/GOES-R data in the forecast process once the data are available in Advanced Weather Interactive Processing System (AWIPS). Key decision makers, including the NWS Operational Advisory Team (NOAT) were closely involved in this review. The NOAT was instrumental in formally evaluating

each project and proposing changes to the project activities to provide better focus for operational weather support.

This year we also instituted a series of science seminars that showcase the partnership between NOAA's two main weather satellite programs, JPSS and GOES-R. These periodic seminars highlight the key research activities between these two vital satellite programs. They also demonstrate how NOAA utilizes the capabilities aimed at improved detection and observations of meteorological phenomena to address the critical environmental issues that directly impact public safety, protection of property, and economic health and development. The briefings can be found at <http://www.jpss.noaa.gov/science-seminars-archive.html>.

I hope you enjoy reading this digest, which covers a wide range of topics on the most innovative uses of Suomi NPP data, and that you find it useful.

Acknowledgments

Thank you to: Julie Price, for leading the development of these articles; Bill Sjoberg for his coordination and support of PGRR projects; Lauren Gaches and Stephanie Moore, for the assistance extended to the development of this digest; George Tuggle, for the cover design; the NOAA JPSS Office, for their ongoing support in the development of this digest; and the authors and editors.

Mitch Goldberg

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From the Director



It is my honor and privilege to write to you as the Director of JPSS. I represent a large team of exceptional individuals dedicated to assuring continuity of polar weather observations. They serve as part of a larger weather enterprise dedicated to ensuring that the United States is a “Weather-Ready Nation.”

JPSS ensures continuity of critical weather observations in the early afternoon orbit. Our European partners with the Meteorological Operational satellite (MetOp) fly similar instruments to provide continuity of observations in the mid-morning orbit. It takes two orbits to provide 85 percent coverage of the earth’s surface for each six hour input cycle to the global numerical weather forecast models. These observations are supplemented by Defense Meteorological Satellite Program (DMSP) in the early morning orbit and the Japan Aerospace Exploration Agency (JAXA) Global Change Observation Mission – Water (GCOM-W1) mission in the early afternoon orbit.

In the last three years, we have experienced more than 30 disasters surpassing \$1B in damage. Our advanced weather enterprise gives the critical advanced warnings to save lives, protect property, and promote economic efficiency. These results are supported by our international partner, the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). EUMETSAT released a study last year that indicated in Europe approximately 1/3 of all economic activity was weather sensitive. Using very conservative economic factors derived from several related studies, they found that overall return on investment was several multiples of the annual cost.

Anecdotally, we know we are having a big positive impact; we are losing fewer lives in severe weather events. These days, proactive actions are being taken that just a little over a decade ago would not have been, based on high confidence in the forecasts, like airlines moving their planes before blizzards, big box stores and power companies stocking up and repositioning, then moving in fast after a storm passes to get people and business back on their feet. Data from the Suomi NPP satellite have helped improve the NOAA NWS ability to accurately forecast severe weather events in its three-to-seven day window, critical for effective severe weather emergency response planning.

Not only does JPSS return vastly more data than past systems, it also provides substantial increases in data quality and some unique new capabilities. In general, all of the instruments have greater swath width, increased channels, higher resolution, lower noise, better stability and much improved calibration. These features have been shown by users to provide significant enhancements to our two most important missions: supporting mid-range forecast three-to-seven days in advance, and providing imagery for near term forecasting in Alaska and the Polar regions. They also support significant improvement in a wide variety of other important weather and environmental forecasting, and monitoring. Studies have clearly shown that loss of JPSS capability would have immediate impact on our forecasting capability. JPSS is now serving as a primary tool for predicting weather in Alaska and the Polar regions – locations where geostationary satellites cannot provide acceptable views. In Alaska, JPSS will provide nearly all of the weather forecasting for aviation, as well as for the economically vital

maritime, oil and gas industries. Data from Suomi NPP also contribute to the U.S National Ice Center, which provides snow and ice products to support the military as well as the transportation and energy sectors. The NWS WFOs in Alaska use the data from VIIRS to produce graphic analyses of sea surface temperatures and sea ice, as well as five day sea ice forecasts year round.

In areas where ground based data sources are sparse, such as the Pacific region, Suomi NPP data provides the information needed to accurately track and predict severe weather events. The region's distinctive geography has a high vulnerability to hazards and climate variables such as typhoons, tornados, tsunamis, heavy rains, droughts and tropical cyclones that threatens island wildlife and ecosystems.

JPSS increases tropical cyclone forecasting capability with ATMS microwave soundings providing more detail of the warm core, which helps indicate the strength of the cyclone. As ATMS provides higher spatial coverage and its higher spatial resolution increases our ability to observe the warm core, we are able to eliminate gaps. Moreover the VIIRS DNB enables us to observe in great detail a cyclone's overall structure at night, which generally is more difficult with only infrared observations. One of the most powerful storms in history, Super Typhoon Haiyan, struck the Philippines on November 8, 2013. Haiyan pounded the Philippines with strong winds and heavy rain that resulted in flooding, landslides, and widespread damage. Suomi NPP provided incredibly detailed looks of Haiyan's eye and its structure during both day and night. Scientists are exploring the use of the DNB to monitor power outages in the wake of these meteorological disasters, as long-term outages may significantly impact the wellness, safety, and recovery efforts within the affected areas. Night time images from the DNB showed the location and spatial extent of power outages in the wake of this tremendous storm

Another world class sensor that works in tandem with ATMS is the Cross-track Infrared Sounder (CrIS). This is the first in a series of advanced operational infrared sounders that provide more accurate, detailed atmospheric temperature and moisture observations for weather and climate applications. CrIS provides much higher vertical resolution of atmospheric temperature and water vapor and also provides trace gas products such as carbon monoxide and methane. Studies on forecast impacts have shown that advanced infrared sounders, such as CrIS, and microwave sounders, such as ATMS provide the largest impact of any observation type in reducing forecast uncertainty. Without these sounders, forecast skills would degrade significantly. CrIS data are also used in hurricane forecasting.

In April, the first of five instruments that will fly on JPSS-1 – the Clouds and the Earth's Radiant Energy System (CERES) – successfully completed pre-shipment review. CERES measures reflected sunlight and thermal radiation emitted by the Earth and builds on the highly successful legacy instruments flown on NOAA's previous Polar-orbiting Operational Environmental Satellites (POES) and NASA's Earth Observing System (EOS) missions. Right on the heels of CERES, the Ozone Mapping Profiler Suite (OMPS) instrument successfully completed its pre-shipment review in June. OMPS tracks the health of the ozone layer and measures the concentration of ozone in the Earth's atmosphere. The completion of an instrument's pre-shipment review marks the final step before it is shipped for integration with the spacecraft bus. Instrument integration is scheduled for early 2015 and we are on track for our December 2016 launch planning date.

We are also making progress on JPSS-2 with all the instruments under contract, and parts starting to roll in. Our Block 2 ground is on track for transition to operations in 2016, providing multi-mission capability, technology refresh, high security, and a modern cost effective architecture. We have also made great progress on operational use of direct read out, through our proving ground/ risk reduction effort to support rapid access to JPSS data in the Alaska region.

Overall, the capabilities of JPSS continue to support all four NOAA mission areas: Weather Ready Nation, healthy oceans, resilient coastal communities and economies, and climate adaptation and mitigation. October 28, 2014 marked the three-year anniversary of the launch of the Suomi NPP satellite from Vandenberg Air Force Base, California. In its first three years Suomi NPP is fulfilling its intended purpose - to provide the first flight of the JPSS instrument suite, while producing high-quality data supporting short-term weather forecasts and data assimilation for use in NWP models.

Thanks to the hard work and diligence of our JPSS team and partners, our flight missions are proceeding well. Suomi NPP is doing great, with high data availability, no signs of significant issues, and users telling us that the data are exceeding expectations. JPSS-1 is on track, JPSS-2 is moving forward, and intensive planning for the future beyond JPSS-2 is underway. I too offer my thanks for the many contributors to this digest, and to our JPSS science team and science community for their work which enables us to deliver the benefits of JPSS. We have a lot to be proud of and the best is yet to come.

Harry Cikanek

Director, Joint Polar Satellite System (JPSS)
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Contents

Section 1:	Tropical Cyclone Satellite Data Assimilation Using JPSS and GOES-R Datasets	1
Section 2:	United States Naval Research Laboratory (NRL): A Strategic Joint Polar Satellite System (JPSS) Partner in the Application of VIIRS Capabilities	14
Section 3:	The Visible Infrared Imaging Radiometer Suite (VIIRS) Ushers in a New Era of Support to the NOAA Oceanographic Mission	24
Section 4:	Uniform Multi-Sensor Algorithms for Consistent Products	35
Section 5:	Development of Algorithms for Retrieval of Chlorophyll-A in the Chesapeake Bay and other Coastal Waters Based on JPSS-VIIRS Bands.....	46
Section 6:	VIIRS Active Fire Data for Fire Weather Applications: JPSS and GOES-R Activities Supporting 2013 Fire Incidents	54
Section 7:	The Suomi National Polar-orbiting Partnership (S-NPP) Ushers in the Next Generation of Aerosol Products for Air Quality Applications.....	65
Section 8:	The NOAA Visualization Laboratory: Putting Satellite Imagery into Your Hands.....	74
Section 9:	The Proactive Quality Control (PQC) in Ensemble Data Assimilation: An Innovative Approach to Detecting Bad Observations.....	81
Section 10:	NOAA Satellite Training: Preparing the End-User Community for New Data and Products from the Nation's Next Generation Environmental Satellites	88
Section 11:	Infusing S-NPP PMW Retrievals to CMORPH Precipitation Estimates for Improved Weather, Climate, and Hydrological Applications.....	96

JPSS USER PERSPECTIVE
What the users are telling us about JPSS

Section 1

**Tropical Cyclone Satellite Data Assimilation Using JPSS and
GOES-R Datasets**

Joint JPSS/GOES-R Science Seminar

*This article is based in part on the **November 18, 2013** joint JPSS-GOES-R Science Seminar presented by Mark DeMaria, Chief, Regional and Mesoscale Meteorology Branch, NOAA/NESDIS/STAR, Fort Collins, CO; Fuzhong Weng, Chief, Satellite Calibration and Data Assimilation Branch NOAA/NESDIS/STAR, College Park, MD; Jun Li and Christopher Velden, Senior Scientists, UW/CIMSS, Madison, WI; and Tomislava Vukicevic, Research Meteorologist, NOAA/OAR/AOML, Miami, FL.*

Contributing editors: Fuzhong Weng, Mitch Goldberg, Julie Price, William Sjoberg, and Kathryn Shontz



This image was taken from Wikimedia Commons. It shows aerial views of the damage caused by Hurricane Sandy to the New Jersey coast taken during a search and rescue mission by 1-150 Assault Helicopter Battalion, New Jersey Army National Guard, October 30, 2012.

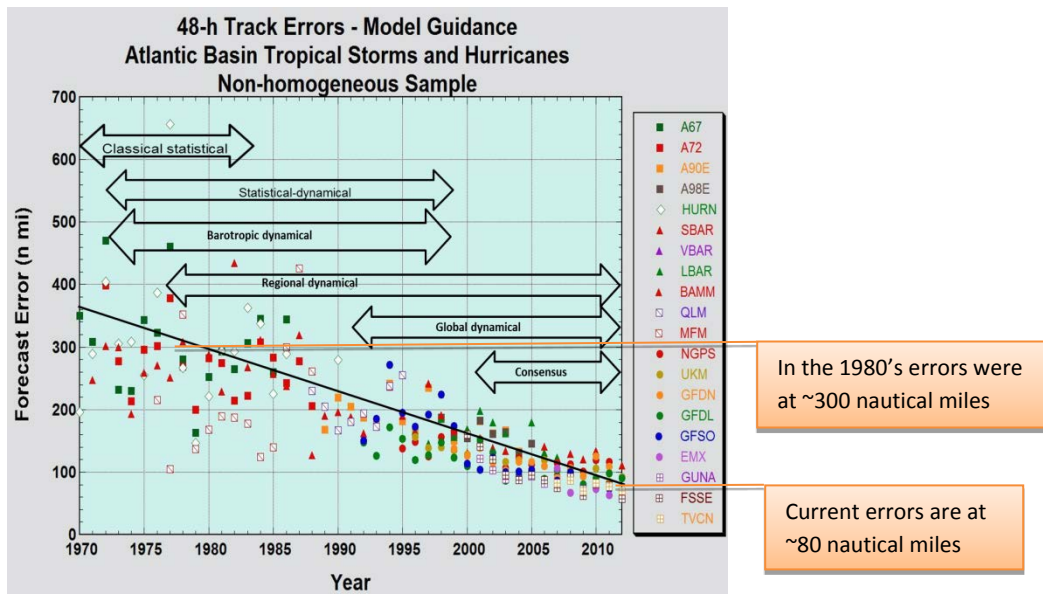
Photo credit: Master Sgt. Mark C. Olsen/U.S. Air Force/New Jersey National Guard

Tropical cyclones (TCs) are major, dangerous and disruptive weather events. Therefore, providing an accurate forecast in advance of a high-impact weather event such as a TC is essential for effective disaster planning, mitigation, and response. More importantly, it is critical that there are tools in place to provide the data needed to make predictions of these high impact weather events in a timely manner. Through their Proving Grounds (PG), the JPSS and GOES-R programs support a number of different projects with a common theme of improving TC forecasting with the use of satellite data. In order to highlight some of the advancements that have been made in TC forecasting, both programs organized a joint science seminar titled “Tropical Cyclone Satellite Data Assimilation.” The seminar, which was held on November 18, 2013, created an opportunity for the leading experts in TC research to learn about each other’s research activities and to exchange ideas. To quantify errors associated with TC forecasting, Mark DeMaria initiated the discussion by positing to the audience that despite rapid advancements in data assimilation techniques and NWP models, TC forecasts remain susceptible to large errors, especially those associated with rapid intensity changes.

For decades, tropical cyclone centers have used various aids to forecast storm behavior. For example, Numerical Weather Prediction (NWP) models have become fundamental components of predicting TC tracks and future intensity. The challenge in forecasting rapid intensity changes is partially due to the

difficulty in prescribing accurate initial conditions of the TC structure and its surrounding environment. And, as a TC spends most of its lifetime over the ocean, where conventional observations are sparse, initial conditions are crucially dependent on the accurate assimilation of data from satellites. Over the years, satellite data have increasingly been assimilated into NWP models, and have played a critical role in the notable improvement of TC track forecasts. Given the increasing space and time resolution of satellite data, it is important that we continue to seek optimal methods to exploit the use of these datasets in data assimilation systems.

There are three basic ways to utilize satellite data to improve TC forecasts. The first method involves the use of data for basic analysis, i.e., to find out a TC's initial position, intensity, and structure. The second method incorporates satellite data into statistical-dynamical models and statistical post-processing techniques. The third method assimilates data into physically based numerical forecast models, and is the primary focus of this article.



This figure shows a non-homogeneous sample of 48-h track forecast errors from all the various guidance models for the Atlantic basin.

In the figure above, the current NWP model errors for predicting 48-hr TC track positions are on the order of 80 nautical miles (n mi), whereas even as recent as the early 1980s they were around 300 n mi. These improvements in the ability to predict TC tracks can be attributed to several advances, including the development of dynamical computer models, and satellite data assimilation.

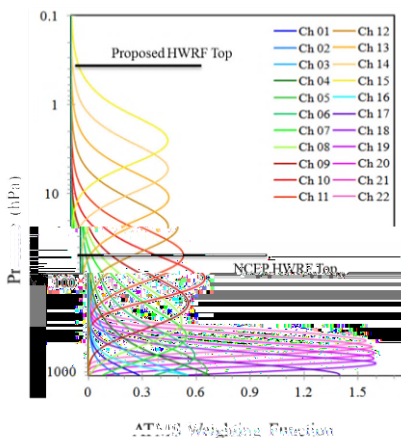
Data assimilation is the process of incorporating satellite and conventional observations through a short forecast (~6 hr) into NWP models to accurately describe the state of the atmosphere. It is a core component of any earth system model. Satellites provide global and frequent coverage of the Earth's atmospheric and oceanic conditions, especially in remote areas and over the ocean. Thus, well over 90% of all assimilated data for NWP are derived from satellite observations.

This article presents in some detail three Proving Ground (PG) projects designed to assimilate data into numerical forecast models to improve TC forecasts. These projects use operational and research versions of the Weather Research and Forecast (WRF) model, coupled with advanced data assimilation systems. They combine in-situ data with satellite data from NOAA's next generation polar-orbiting – the Joint Polar Satellite System (JPSS) and geostationary – Geostationary Operational Environmental Satellites – R series (GOES-R) satellite programs to help address the ability to forecast TC intensity changes. The first discussion in the article is on satellite data assimilation in the Hurricane Weather Research Forecast (HWRF) and was presented by Fuzhong Weng. This is followed by two discussions which describe the impact of direct radiance assimilation of microwave observations from a number of Low Earth Orbiting (LEO) satellites, as well as results from assimilating Atmospheric Motion Vectors (AMVs) derived from geostationary satellites. More specifically, there is a discussion on a near real time (NRT) regional Satellite Data Assimilation system for Tropical storm forecasts (SDAT), which was presented by Jun Li. This is followed by a discussion on assimilating high resolution AMVs, which was presented by Chris Velden. The improvements in the AMVs from the higher sampling rates expected from GOES-R are being evaluated using rapid scan imagery from the current GOES. The article concludes with Tomislava Vukicevic's talk, which focused on the effect of the satellite data in combination with aircraft observations are also presented, as well as Observing System Simulation Experiments (OSSEs) to estimate the impact of future in-situ and satellite data.

Improved Hurricane Forecasts through Satellite Data Assimilation in the Hurricane Weather Research Forecast (HWRF) (Weng)

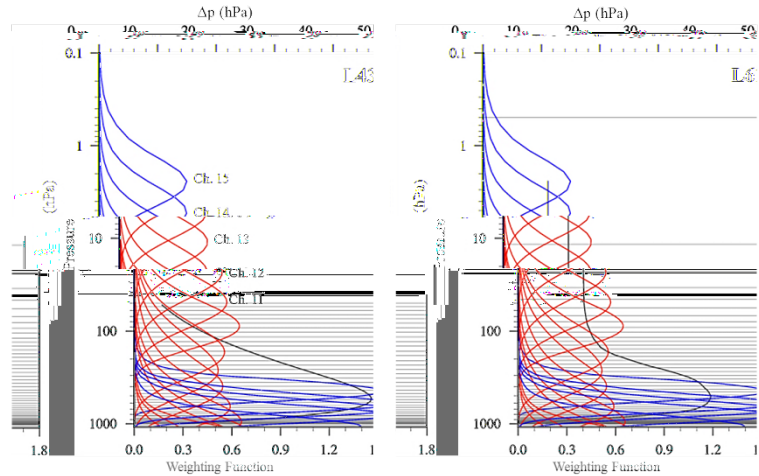
Satellite data is incorporated into NWP models using data assimilation (DA) techniques to generate NWP forecasts that are closer to observed values. DA applications such as NOAA's National Centers for Environmental Prediction (NCEP) three-dimensional variational (3D-Var), Gridpoint Statistical Interpolation (GSI), are used by the TC research community for both global and regional model analysis. These applications utilize environmental satellite data sets encoded in the Binary Universal Form for data Representation (BUFR) format. At many NWP centers, BUFR data is delivered or generated in near-real time to meet operational priorities.

ATMS Weighting Functions



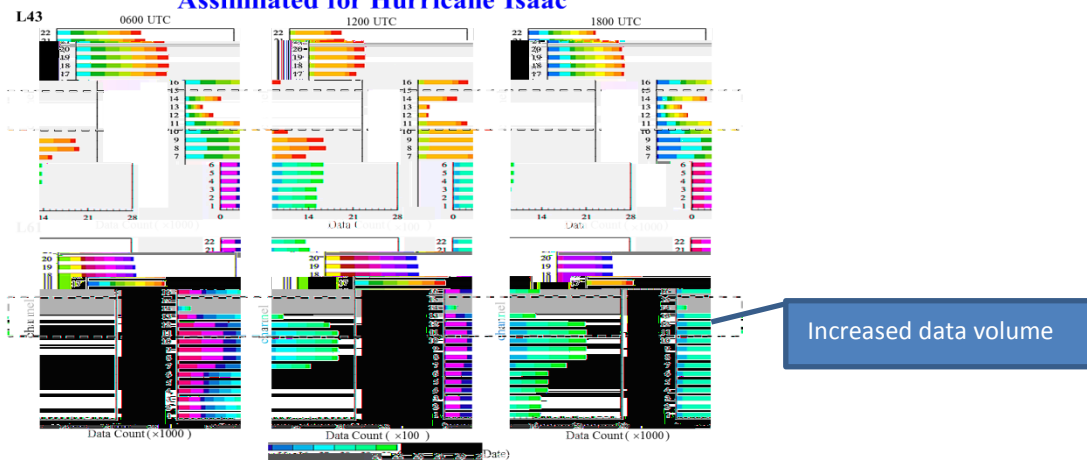
Scientists at NOAA's Center for Satellite Applications and Research (STAR) set up a data assimilation experiment in which they tested the resultant GSI-derived forecasts against what occurred for a particular meteorological event. The experiments focused on the 2012 hurricane season, directly assimilating ATMS radiance data to produce experimental products for TC monitoring. During the experiments, STAR scientists discovered that some interfaces were not optimized for regional model applications, particularly where the models were not run to much higher than 50hPa. By limiting the vertical extent of the model runs much of the satellite radiance information can be

missed. The data at these higher levels of the atmosphere have been found to be critical in regional Hurricane Weather Research Forecast (HWRf) models, and their loss can create a negative effect on downstream operational forecasts. In their experiments, STAR scientists re-configured the HWRf / GSI model to include more vertical layers and a higher model top for more effective uses of satellite sounding data in the analysis of fields throughout the atmosphere. Data from the Advanced Technology Microwave Sounder (ATMS) on the Suomi National Polar-orbiting Partnership (SNPP) was found to be an excellent test case for assimilating data from the upper part of the atmosphere into HWRf. The ATMS instrument captures details of vertical temperature and moisture structures throughout the atmospheric column. It has the ability to penetrate through deep, non-precipitating clouds and therefore can provide vertical soundings under all weather conditions. Microwave sounding data are critical to NWP. More importantly, numerical models of TCs utilize sounding data to improve track, intensity and structure forecasts. To account for the missing data and to fully utilize the ATMS sounding in the HWRf, the scientists at STAR raised the model top (as shown in the ATMS weighting function image above) allowing more satellite data to be assimilated into the forecast model.



Zou et al. (2013)

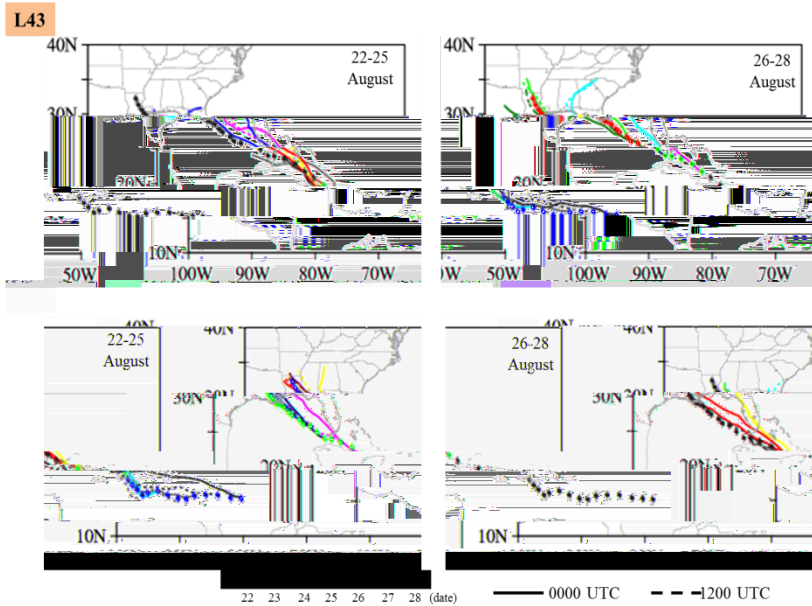
Data Counts of ATMS Radiance Data Assimilated for Hurricane Isaac



This figure provides an illustration of increased data volume in a model top sensitivity experiment using hurricane Isaac as an example. In this experiment ATMS channels 11-13 are compared between L43 (baseline) which its model top limited to 50mb and L61 (control) which has its model top raised to 0.5mb.

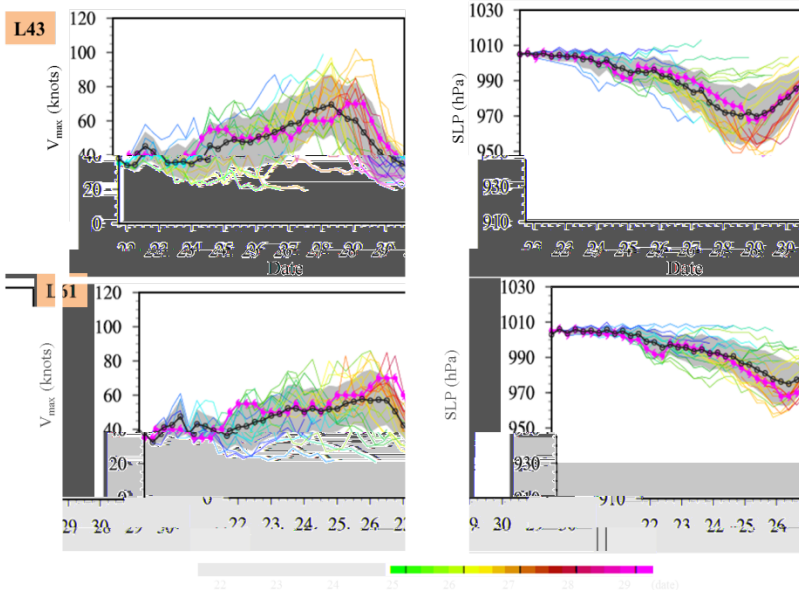
Impacts of Sensitivity Experiments on Forecasts of Hurricane Isaac

Forecast Tracks of Hurricane Isaac



These figures depict predicted vs. observed tracks for Hurricane Isaac from August 22-28. The NCEP 2012 HWRf revised with a higher model top (L61) demonstrated that assimilation of satellite data reduced the forecast errors of Hurricane Isaac's track.

Forecast Intensities of Hurricane Isaac



These figures show the intensity forecast for Hurricane Isaac from August 22-30, 2012. The best track intensity is given by the black dotted line. The assimilation of satellite data (L61) resulted in better intensity forecasts.

To evaluate the impacts of the GOES imager radiances and SNPP's ATMS and CrIS data assimilation on their modified HWRf model hurricane forecasts, STAR scientists performed sensitivity experiments using 6-hr HWRf forecasts as the background in GSI which is called a warm start. Testing against different assimilation scenarios, the scientists focused on comparing the impacts from assimilating SNPP, and the MetOp Infrared Atmospheric Sounding Interferometer (IASI) instrument

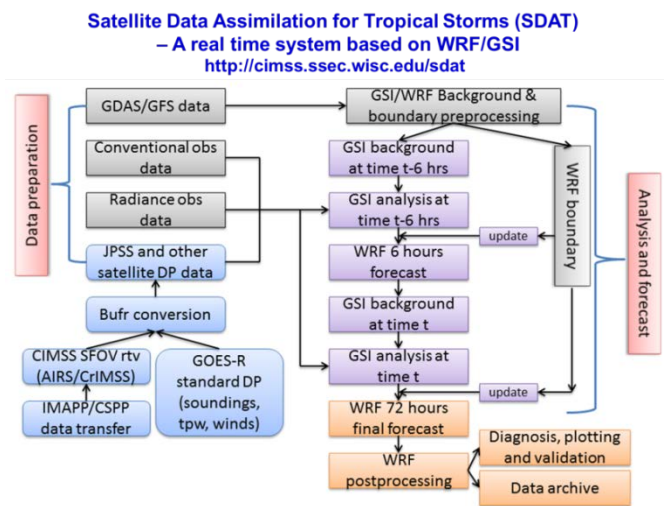
A higher model top allows more upper-level microwave and infrared channels to be assimilated into HWRf, resulting in improved atmospheric steering and track forecasts. The results from these sensitivity experiments showed marked improvements in storm track and intensity forecasts, with the assimilation of satellite data in HWRf, and a higher model top (L61).

A Near Real Time JPSS/GOES-R data assimilation system (Li)

For NWP models, observations of atmospheric temperature and moisture information in environment are very important to the prediction of the genesis, intensification, motion, rainfall potential, and landing impacts of TCs. The Cross Track Infrared and Microwave Sounder Suite (CrIMSS) onboard the SNPP provides high vertical resolution temperature and water vapor information needed to maintain and improve NWP forecast skill, and is also critical for the prediction of TC evolution. The infrared component of the CrIMSS is an interferometer-based Cross-Track Infrared Sounder (CrIS), and the microwave component is ATMS. In order to maximize the benefits of SNPP measurements for TC forecasts, a near real time (NRT) regional Satellite Data Assimilation system for Tropical storm forecasts (SDAT) was developed and has been running at the University of Wisconsin's Cooperative Institute for Meteorological Satellite Studies (CIMSS) since August 2013. The regional NWP models (WRF – Weather Research and Forecasting) along with the operational community GSI assimilation system developed by NCEP are used as the frames of SDAT.

The SDAT comprises of data ingestion and processing, data assimilation and forecasting. The conventional and satellite observations (radiances, soundings, Precipitable Water layer – LPW etc.) are encoded into the Bufr format used by GSI, then 72-hour forecasts are produced after each assimilation time. SDAT also assimilates products such as soundings from SNPP and high temporal resolution LPW from current GOES Sounder and GOES-R ABI.

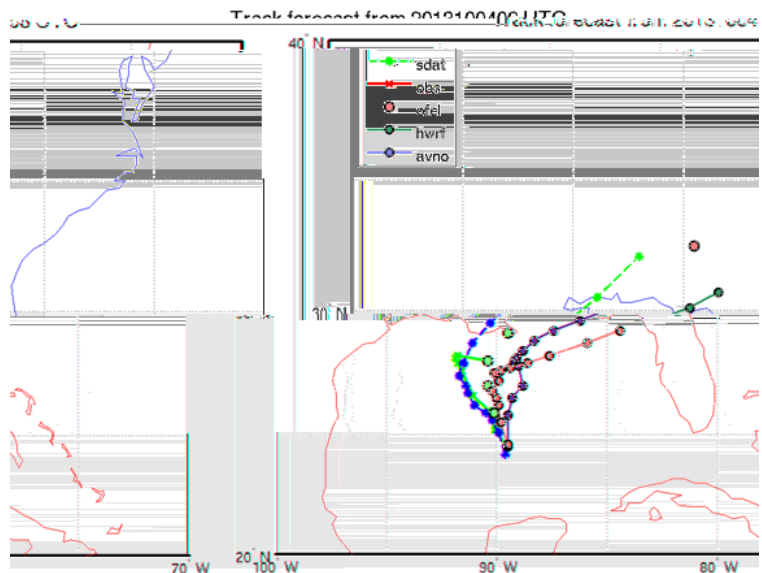
Even though SDAT was developed for tropical storm forecasts, its value to non-tropical systems was demonstrated during the week of September 9, 2013, when a slow-moving cold front stalled over Colorado, clashing with warm humid monsoonal air from the south. This extreme weather event caused heavy rain and catastrophic flooding along Colorado's Front Range from Colorado Springs north to Fort Collins. The situation intensified on September 11 and 12. Boulder County was worst hit, with 9.08 inches (231 mm) recorded September 12 and up to 17 inches (430 mm) of rain recorded by September 15, which is comparable to Boulder County's average annual precipitation (20.7 inches, 525 mm). The image that follows shows the assimilation of the SDAT forecast for this event.



The 72 hour cumulative precipitation forecasts (lower right) from SDAT started at 18 UTC on 10 September 2013, and observations (upper left). A GOES Imager water vapor image (lower left) indicates deep plumes of moisture (blue, white, and green) are drawn towards the Front Range from the Pacific and the Gulf of Mexico by the circulation around an upper-level low (L) over the Great Basin, at 11:15 pm MDT on September 11, 2013, during the peak rainfall intensity in Boulder. Drier air is shown in yellow.

In 2013 there was not much hurricane activity over the Atlantic Ocean. Hurricane Karen is the only weak hurricane to make landfall onto the U.S. It is found that SDAT forecasts are closer to the observations than other dynamical models, and are also very close to the official guidance (see image on the right).

SDAT is able to provide track and intensity products to GOES-R/JPSS proving ground next hurricane season in the Automated Tropical Cyclone Forecast (ATCF) system that the National Hurricane Center (NHC) uses. Furthermore, CIMSS scientists will collaborate with NHC and CIRA on the application of SDAT near real time products.



SDAT track forecasts and NHC official guidance, along with operational HWRF and GFS (avno) forecasts for Hurricane Karen (2013). Note that the observations are available at only limited time period.

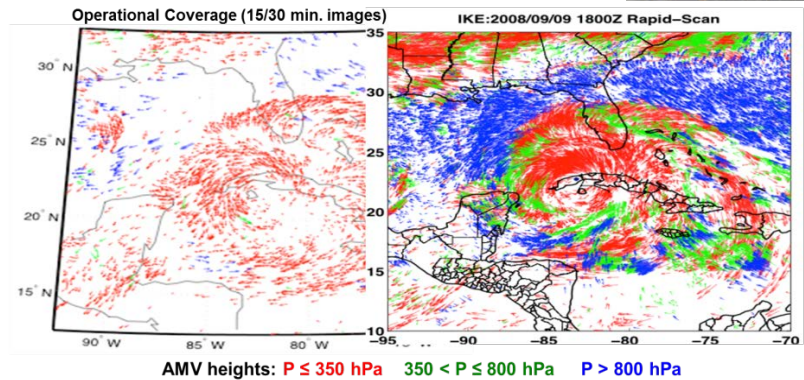
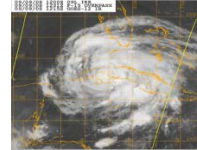
Influence of Deriving and Assimilating High-Resolution Satellite-Derived Winds on Mesoscale Analyses and Forecasts of Tropical Cyclones in the GOES-R Era (Velden)

Atmospheric Motion Vectors (AMVs) are derived by tracking clouds or water vapor patterns through consecutive images from geostationary satellites. Recent studies have been looking at the impact of high spatial and temporal resolution AMVs derived from GOES rapid-scan data on hurricane model analyses and forecasts. The presumption is that the higher density AMV observations can help define the smaller-scale flow features in the TC vortex and near-environment that may be important to improving model initial conditions and forecasting of short-term intensity and track changes. Improving data assimilation schemes can better allow the increased information content of the high-density AMV observations to be analyzed, but must be tested and finely-tuned to optimize positive impacts.

For smaller high-impact weather events such as TCs that are defined on much smaller scales, different strategies, such as the use of more frequent imaging that allows for improved cloud tracer selection/tracking and mesoscale flow depiction, can be used to process AMVs. It is important to demonstrate this potential impact now, as GOES-R will provide 5-15 minute imaging routinely, and 1-minute sequences on demand, particularly over high impact weather events.

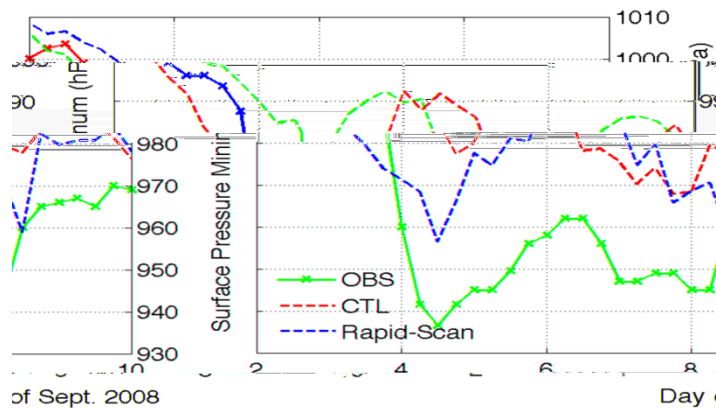
As a proxy for GOES-R 5-min. imagery, GOES-East rapid-scan imagery (7-min.) is used to derive AMVs.

-- Example: Hurricane Ike (2008) --



Example showing the normally-available AMV coverage (left) vs. the dramatically increased coverage obtained from GOES rapid-scan imagery (right) during Hurricane Ike as it was approaching landfall on Cuba in 2008.

Hurricane Ike Intensity Analyses



Preliminary results from Hurricane Ike intensity analyses indicate that assimilation of the GOES rapid-scan AMVs into the mesoscale DART/WRF system produces superior analyses of Hurricane Ike's intensity (OBS) over a Control (CTL) without the R/S winds.

These initial results using the DART/WRF system in which enhanced AMVs from GOES were assimilated are promising, and further studies are planned.

Scientists at CIMSS conducted an impact study for Hurricane Ike using the WRF model (ARW version 3.1.1). The study used a 9km moving nest grid (198 x 198 x 36) with feedback to a 27km grid (215 x 205 x 36), and 3-hr forecast fields for analysis boundary conditions. The experiments assimilated hourly GOES rapid scan (R/S) AMVs into the Data Assimilation Research Testbed (DART) and compared those analyses and resulting forecasts using the WRF model with and without the input of the R/S AMVs. The attending figure illustrates the improvements to the initial model analyses when the GOES R/S AMVs

Regional Observing System Simulation Experiment (OSSE) Objectives for TCs (Vukicevic)

Observing System Simulation Experiments (OSSEs) are used to evaluate the potential benefits of future in-situ and satellite observations in NWP. Some of the benefits of using OSSEs include easy control of the experiments, precise knowledge of the data properties and errors, and knowledge of what really happened (i.e., truth). As the truth is fully known for the OSSE, evaluation of observation impact may be calculated in ways not possible with real observations. OSSEs may be used to investigate how data assimilation systems use different types of observations. NOAA's Atlantic Oceanographic and Meteorological Laboratory (AOML)/ Hurricane Research Division (HRD) performs regional OSSEs for TCs to:

- Evaluate the potential impact of new (proposed) observing systems on hurricane track and intensity predictions.
- Evaluate tradeoffs in the design and configuration of proposed observing systems (e.g. coverage, resolution, accuracy and data redundancy).
- Optimize sampling strategies for current and future airborne and space-based observing systems.
- Evaluate and improve data assimilation and vortex initialization methodology for hurricane prediction.

The following section discusses how the HRD combines core observations from satellites and aircrafts and assimilates them into numerical models. This is accomplished using HEDAS (HWRF Ensemble Data Assimilation System) – an in-house system that is used to assimilate hurricane inner-core (in a 3-km inner nest) observations for high-resolution vortex initialization. In addition, the impact of various

assimilation techniques is discussed, and the concepts introduced in the preceding sections are illustrated in the context of OSSEs, which can be used to assess the impact of different data types.

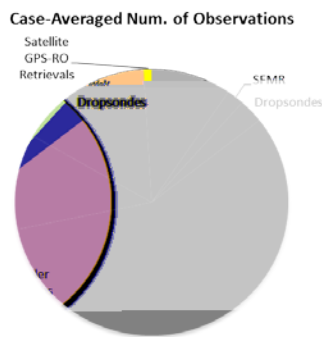
HWRF Ensemble Data Assimilation System (HEDAS)

HEDAS is an ensemble-based EnKF data assimilation system which is interfaced with NOAA’s 2012 version HWRF model. It has been run in near real time on NOAA’s Jet supercomputer. The system assimilates aircraft data (radar, dropsonde, flight level, SFMR surface wind speed) from NOAA P-3 and G-IV, Air Force Reserve C-130, and NASA Global Hawk aircraft, and satellite AMVs, AIRS and GPS-RO retrieved temperature/moisture (T/Q) profiles.

Summary of 2013 HEDAS Assimilations

Platform	Num. Obs.	Num. Cases	Avg. Num. Obs.
Flight Level	75,826	36	2,106
SFMR	15,459	34	455
Dropsondes	21,420	33	649
Doppler Superobs	267,310	21	12,729
Satellite AMVs	112,749	44	2,562
Satellite AIRS Retrievals	80,589	23	3,504
Satellite GPS-RO Retrievals	4,992	24	208
Total	578,345	44	13,144

The 2013 HEDAS Assimilations chart (left) shows that in 2013 majority of the data was obtained from doppler wind superobs, which were obtained mainly from the NOAA P-3 and G-IV aircrafts. Doppler observations however, provided less than half of the total cases. Satellite AMVs not only provided a good number of data points but they were also available in all of the cases. Even though AIRS retrievals were not as readily available, they provided more thermodynamic observations than dropsondes.

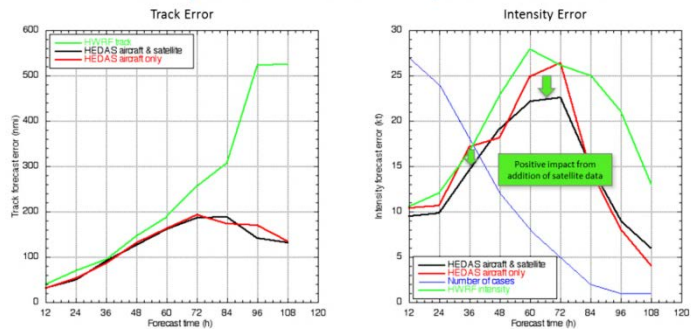


By Altug Aksoy (NOAA/AOML/HRD & U. Miami/CIMAS)

2013 HEDAS: Assimilated observations – summarized by platform

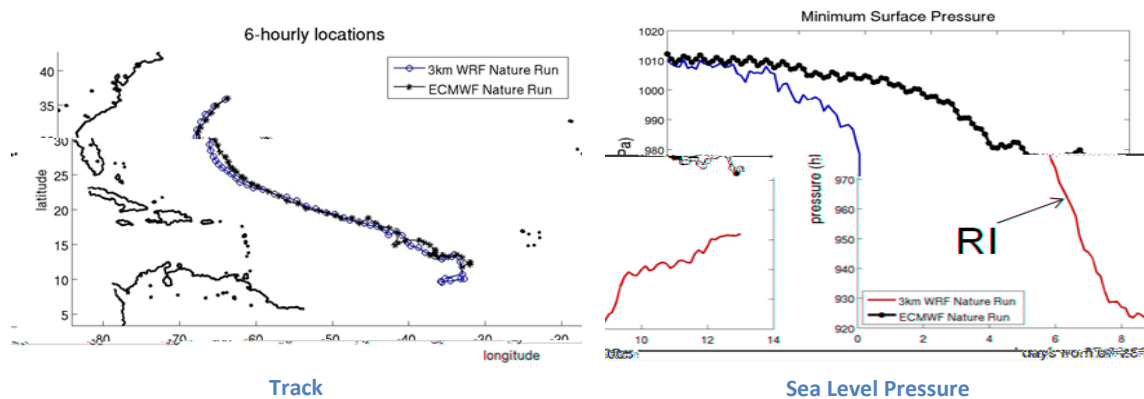
The satellite observations impact charts (right) clearly show that the addition of satellite data to aircraft data improved forecasts especially for intensity for the first 72 h. Although not reflected in the statistics, another positive impact was that with satellite data, the model inner nest was better able to follow the storms.

IMPACT OF SATELLITE OBSERVATIONS ALL DATA (AIRCRAFT + SATELLITE) vs. AIRCRAFT ONLY

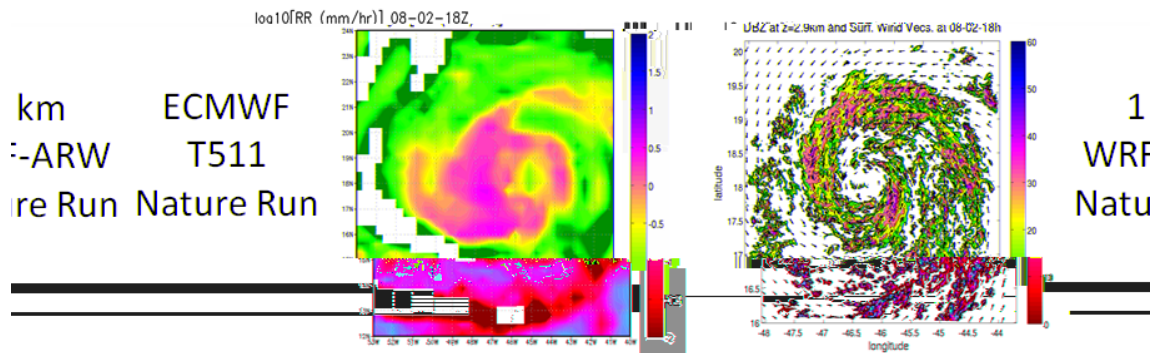


AOML's Regional TC OSSE/OSE System

NOAA's AOML regional OSSE system is based on the HWRF model. Thus far, AOML has tested three options for data assimilation, which include a 3DVAR, a hybrid 3DVAR using GSI analysis, and an ensemble Kalman filter using the HEDAS system. AOML has been running OSSEs in which the WRF-ARW model is embedded within ECMWF T511 global nature run. A nature run is a representation of the atmosphere that plays the role of truth. The figure below of a high resolution hurricane nature run shows a comparison between the global and the WRF-ARW nature runs. While both runs provide nearly identical track forecasts, they differ significantly in terms of sea level pressure and intensification. In the upper right figure, the WRF-ARW run simulated much more rapid intensification (blue line) for this particular hurricane when compared to the ECMWF run (the heavy dark curve).



The WRF-ARW model has performed much better than global models, for certain weather events. This is illustrated in the figure at the bottom, in which the global model (bottom left) provides an extremely coarse and blurry image of this particular TC's structure. Conversely, the WRF-ARW model provides a much more realistic structure (bottom right).



Summary

This article captures the diverse and cutting-edge technical work being done to determine the impact of data from NOAA polar-orbiting and geostationary satellites on every aspect of Tropical Cyclone monitoring and forecasting. In the work highlighted by Fuzhong Weng, JPSS and GOES-R PG science teams continue to make considerable advances towards assimilating Geo and Leo satellite data into regional-scale hurricane models. The work done by Jun Li's team is summarized in the sensitivity

experiments run on Hurricane Isaac. This research showed that the assimilation of satellite data in HWRF with a higher model top led to marked improvements in storm track and intensity forecasts. Chris Velden's group showed the value of their SDAT work, and even with the ongoing analysis and evaluation of SDAT preliminary findings indicate that its forecasts are much closer to observations compared to other dynamic models. In addition, several studies are demonstrating the potential of enhanced AMVs from GOES (and future GOES-R) to impact TC model analyses and forecasts. Finally, Tomislava Vukicevic's team's use of OSSEs showed that the addition of satellite data to aircraft data improved forecasts especially for intensity for the first 72 h. As these teams continue their work, it can be anticipated that additional examples of the value of SNPP and eventually GOES-R data will be documented and communicated.

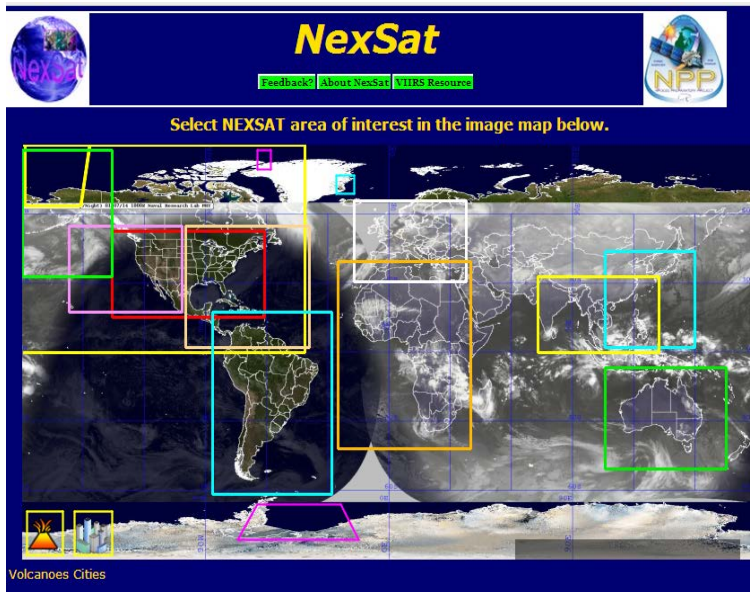
JPSS USER PERSPECTIVE
What the users are telling us about JPSS

Section 2

**United States Naval Research Laboratory (NRL): A Strategic
Joint Polar Satellite System (JPSS) Partner in the Application
of VIIRS Capabilities**

*This article is based in part on the **December 16, 2013 JPSS science seminar** given by Jeff Hawkins, and Arunas Kuciauskas, Naval Research Laboratory, Marine Meteorology Division, Monterey, CA (NRL-MRY).*

Contributing editors: Jeff Hawkins, Arunas Kuciauskas, Mitch Goldberg, Julie Price, William Sjoberg, and Kathryn Shontz



Screen shot of the NexSat homepage illustrating the global coverage as shown by the colored boxes, as well as volcano and city monitoring, which can be viewed by selecting the icons in the lower left corner.

Since 2004, the Naval Research Laboratory in Monterey California (NRL-MRY) has been providing the global community with satellite imagery, and environmental products derived from a constellation of low earth orbiting (LEO) and geostationary (GEO) satellites through its NexSat website: http://www.nrlmry.navy.mil/NEX_SAT.html. NexSat – “**N**ext Generation **S**atellite” - is a public-accessible web-based weather satellite resource developed and maintained by the NRL-MRY, sponsored by the Joint Polar Satellite System (JPSS).

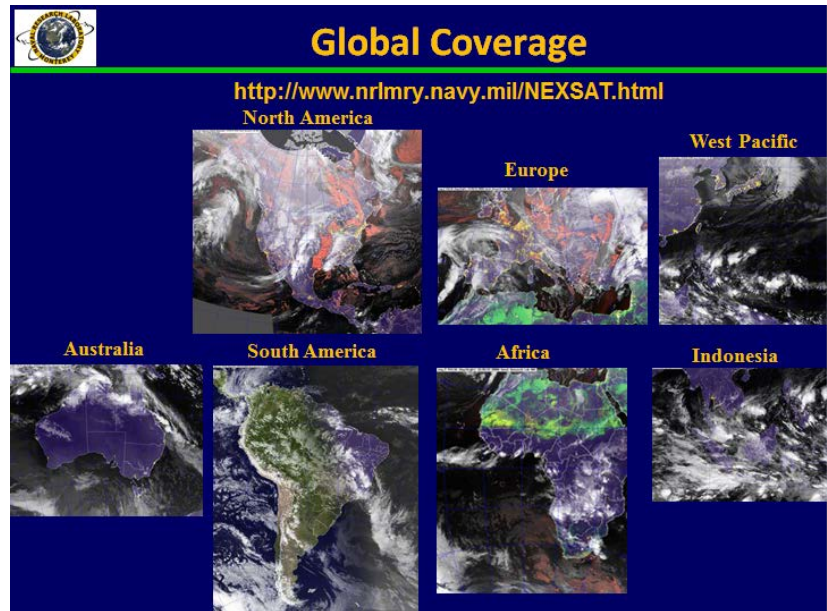
For the operational weather service community, environmental satellites provide a comprehensive view of the world's weather by observing atmospheric

and surface features from a coverage and perspective not available by other means. Satellite digital datasets are used to generate multiple meteorological images and derived products, for example, visible, infrared, water vapor, fire and dust detection, snow cover, cloud fields, and so forth. For websites such as NexSat, these image products are freely distributed to the global community toward a wide scope of applications that includes weather forecasting, hydrology (water management), aviation, a myriad of scientific research, environmental modelling, disaster preparedness and relief, academia, and weather hobbyists, to name a few. A large data source for NexSat products is the Visible and Infrared Imaging Radiometer Suite (VIIRS) sensor onboard the Suomi National Polar orbiting Partnership (SNPP) satellite, that provides a robust suite of new capabilities such as higher spatial resolution, multiple spectral channels, and a broader swath that provides a “next-generation” advancement toward scientific research and practical applied uses. VIIRS data is obtained via the Svalbard data downlink site, which receives every SNPP orbit and then sends the data to the IDPS site at NOAA (Suitland). NOAA then bent pipes the data to the Fleet Numerical Meteorology and Oceanography Center (FNMOC), which is accessible to NRL-MRY.

One of NexSat’s major strengths lies in its ability to provide state of the art, near real time products, on a global scale, from multiple LEO/GEO sensors, thus providing operational users with just-in-time products, and fulfilling a JPSS requirement to demonstrate the superiority of VIIRS by facilitating intersensor (AVHRR, MODIS, OLS, vs. VIIRS) comparisons on a daily basis. Additionally, NRL-MRY incorporates existing algorithms for NexSat display via collaborative efforts from the NRL-MRY modeling community, NRL-Stennis (Oceanography Division), the Cooperative Institute for Research in the Atmosphere (CIRA), the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), and the Cooperative Institute for Meteorological Satellite Studies (CIMSS).

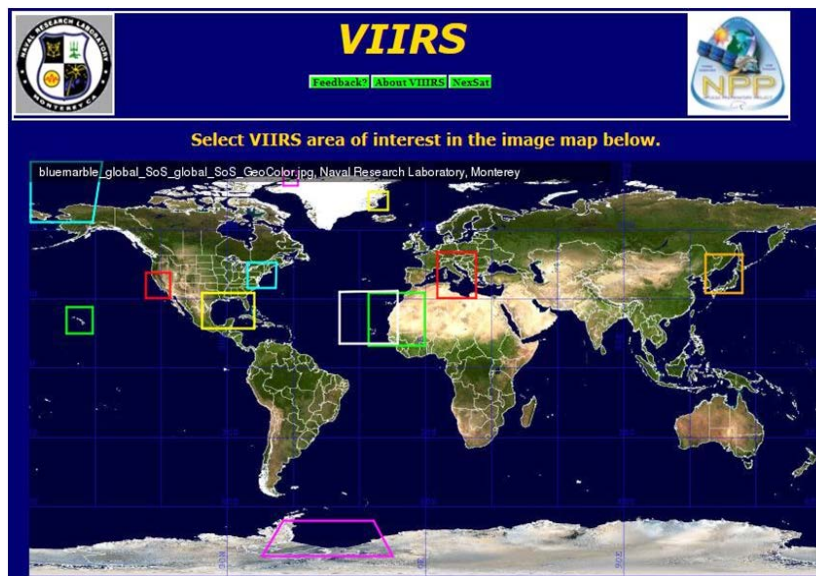
For example, to quicken the creation of products over the continental United States (CONUS), NRL-MRY utilizes VIIRS datasets from the CIMSS Direct Readout (DR) site. This line-of-sight data capture from the UW-CIMSS DR method allows NRL-MRY to produce CONUS imagery with less than one hour latency.

This image provides a view of major domains in NexSat featuring the day/night GEO-color products. GeoColor (Steve Miller, CIRA) uses daytime NASA Blue Marble and nighttime OLS night light composites as backgrounds. The red/pink shades in N America, Europe and Africa are generated using a powerful low cloud product that helps to distinguish low clouds (pink shades) from the rest of the cloud fields at night. The green shades during the night over Europe and Africa take advantage of Meteosat MSG multi-spectral capabilities to help discern false low clouds from terrain.



Along with NexSat, the JPSS-sponsored Cal/Val web page, NRL-VIIRS: www.nrlmry.navy.mil/VIIRS.html is devoted specifically to VIIRS-derived image products and attempts to exploit the sensors' full radiometric, spatial, and temporal sampling while providing the Calibration and Validation (Cal/Val) team with near real-time imagery products and environmental data records (EDRs). NRL-MRY has been able to tap into the VIIRS global digital data sets via a number of collaborations that includes the following: Direct Receive (DR) sites located at the U. of Wisconsin (CIMSS), the NRL Stennis Space Center

Oceanography Division at Stennis Space Center, MS, the AFWA-IDPS site's "bent pipe" downlink to NRL-MRY via FNMOC, and finally the NOAA IDPS site. These datasets are then ingested by NRL-MRY to develop image products to the Cal/Val team for investigation and inter-comparisons. These efforts have helped support multiple studies, including post-launch activities involving comparisons between the mostly superior capabilities of VIIRS against its heritage counterparts.



Screen shot of the NRL-VIIRS homepage.

This article provides an overview of NRL-MRY's NexSat website, consisting of image examples with particular emphasis on VIIRS-derived products that demonstrate the superb new capabilities of VIIRS. It will showcase the value and applicability of NexSat's near real-time image products and environmental data records (EDRs) on a global scale that includes the Arctic and Antarctic regions. The article also outlines some NRL-MRY outreach and training, and Cal/Val activities.

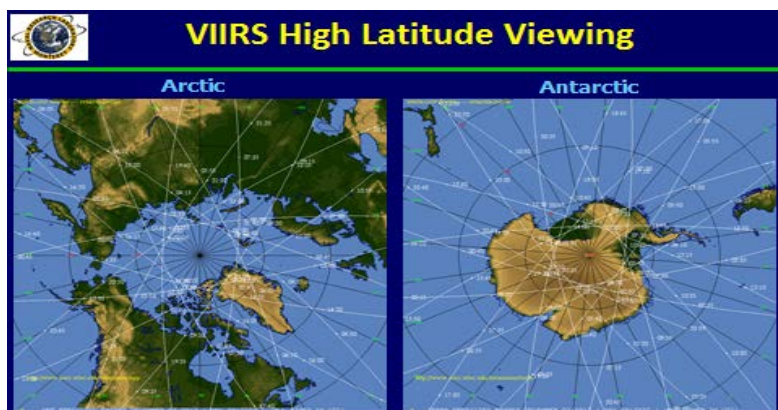
NRL-MRY processes a huge volume of VIIRS data (~1.5 TB) every day (see image on the right). NRL-MRY data comes from 30 different LEO and 7 GEO satellites. Thanks to its collaborative efforts with FNMOC, AFWA, NOAA, NASA, and the Naval Oceanographic Office, NRL-MRY acquires these data sets with superior data latency (time between satellite overpass and appearance on the NRL-VIIRS website) i.e., less than 1 hour for GEO sensors and between 0.5 - 3 hours for the LEO sensors.

NRL-MRY Satellite Digital Data Sets

Polar Orbiting Satellites (30)	GEO Orbiting Satellites (7)
Imagers (Vis/IR): NOAA - AVHRR (4) METOP - AVHRR (2) DMSP - OLS (4) NASA - MODIS (2) NOAA - VIIRS	
Microwave Imagers: DMSP, SSM/I, SSMIS (3) NASA, TMI, SMOS NRL, WindSat	
Micro Sounders: NOAA/MetOp, AMSU-B (3), MHS (2) Microwave Radar: NASA, TRMM PR, CloudSat, A-SCAT-A/B, OceanSat-2 Foreign	
Collaborations: FNMOC, AFWA, NASA, NOAA, CIRA	<p>Data latency: GEO < 1 hour LEO 0.5 - 3 hours</p> <p>Data volume: ~ 2.5 TB/day</p> <p>Courtesy: Johnson & EUMETSAT</p>

NRL-MRY accesses data from 30 different LEO sensors. It also has access to the global suite of GEO sensors.

Supporting the Polar Regions

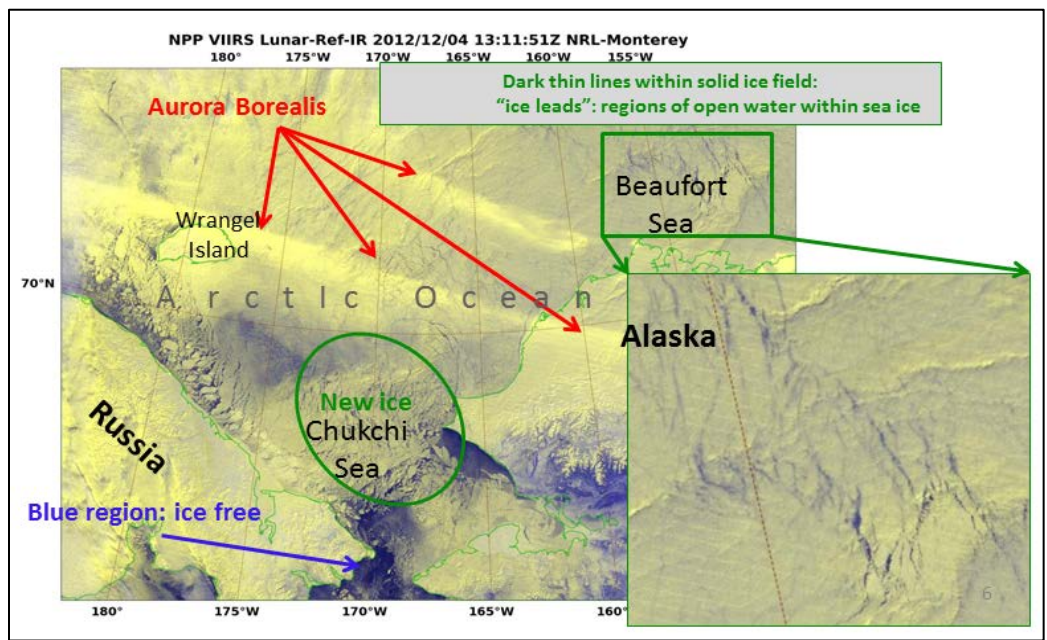


The large VIIRS 3000 km swath provides multiple views per 24 hour period in the polar regions as noted in the orbital track graphic displayed here: nadir ascending/descending tracks plotted

CIMSS web site:
<http://www.ssec.wisc.edu/datacenter/npp/>

Due to their orbital geometry, or more specifically, the oblique angle between the earth's surface and the satellite sensor, GEO satellites do not sample high latitude regions very well. Thus, regions like Alaska, which get frequent polar overpasses, greatly benefit from VIIRS data (see the daily VIIRS pass coverage in the figure above). In addition, VIIRS has better spatial resolution than GEO imagers. Within a rapidly diminishing sea ice environment, the US is ramping up efforts to expand a variety of Arctic tactical and exploration interests. In response, NexSat and NRL-VIIRS have recently established domains

within the Arctic and Antarctic (see coverage boxes in the 1st figure above) to monitor the Cryosphere, primarily with VIIRS products. The image below is an example that takes advantage of the VIIRS low light Day/Night Band (DNB) sensor, together with lunar lighting, to reveal unprecedented night time views of sea ice, particularly during the long winter nights. Prior to the SNPP, much of the environmental detail (sea ice development, structure, movement, etc.) was inherently hindered by the availability of only IR during the long polar darkness periods experienced by previous weather satellites.



Example of an Arctic product in NexSat and NRL-VIIRS featuring a night time view of sea ice, open water, and the aurora over the Arctic Ocean using a combination of DNB and IR, together with a recently developed lunar model by Dr. Steve Miller (CIARA). During this scene, the nearly full moon helps to illuminate clouds and sea ice. The inset displays open water areas within sea ice known as “leads”.

The effective use of satellite observations over Polar Regions is necessary for accurate forecasting and warning of events such as rapid sea ice formation and structure, iceberg flows, etc.

As NexSat makes satellite data and imagery available in near-real time (30 minutes – two hours), NOAA/NWS forecasters in regions such as Alaska can use the NexSat website as another source of satellite data ensuring they are better equipped to make accurate determinations on the severity of a weather-related threat and issue the coordinating warnings.

Night time viewing of natural and man-made phenomena. When lunar (moon) illumination is available, targets are revealed via lunar reflection, and when there's no moon targets are revealed via light emission.

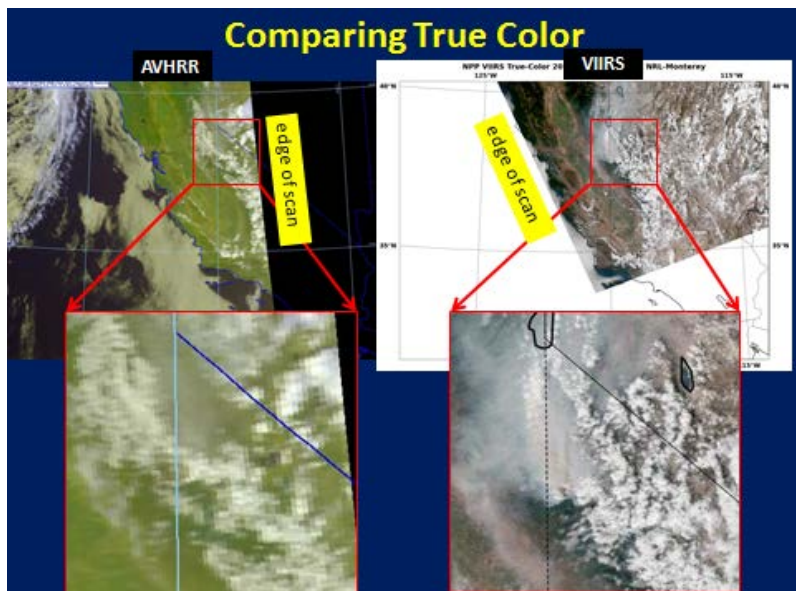
Additional Operational Value of NexSat Satellite Imagery

Satellite images can be used to observe many kinds of phenomena. For example, in the past few years NexSat products have been used extensively at regional and global scales to detect and monitor fires. In the United States, the first sensor used for fire detection was the Advanced Very High Resolution Radiometer (AVHRR) aboard NOAA polar orbiting satellites. VIIRS, on the SNPP satellite provides advanced capabilities for fire detection. In the example below, the Fort Collins, CO wildfire was monitored by NexSat using both the DNB for night time views and Natural Color for daytime views.



Monitoring the wild fire just outside of Fort Collins during June, 2012. Left: DNB multi-spectral product display capturing light from the developing fire. Right: The next day, VIIRS-derived natural color depicts the fire source (hot spot), smoke, and burn scar about the fire.

For fire monitoring, the ability to detect the fire source can play an important role, particularly around the scan's edge of pass. In 2013, the Rim Fire scorched through the backwoods of Yosemite National Park for 69 days between August and October. It was the third-largest wildfire in California's history. In the true color image example on the next page, the "blurred view" within the AVHRR true color product makes it difficult to discern the fire source and smoke above the Rim Fire. In contrast, the VIIRS product retains image clarity. VIIRS captured the direction of fire activity both through the location of detections



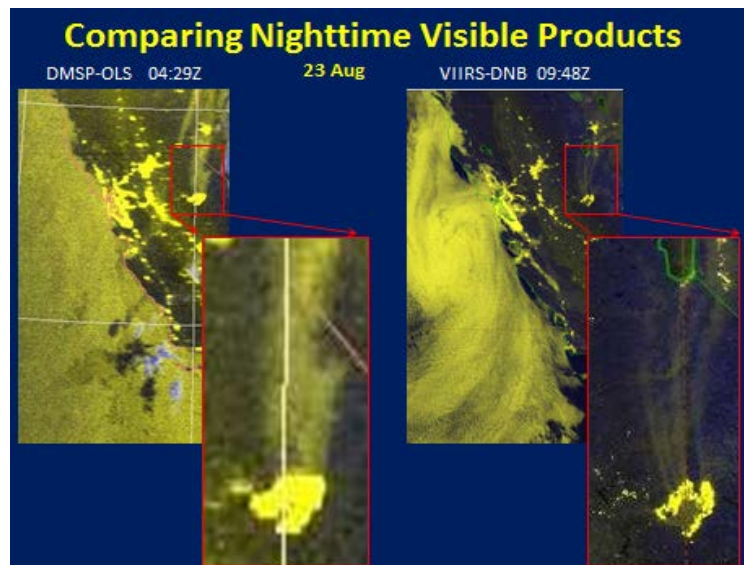
A comparison of true color edge of scan products between AVHRR (left) and VIIRS (right). The AVHRR true color product makes it difficult to discern the fire source and smoke above the Rim Fire

and the corresponding smoke plume. VIIRS could potentially enable earlier detection of fires to support fire early warning, monitoring and management.

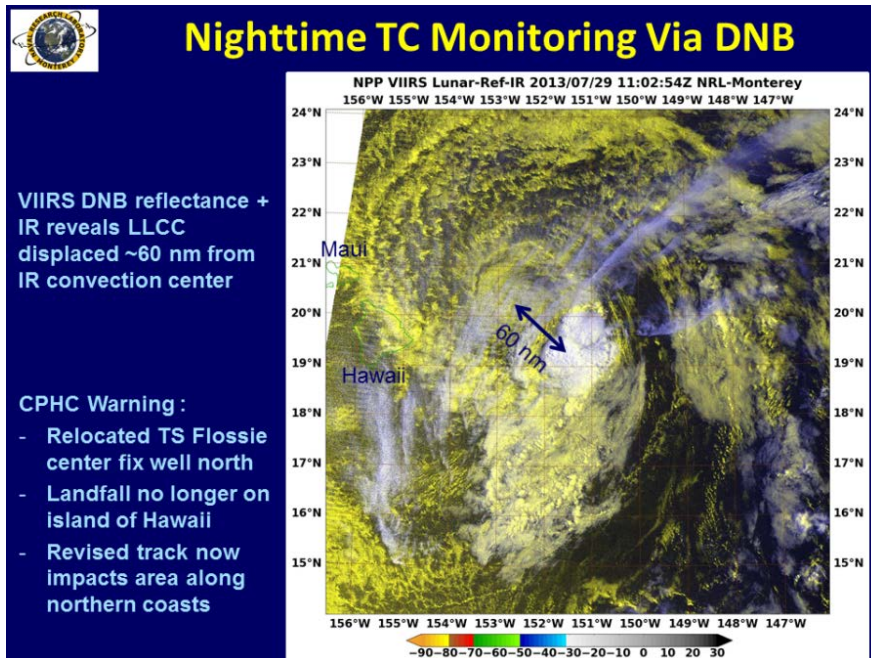
NexSat has also been at the forefront of nighttime applications, by demonstrating nighttime detection of fires, gas flares, polar sea ice, tropical cyclones and volcanoes using the DNB capabilities. The DNB is the only

calibrated low-light visible-band sensor that transcends many of the traditionally understood limitations of nighttime environmental sensing. As shown in the image on the right, the DNB revolutionizes nighttime remote sensing capabilities by leveraging reflected moonlight to sense clouds, fog, and surface features such as snow cover, in addition to emitted light from cities, fires, gas flares, and other sources.

NRL-MRY's tropical cyclone (TC web page) website monitors various aspects of TCs around the world. The ability of the DNB for night time viewing of these features will provide an invaluable resource toward improvements in properly tracking the low level circulation center (LLCC), which is crucial toward location and prediction of TC movement.



Comparison of nighttime products. The DMSP OLS low light sensor (left) pales in comparison to the sharpness of the fire center and the associated smoke plume as shown in the VIIRS DNB image (right).



Monitoring TC Flossie using the DNB enhanced with IR and the lunar model. The annotation in the center indicates the difference between the actual surface low and the anticipated low derived within the mid and upper level cloud field.

The example above dramatizes how the DNB can help reduce the inaccuracies involved with tracking a TC. In this example, the center of Tropical Storm Flossie was relocated ~ 60 nm northwest on July 29, 2013 at 12Z due to DNB imagery clearly revealing the LLCC had become separated from the IR convective center of mass (mid-upper level). Instead of heading towards the Big Island of Hawaii, Flossie was now headed further north along the northern edge of the Hawaiian Islands and posed a much smaller threat since they would be on the southern (weaker) side of the slowly weakening storm. Thanks in part to the DNB at night, the actual depiction of the low level flow can assist forecasters in properly locating actual locations and providing more accurate assessment of storm locations and movement.

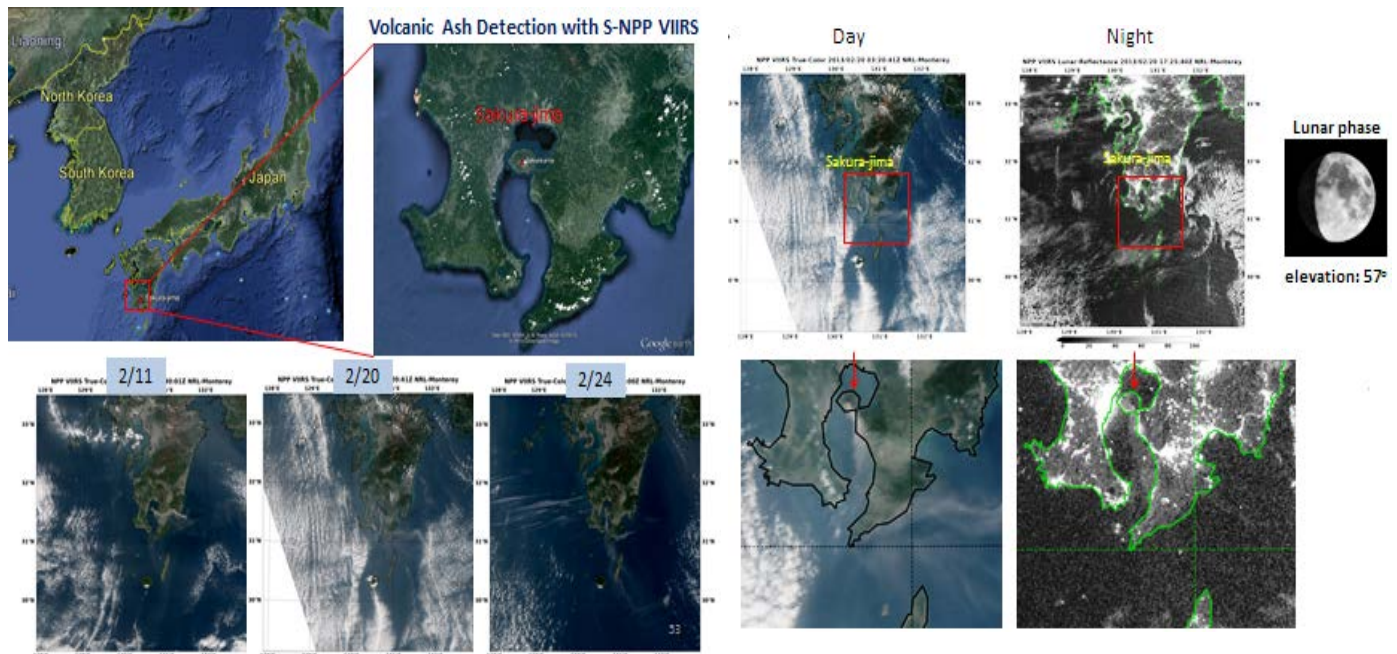
Outreach and Education

NexSat provides support to a wide variety of civilian and military missions. These include disaster monitoring (volcanoes, fires, earthquakes, and flooding), multiple field programs around the world, mesoscale monitoring, and education initiatives. For example, NRL-MRY educates scientists and the public on current and future sensors, and has been a consistent partner with the COMET program in educating the public in various aspects of VIIRS. The COMET Program was established in 1989 by the University Corporation for Atmospheric Research (UCAR) and NOAA’s NWS to promote a better understanding of mesoscale meteorology among weather forecasters. It provides education and training support for the environmental sciences. The COMET team draws upon the expertise of NRL-MRY subject matter experts (SMEs) to provide detailed information and examples. Using NexSat products, these SMEs specialize in packaging the information in a graphical manner that can be easily grasped by the layperson. The COMET modules are online and accessible 24/7.

NexSat also teamed up with the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS) to educate volunteer weather observers into the realm of basic remote sensing. Thus, the overarching goal for NexSat is to provide the public with operational, research-oriented, inventive, educational tools in the current timeframe, and also toward the next generation of environmental satellite systems.

NexSat's Work With International Weather Agencies

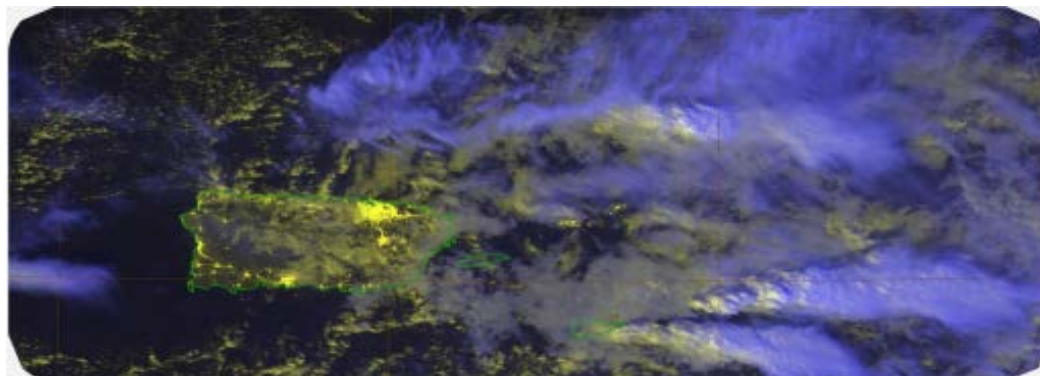
NRL-MRY recently added to NexSat S-NPP VIIRS products that enhance its suite with high spatial resolution products during the day. The product suite, which include near real-time digital satellite imagery, have been actively used to support the global community in various weather-related field campaigns. VIIRS also provides unparalleled nighttime views of volcanic activity at night, as shown in the images below. In 2013 NexSat played a supporting role for agencies involved with the monitoring of volcanic eruptions, such as Sakura-jima, a volcano located in southern Japan, which became active with a series of explosions that generated volcanic ash plumes during the month of February. The plume altitudes reached 4,000 – 12,000 feet above sea level.



S-NPP VIIRS true color images of Sakura-jima. These images show fine detail (0.74 km pixel size) of plume releases extending south and east from the source.

Sakura-jima on one of the days, as the lunar phase was >3/4 full, the DNB was able to continue the monitoring of the plume within the moon-lit night.

As part of its outreach efforts, NRL-MRY provided a customized NexSat domain of satellite imagery for Puerto Rico to the NWS Weather Forecast Office (WFO) in San Juan.



NRL-MRY and the San Juan WFO have established a user/developer feedback loop through which NRL-MRY learns about the utility of its NexSat website, and the WFO gets to utilize the custom satellite products from NexSat. Over the past year NRL-MRY has provided the WFO in San Juan a variety of environmental products, and helped them in fire weather monitoring. It also helped the WFO in implementing VIIRS including dust products, which were particularly helpful in monitoring the Saharan Air Layer (SAL), a feature that impacts the respiratory aspects of those encountering SAL air. The SAL is a plume of very dry, dusty air which forms over the Sahara Desert during the late spring, summer, and early fall and usually moves out over the tropical North Atlantic Ocean every 3-5 days. Scientific research seems to indicate that the SAL has a weakening effect tropical cyclone intensity and formation.

Summary

Given technological advances in the recent decades, websites such as NRL-MRY's NexSat, which transition imagery to value-added products, have become avenues through which satellite imagery and data can be distributed to various users. NexSat does more than illustrate the latest findings and advantages of newer products. It has also become a viable instrument through which the latest information on multiple satellite environmental products, such as VIIRS fire detection, snow cover, true color, biomass can be disseminated in near real time. NRL-MRY obtains data from 30 different LEO and 7 GEO satellites, and therefore processes huge volumes every day. Through collaborative efforts with FNMOC, AWFA, NOAA, NASA, and NRL-SSC, NRL-MRY provides some of the best latency times for VIIRS as well as the rest of the datasets. This is especially important for high impact events as it allows forecasters to quickly evaluate regional weather events and rapidly disseminate information.

In addition, NRL-MRY is in partnership with the COMET Program (www.meted.ucar.edu) to provide world-class public education on VIIRS in a variety of satellite training modules. As part of its outreach efforts, both NRL-VIIRS and NexSat provide a wealth of resources to a wide range of research and development activities. NexSat actively supports international agencies by providing various products during weather-related field campaigns including volcano, fire and flood monitoring. The NexSat provides a wealth of environmental products and satellite imagery to the global community and communicating its capabilities in near-real-time and in a visually intuitive way is bound to broaden the spectrum of potential users.

JPSS USER PERSPECTIVE
What the users are telling us about JPSS

Section 3

**The Visible Infrared Imaging Radiometer Suite (VIIRS) Ushers
in a New Era of Support to the NOAA Oceanographic Mission**

*This article is based in part on the **January 27, 2014** JPSS science seminar given by Cara Wilson, National Marine Fisheries Service, Southwest Fisheries Science Center (NMFS/SWFSC), Environmental Research Division, Pacific Grove, CA.*

Contributing editors: Cara Wilson, Mitch Goldberg, Julie Price, William Sjoberg, and Kathryn Shontz



Oceans cover more than 70 percent of the Earth's surface, yet their remoteness, complex dynamics, size, and hidden depths make them particularly challenging to observe. Given their strategic placement in space, environmental satellites observe the Earth and provide key measurements of its geophysical, biological and chemical attributes. These satellites provide oceanic measurements, of habitat and ecosystems that influence marine resources, at spatial and temporal resolutions that are impossible to achieve any other way. NOAA's National Marine Fisheries Service (NMFS) is responsible for managing more than 900 commercially important stocks and close to 210 protected or endangered species. NMFS acts as a steward of living marine resources, which involves ecosystem and habitat characterization and stock assessment. Annual fish quotas and other management measures to achieve optimum yield are established based on stock assessments. At a minimum, a quantitative stock assessment requires monitoring of catch, abundance, and biological characteristics of the stock, which helps avert overfishing. Even though NOAA's environmental satellites do not observe fish stocks directly, they still provide valuable scientific measurements from the oceans. These include global ocean data sets of sea-surface temperature (SST), sea-surface height (SSH), winds, and chlorophyll (Chl), among other parameters. While NOAA satellites provide many types of data sets, ocean color is a critical resource which is used to help assess the health and productivity of marine ecosystems on a global scale. It is especially important to fisheries as it is the only remotely sensed biological measurement. It helps to determine the nature and concentration of substances in surface waters. And, it is used in combination with models to understand the dynamics of the ocean ecosystem.

This article highlights the efforts being made by NOAA's Southwest Fisheries Science Center (SWFSC) Environmental Research Division's (ERD) to facilitate access to VIIRS ocean color and SST data (henceforth just VIIRS data) to end-users of oceanographic data. It summarizes four key activities the ERD has undertaken towards this effort. These are:

- (1) making VIIRS data available on the SWFSC Environmental Research Division's (ERD) ERDDAP server;
- (2) modifying the Environmental Data Connector (EDC), an existing free software extension that increases the ease of importing VIIRS data into ArcGIS – geographic information system software that is used frequently within the NMFS and NOS;
- (3) conducting a short satellite course aimed at showing NOAA participants (NMFS and NOS), how to access and utilize satellite data through a variety of different protocols; and
- (4) the creation and dissemination of scripts that allow easy access to remote datasets from within desktop applications, such as Matlab and R.

Oceanographic satellite data is used in a wide array of activities throughout NMFS and NOS. In this article, these activities are highlighted with projects that were worked on during the 2013 NOAA satellite data training course.

Economic Importance of the US Fishing Industry

While there is no comprehensive global database on fish stocks, the United Nations Food and Agricultural Organization (FAO) has reviewed close to 600 marine fish stocks from oceans world-wide. The FAO has been monitoring marine fishery resources and providing reports to global audiences including scientists and policy makers since 1973. In its 2012 State of World Fisheries and Aquaculture (SOFIA) publication, the FAO states that between 1974 and 1989 the percentage of overexploited stocks increased from 10 percent to 26 percent. Subsequent to 1990, there was a sustained, but not frequent, increase in the numbers of overexploited stocks. According to the report, most stocks of the top ten species, which represent close to 30 percent of the global catch, are fully exploited and, therefore, do not have any potential for increases in production. Moreover, some stocks are overexploited and increases in their production may be possible if effective rebuilding plans are put in place. By FAO definitions, fully exploited stocks produce catches that are at or close to an optimal yield level, with no expected room for further expansion. Overexploited stocks produce lower yields than their biological and ecological potential, and do not have any potential room for further expansion. In addition, these stocks face a much higher risk of stock depletion/collapse. In the long run, the thriving fishing industry has resulted in over fishing of some fish species, potentially putting the local populations that depend on them for dietary or economic reasons at risk of losing valuable sources of livelihood.

Within NOAA fisheries, ocean color data are used to help identify areas that contain large populations of commercial fish stock, for monitoring fishing activities or for conservation efforts. For example, in one application, satellite data has been used to help identify favored areas of maritime species, and in another application, it has been used to predict the movement and congregation of endangered right whales in the Atlantic with the aim of minimizing the number of lethal interactions with ships. In addition, NOAA scientists use satellite derived ocean color data to develop products that can be used to detect, characterize and monitor the environment of living marine resources. For example, the timing of the spring algal bloom may influence recruitment – the number of new individuals entering a stock. Conventional wisdom dictates that recruitment success is tied to the degree of timing between spawning and the seasonal phytoplankton bloom, which makes satellite observed-Chlorophyll (Chl) the most useful way to observe these changes. Unlike satellites, traditional shipboard measurements have limited spatial and temporal resolution, therefore, with satellite ocean color data, the changes in the

timing and magnitude of the seasonal bloom can be clearly seen. In addition, ocean color data is used to classify the productivity of the oceans, and also to monitor a number of issues that impact fisheries, such as, harmful algal blooms (HABs), coastal water quality, long-term ocean variability, and derelict fishing gear. Ocean color data has also been employed to delineate marine protected areas (MPAs), identify zones that contain large populations of commercial fish stock for the specific purposes of monitoring fishing activities, and for conservation efforts by NOAA's NMFS.

Assisting the NOAA Ocean Mission in its Application of Satellite Data

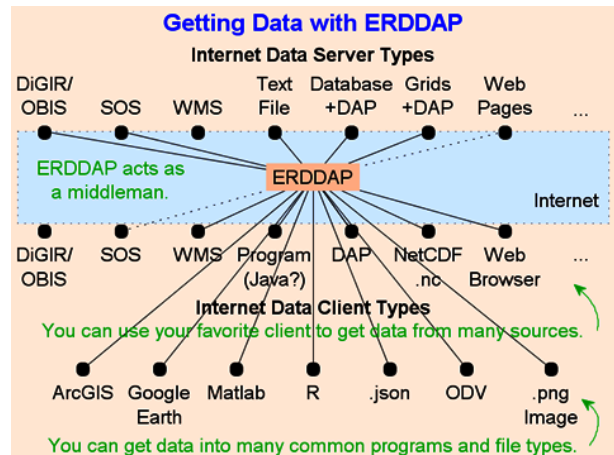
The high temporal and spatial resolution of satellite data, their continuity, and global coverage make them important assets for monitoring and characterizing marine ecosystems. Yet oceanographic satellite data remain underutilized by both the operational user community and marine resource managers. Even though satellite data have progressively become an essential part of many environmental earth observation systems, they can be difficult to access, manipulate and process, particularly for people who are unfamiliar with it. Moreover, the work required to get relevant parameters can be cumbersome, or the parameter itself may not be readily available or easily calculated, for example, trying to obtain climatologies required to generate anomalies, or front locations from SST fields. In addition, trying to obtain measurements of primary productivity from Chl can be expensive and time consuming. And, rigorous 'data mining' is needed to match up satellite data with telemetry records. Another reason why the oceanographic community has been slow to embrace satellite data is because their time-series are relatively short compared to many fisheries datasets that span decades. A long time series is relevant to understanding oceanic seasonal cycles and interannual differences.

For years the oceanographic user community has relied upon ocean color data from the Sea-viewing Wide Field-of-view Sensor (SeaWiFS), the Moderate Resolution Imaging Spectroradiometer (MODIS) and MEdium Resolution Imaging Spectrometer (MERIS). Given the demise of the SeaWiFS and MERIS satellites, and the beyond-design life age of the MODIS sensor, there has been concern about the future availability of ocean color data. Because of this, ocean color data from the Visible Infrared Imaging Radiometer Suite (VIIRS) has been eagerly anticipated by the oceanographic community. With the launch of VIIRS on the Suomi National Polar-orbiting Partnership (SNPP) satellite in Oct 2011, a gap in the continuity of US ocean color was narrowly avoided. The absence of an easily identifiable operational need for ocean color data was largely responsible for the probable gap. VIIRS data enabled the continuation of this important time-series of ocean color data. Satellite ocean color data is particularly important to fisheries, since it is the only remotely sensed parameter that measures a biological component of the ecosystem. The JPSS Proving Ground (PG) projects ensure continuity of heritage and other NOAA products using VIIRS ocean color (OC) and sea surface temperature (SST) data. To this end, the JPSS PG engages NOAA users such as the National Marine Fisheries Service (NMFS) and the National Ocean Service (NOS) for operational uses of VIIRS data.

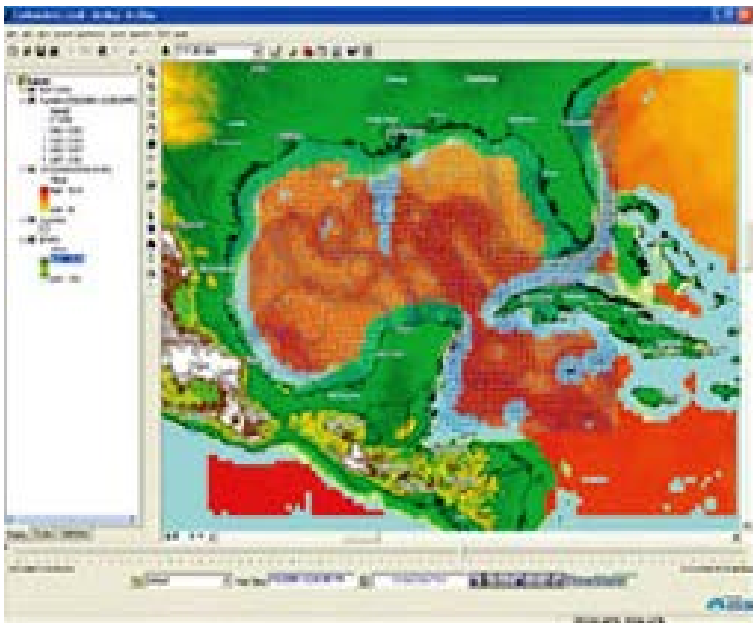
The Environmental Research Division's Data Access Program (ERDDAP)

Given the growing desire for “one-stop” shopping from the oceanographic data user community, the SWFSC ERD has developed a variety of tools to make using satellite data an easier process. To facilitate access to VIIRS data, it was placed on the ERDDAP server at the SWFSC ERD facility. In addition, ERD revised the EDC tool (an ArcGIS interface to ERDDAP) to work with telemetry data.

The ERDDAP was developed at ERD to provide easier access to datasets. It is both a web application and a web service. It unifies the different types of data servers, which gives the user a consistent way to get the data they want, and in the format they want. It also allows the user to make graphs and maps. The data is available in multiple data formats such as, netcdf, grib, csv, ESRIcsv, JSON, ODVtext, mat, text and more. Images are also available in multiple file formats such as png, transparent png, pdf, and kml.



The Environmental Data Connector (EDC)



ArcGIS display showing data retrieved using EDC. All datasets shown are from OPeNDAP sources

Satellite data have been largely inaccessible for those working with GIS tools, such as fisheries scientists and marine resource managers. Developed by the Applied Science Associates, Inc. (ASA), the Environmental Data Connector (EDC) provides the science and management community easy selection to, and importation of, any dataset served by the Thematic Real-time Environmental Distributed Data Services (THREDDS), Open-source Project for a Network Data Access Protocol (OPeNDAP), Sensor Observation Service (SOS), or ERDDAP catalogs into ArcGIS 9.2. More specifically, it enables them to connect directly to a variety of data services, including OPeNDAP, SOS, and ERDDAP, from several commonly used data analysis packages, including ArcGIS, Matlab, R, and Excel.

The NOAA Satellite Data Training Course

Since 2006 the SWFSC ERD has been conducting 3-day short courses in oceanographic satellite data¹. These courses are aimed at NOAA participants and in particular, NMFS and NOS scientists. They are also open to non-NOAA participants. The courses were developed by SWFSC ERD scientists Cara Wilson and the late Dave Foley, in conjunction with Ted Strub at the Cooperative Institute for Oceanographic Satellite Studies (CIOS) at Oregon State University in Corvallis, Oregon.

The objective of the course is to provide an overview of the types of environmental satellite data available, where and how to access the data, and methods of working with the data, including importing into Geographic Information Systems (GIS) applications, and accessing data through Matlab and R. The course relies primarily upon data served off of the ERDDAP server at ERD.



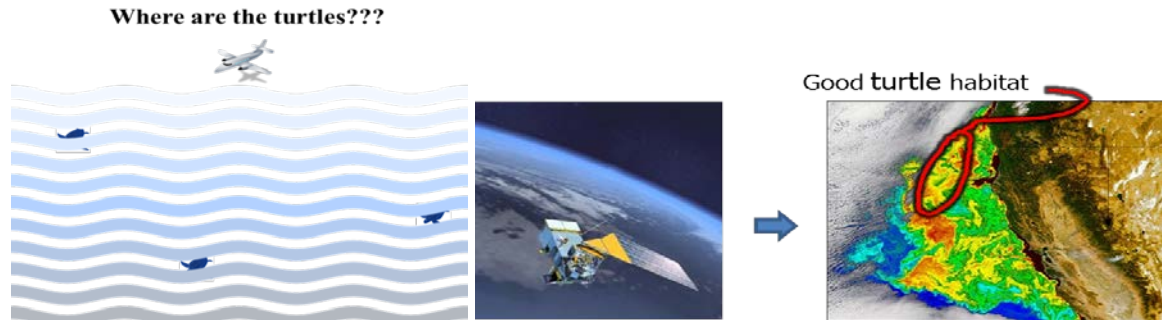
In the 2013 course particular emphasis was placed on accessing and utilizing ocean color data from the VIIRS sensor. Participants in this course discussed possible ways that NMFS and NOS can use satellite derived oceanographic data operationally. For example, SST data can be incorporated into aerial surveys to determine the regional distribution of endangered turtles and whale species, as well as ecological forecasts of salmon stocks. NOAA fisheries are transitioning from traditional fisheries management to ecosystem-based management (EBM). As they transition they are ingesting satellite data into their EBM models with the ultimate goal to improve model accuracy, and provide better forecasts of fisheries stocks for fish stock assessments and living marine resource management. Below are some of the initiatives being worked by NOS and NMFS.

Turtle Spotting

The leatherback sea turtle (*Dermochelys coriacea*) is one of the largest reptiles in the world. And, of all the sea turtle species, the leatherback migrates longer distances, and has the widest range. In the Pacific Ocean populations of adult leatherback turtles have been rapidly declining. Interactions with

¹ <http://www.pfel.noaa.gov/events/NOASatCourses/>

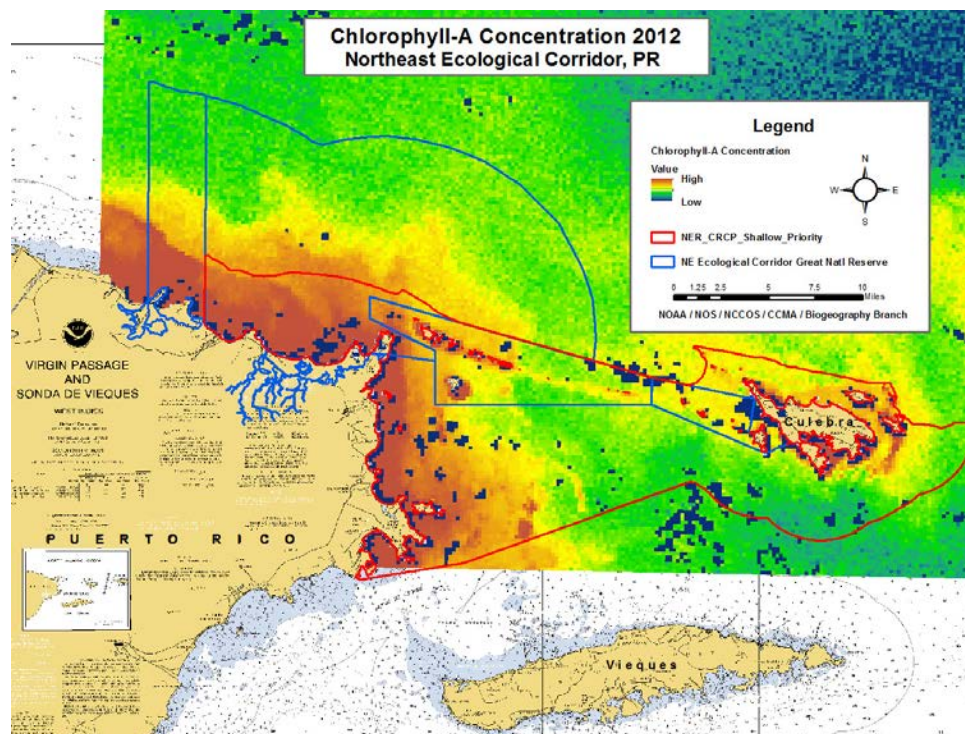
fisheries are believed to be a major cause of their mortality. NOAA scientists are using VIIRS data to characterize leatherback habitats off the US west coast, and also determine the oceanographic processes linked with leatherback movements.



Using VIIRS data to locate the best leatherback turtle population habitats in the Pacific Ocean

Using VIIRS to Provide a Biogeographical assessment of new Marine Protected Area (MPA) in Puerto Rico

MPA managers use a variety of tools to help them map, analyze and manage the marine resources under their jurisdiction. Among the tools used are geographic information systems (GIS) which generate statistics that provide useful ecological and management information on the marine resources in the ocean, and also help MPA managers to determine whether these resources are adequately protected. Even though spatial analyses using GIS is powerful, it can be complicated and time consuming to reveal meaningful results that support management decisions.

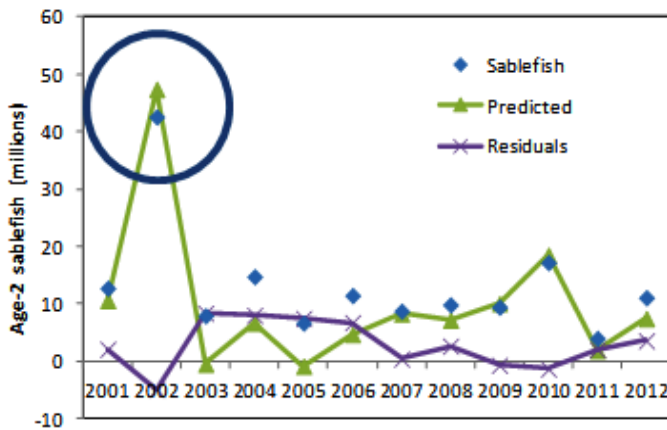


Spatial analysis obtained from VIIRS SST data, which shows the area for ecological monitoring and natural resource management

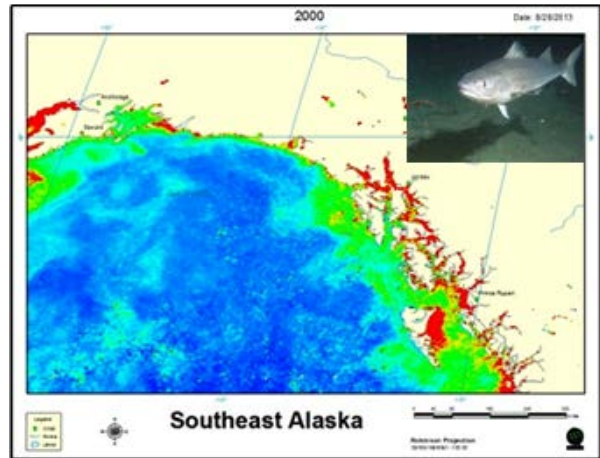
A team of scientists from the NOS plan to use high resolution VIIRS 750 m SST and MERIS 300 m ocean color data to look at MPA designations around Puerto Rico. The National Centers for Coastal Ocean Science's (NCCOS) Biogeography Branch, in particular, plans to use a 10-year time series of SST and ocean color/chlorophyll, along with high resolution bathymetric data, for a marine spatial analysis of the area for ecological monitoring, natural resource management, and predictive modeling.

Ecological Indicators for Sablefish Recruitment

The sablefish is a fast growing, widely distributed, highly valuable commercial species that generates approximately \$ 142 million for the U.S. fishing industry. The Alaska Fisheries Science Center (AFSC) uses satellite ocean color data as an ecological indicator in determining sablefish recruitment. Recruitments are estimated as two year-olds. High age-2 recruitment in 2002 was attributed to high



Age-2 sablefish modeled as a function of Chl-a (t-2), sea temperature (ST) (t-2), and age-2 sablefish (t-1) with data collected in situ, 1999-2010 (Martinson et al. 2013).

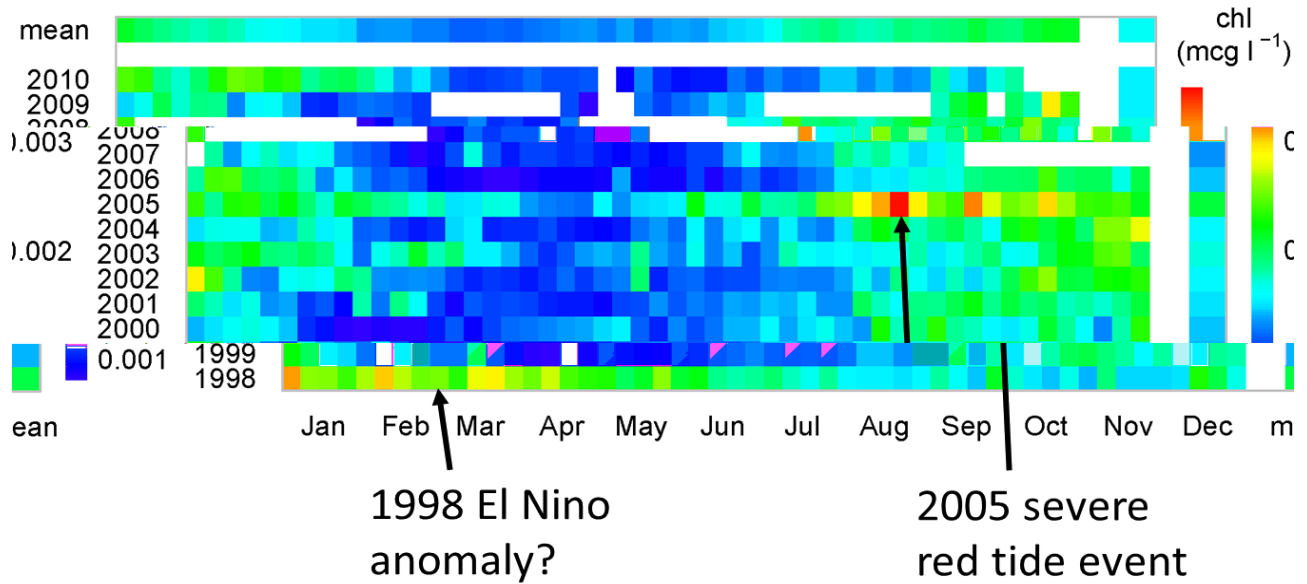


Coastal rearing habitat for young sablefish

Chl-a in the late summer in 2000 (as shown in the image on the left). Estimates for most recent years are highly variable with large uncertainty and are often excluded from model projections. VIIRS data is used to explore the integration of satellite derived environmental time series which consists of SST, chl and sea surface height (SSH) into the sablefish stock assessment to reduce recruitment uncertainty.

Ecosystem Monitoring in the Gulf of Mexico

Phytoplankton – microscopic organisms or algae that live in the ocean’s surface waters – contribute almost half of the world’s total primary production, which is the process by which carbon dioxide is taken up by plants and converted to new organic matter by photosynthesis. These organisms form the base of the marine food chain. Phytoplankton, however, can sometimes grow explosively, creating what is referred to as harmful algal blooms. An intense bloom can produce harmful impacts on marine ecosystems. Satellites provide a broad area of coverage in HAB detection and monitoring. Nonetheless, in situ sampling is still necessary as satellites are impacted by clouds, and cannot measure currents or salinity effectively. NOAA scientists use satellite SST data to identify candidate areas where blooms can occur. They also use satellite ocean color observations, such as Chl concentration, which provide measurements of phytoplankton abundance in the marine environment, to monitor, and track the location and movement of HABs. In addition, the satellite ocean color observations provide information on the health of important fisheries’ habitat.



Chl concentrations for the West FL Shelf –weekly means by year

In 1998 the West Florida shelf experienced Chl-a levels that were higher than typical and remained elevated nearly the entire year. The year 2005 was also anomalous as the region experienced high Chl-a concentrations again, and like in 1998, these persisted for a longer period than typical. According to NOAA scientists, the 2005 event may have been a result of the four hurricanes that passed over the region and a red tide bloom that persisted for that entire year.

Spatial Distribution and Feeding Ecology of Chinook Salmon in the Yukon Delta

Chinook salmon is an important commercial, recreational, and subsistence resource in the Yukon River. Yet, many aspects of the early marine ecology of juvenile Chinook salmon during the first critical period – from outmigration through the first marine summer – are not well understood. During this period, the fish must feed and grow to obtain sufficient size to store energy during their first winter at sea.

VIIRS data will be used to help characterize habitat usage, feeding, and condition of juvenile Chinook salmon in the Yukon River delta from ice-out through the first marine summer. This data will help connect out-migrating juvenile Chinook salmon habitat use, growth, and condition in the shallow, nearshore and intertidal waters of the Yukon Delta to existing data on juvenile Chinook salmon distribution and condition on the eastern Bering shelf.



Yukon River delta and plume as viewed from the Landsat 7 satellite on Sept. 22, 2002. (NASA Earth Observatory). VIIRS provides chlorophyll data needed to assess nutrients and ecological conditions

Summary: VIIRS -- Making the Difference for the NOAA Ocean Mission

The research value of satellite data is particularly important to the oceanographic community, which includes oceanographers and marine resource managers. This community has come to depend upon satellite data for many marine research applications, including monitoring of HABs, marine stock assessments, and characterizing marine habitats and ecosystems. Satellite ocean-color data provide valuable information to the oceanographic community, and it is especially important to fisheries as it is the only remotely sensed biological measurement.

The VIIRS sensor on the SNPP satellite provides critical parameters such as ocean color and SST data to this community. The NMFS has traditionally relied upon electronic tagging to gather information on stock productivity and recruitment, fish behavior, feeding ecology and habitat selection – information needed for accurate and responsible fisheries management. Satellite data, such as ocean color, SST, and SSH are necessary to place the telemetric data from tags in an environmental context as part of the NOAA Fisheries transition to an ecosystem approach to management.

Despite its usefulness and potential value; the oceanographic community has been slow to embrace satellite data, and in particular ocean-color data, citing issues such as dissemination of the data, unfamiliarity with it, unavailability of desired products, and so forth.

Satellite data literacy can be enhanced through training courses specifically designed for target audiences. In regard to data dissemination and usage, NOAA has held several satellite courses for its scientists since 2006. These courses target two broad groups of users: ArcGIS users, and marine biologists who work with tagged animal data. The courses have been found to be particularly helpful when both data providers and data users are involved. In addition to educating participants about the availability, access, and use of satellite data, providers obtain a better understanding of user needs and requirements.

Issues relating to data accessibility involve the use of ArcGIS – geographic information system software that is used frequently within the NMFS and NOS. Importing satellite data into ArcGIS can be cumbersome, particularly for lengthy time-series. As a result, the EDC tool (an ArcGIS interface to ERDDAP), which allows users to browse and subset large amounts of data online, has been modified to make it easier to import VIIRS data. For some, trying to obtain values associated with a telemetry track from global satellite datasets can be quite tasking. ERD has developed scripts that work with Matlab and R to effortlessly perform these match-ups. With JPSS funding the EDC was revised to also allow this capability.

With VIIRS data, the potential for a critical gap in ocean color data – created by the demise of the SeaWiFS and MERIS satellites, and the beyond-design life age of the MODIS sensor – was averted. VIIRS data enabled the continuation of this important time-series of ocean color data, particularly for applications such as HAB detection and monitoring, marine stock assessments, and habitat characterization for living marine resources. In addition, with VIIRS high-quality global ocean color products in support of research and operational applications will continue to be produced.

Lastly, the JPSS PG projects including those highlighted in this article ensure continuity of heritage and other NOAA unique products using VIIRS ocean color data; independently assess data/product quality, and ensure end user utilization.

JPSS USER PERSPECTIVE
What the users are telling us about JPSS

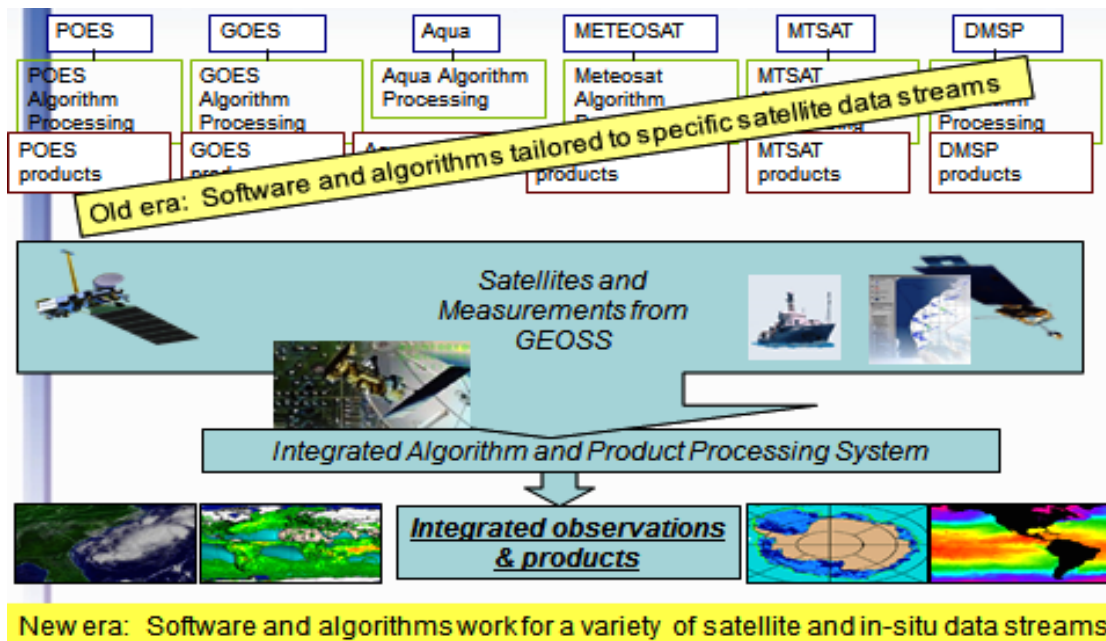
Section 4

Uniform Multi-Sensor Algorithms for Consistent Products

*This article is based in part on the **February 24, 2014** joint JPSS-GOES-R Science Seminar, which was presented by Walter Wolf, NOAA/NESDIS/STAR, College Park, MD.*

Contributing editors: Walter Wolf, Istvan Laszlo, Shobha Kondragunta, Andrew Heidinger, and Mike Pavolonis, Mitch Goldberg, Julie Price, William Sjoberg, and Kathryn Shontz

New and Old Algorithm Product Capabilities



Pathway to Multi-System Integration

NOAA satellite programs have traditionally pursued their own individual algorithm development program and separate ground system. Each program has developed its own mission unique pre-launch and post-launch instrument calibration and validation approach. In addition, these programs have developed their own customized user engagement and training programs, software, documentation, and schedule practices. This approach generally leads to increased and redundant costs, sub-optimal performance, more complex transitions to operations, difficulty in blending products due to the different algorithms and processing, and wide variations in user preparation/readiness.

NOAA's major satellite programs are preparing to transition away from heritage satellite systems (POES², GOES³) to the next generation satellite systems (JPSS⁴, GOES-R). This has led to large increases in satellite data but has also created a great opportunity to shift from individual algorithm and product development to integrated processing. This article focuses on the NOAA/NESDIS Center for Satellite Research and Applications (STAR) Algorithm Processing Framework (SAPF) that was developed by the Algorithm Integration Team (AIT). This was in response to a request from the US National Weather Service (NWS) for continuity of NOAA products between current and future NOAA operational satellites. The SAPF also supports NOAA's goal of enterprise solutions by employing the same algorithms for POES and GOES.

² Polar-orbiting Operational Environmental Satellites

³ Geostationary Operational Environmental Satellites

⁴ Joint Polar Satellite System

STAR Algorithm Processing Framework (SAPF)

STAR designs and develops scientific algorithms and satellite processing systems that are transitioned to operations at the Office of Satellite and Product Operations (OSPO). Once these algorithms and systems are transitioned to operations, STAR works in coordination with OSPO to maintain them. The STAR Algorithm Scientific Software Integration and System Transition Team (ASSISTT) specializes in this end to end process that includes design, development, transition to operations, and maintenance for algorithm processing systems and their products.

Within STAR, GOES-R provided an opportunity to develop and implement the GOES-R Algorithm Working Group's (AWG) Product Processing System Framework. This system brought scientific consistency between all products as the same ancillary data was used for all the algorithms. The framework was designed to make it easier for integration of scientific algorithms by enabling the algorithm to be developed and/or tested in both the framework and the scientist's offline research system with little modification or addition to either system. Since the framework is an all-in-one system, it allows algorithms access to a variety of data sets with minimal effort once they have been integrated into the system. The Framework was also designed to handle the processing of any type of satellite data. It was developed to read in the input data, store it in memory and to make it available to the product algorithms. The algorithms were implemented to keep the output products in memory to be used as product precedence for other algorithms within the same data run.

To reduce algorithm development costs and to bring scientific consistency across JPSS and GOES-R products, STAR upgraded the Framework to create the SAPF and is also modifying the GOES-R Advanced Baseline Imager (ABI) algorithms to process data from the Visible Infrared Imager Radiometer Suite (VIIRS), onboard the Suomi National Polar-orbiting Partnership (SNPP) satellite. The SAPF processing system will be delivered to operations in the spring of 2015.

The Road to JPSS Integrated Processing

The Joint Polar Satellite System-1 (JPSS-1) is the second spacecraft within NOAA's next generation of polar-orbiting environmental satellites. The spacecraft, which is scheduled to launch in 2017, follows the SNPP satellite, which launched in 2011. It will provide continuity for accurate predictions of severe weather currently provided by the current NOAA POES along with SNPP. JPSS-1 will provide the global environmental data used in Numerical Weather Prediction (NWP) models for medium and long-term weather forecasts, including severe weather phenomena. Moreover, NOAA's NWS centers will utilize JPSS data for their operational and research products, and services. More importantly, JPSS-1 will provide valuable polar imagery and products in areas not well covered by NOAA geostationary satellites. A number of algorithms developed for the GOES-R ABI, many based on heritage algorithms developed for the Advanced Very High Resolution Radiometer (AVHRR) and Moderate Resolution Imaging Spectroradiometer (MODIS), are being modified within the SAPF to process VIIRS satellite data to create cloud, aerosol, and cryosphere products using enterprise algorithms. Enterprise algorithms are defined as algorithms, using the same software, applied to multiple sensors (e.g. AVHRR, VIIRS, MODIS, ABI) to generate consistent products for the user community with the additional benefit of reducing costs of maintaining and enhancing operational algorithms. The enhanced resolution and additional spectral

channels provided by the VIIRS and future ABI will offer new opportunities for remote sensing, providing more accurate measurements of clouds, aerosols and the cryosphere. These enterprise algorithms will use the same software, ancillary data, and forward model to process both sets of instrument data.

Below are examples of some common algorithms that have been modified to create VIIRS products.

Clouds

Among the atmospheric properties being monitored and examined from space, clouds are particularly important due to their influence on the Earth's atmosphere, weather and climate. Approximately 70% of the Earth's surface is covered by clouds at any one time. For any given atmospheric process, cloud effects are influenced by their type and the time of day. Cloud detection and characterization remains a challenging area of atmospheric research due in part to the large variability in cloud properties. And even though no single sensor is ideally suited for detecting and characterizing all types of clouds, most of these uncertainties can be reduced by satellites as they extract different parameters from clouds, to help determine properties such as height, type, optical thickness, cover, and so forth. In addition, satellites provide data at much higher spatial and temporal resolutions that is not available from other sources. Scientists also use this data to run various tests using complex retrieval algorithms to infer cloud from the amount of Visible and IR radiation measured. Even though satellites are the only source of global retrievals of various cloud properties, the large deviations in their spectral domains can cause dramatically different results in retrieved cloud properties. A multi-sensor approach would best provide consistent cloud products to the user community, even though it is more difficult to design and implement.

NOAA's satellite programs are adopting an integrated system processing approach in which consistent retrievals among the various sensors are used. As a result, a team of scientists from STAR are developing multi-sensor satellite-based products for their user community. In addition to making enhancements to cloud products that can be used on current satellite data and processing techniques to improve cloud identification and properties, they are developing products for the next generation of high spectral and spatial resolution satellite instruments.

Cloud Mask Algorithm

Cloud masking occurs very early in the SAPF processing chain and accomplishes the task of detecting the presence of cloud. The algorithm that filters cloud data out of satellite observations, or rather, the algorithm that indicates the presence or absence of clouds is referred to as a cloud mask. If clouds are found to be present, the algorithm then proceeds to measure their characteristics. In pixels that are determined to be sufficiently cloud-free, geophysical parameters of the atmosphere and Earth's surface are acquired from satellite imagery.

Example output of the Cloud Mask (right) with accompanying 11 micron satellite Image (left) TC Beryl, May 27, 2012

In the figure above (right), the enterprise cloud mask depicts the distribution of cloudiness in vicinity of Tropical Cyclone Beryl on May 27, 2012. The S-NPP data used here has been preprocessed to remove the bow-tie deletion gaps. The Cloud Mask classifies the pixels into one of 4 levels. Clear pixels are shown as blue over water and green over land. Probably-clear pixels are cyan. Cloud pixels are white and Probably-cloudy pixels are red. Over most of the globe, Probably-clear and Probably-cloud occur in the vicinity of cloud or surface-feature edges. In more challenging regions, such as the Arctic, the presence of Probably-clear and Probably-cloudy decisions is much higher as forecasters' confidence and skill in cloud detection is lower in these regions. In addition to these 4-levels, the Cloud Mask also makes a cloud-probability parameter that varies from 0 (confidently clear) to 1 (confidently cloudy). This cloud-probability parameter allows algorithms to optimize the mask for their specific application. In addition, the bits describing the performance of the individual tests are also made available for additional diagnostic information. Development on improving the cloud mask never ceases due its importance to other algorithms. For example, STAR scientists are experimenting with using other S-NPP sensors, such as CrIS, to improve the cloud detection skill in regions where the VIIRS-only approach struggles.

Cloud Phase/Type Inter-comparisons

Forecast and tracking of cloud position and altitude are of prime importance for aviation hazard mitigation. Since surface observations offer limited opportunities to determine cloud types, including the identification of multiple cloud layers, imaging from satellite instruments provide the best opportunities to derive various cloud properties. This is especially true for data sparse oceanic, polar, and high terrain regions remote location.

The Cloud Top Phase product being developed at STAR will enable meteorologists to better monitor and track changes in the properties of clouds, improve icing forecasts for the aviation community, assess freezing rain/drizzle potential, and aid in improving warnings for severe weather. Cloud Phase product information can also be used in advanced ABI applications such as severe weather prediction and

tropical cyclone intensity estimation. The cloud phase/type product is derived from the current generation of GOES and will be adapted with modifications and enhancements, for the GOES-R ABI and SNPP and JPSS-1 VIIRS. The product provides detailed information on the phase (liquid water, ice, and a mixture) of the highest cloud layer and is consistent with lidar derived cloud phase information.

The figures above show cloud phase/type results from several algorithms, including the GOES-R/NDE (enterprise) approach that is being adopted for VIIRS (bottom, right). The enterprise approach (bottom right) provides more detailed information on cloud phase and is more sensitive to tenuous cloud layers both day and night. Unlike the cloud phase algorithm currently being used for VIIRS, the enterprise approach provides results that are day/night independent.

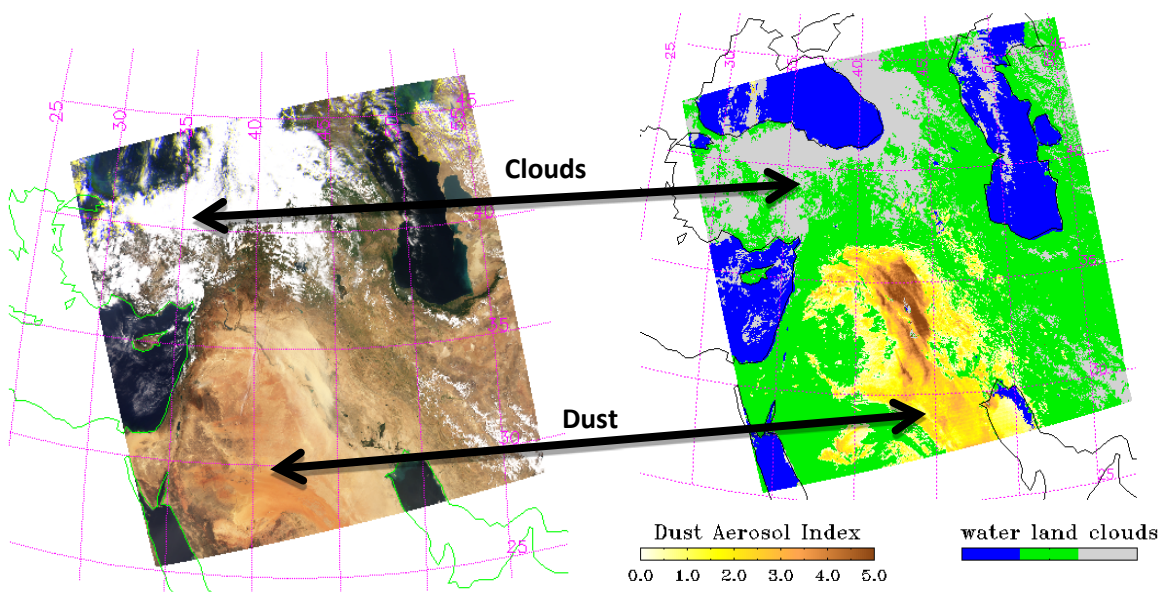
The Dust Aerosol Index

The Dust Aerosol Index (DAI) was created to help with the challenge of differentiating between aerosols and clouds. Aerosols are tiny particles that are suspended in the air. Examples include dust, pollen, smoke, sea spray, volcanic ash, and industrial pollutants. They are a detriment to human health and the environment. Aerosols also play an active role in the Earth's energy balance, hydrological cycle and atmospheric chemistry. Satellite remote sensing is one of the primary methods used to detect and observe aerosols, which are easily visible in satellite imagery when present in high concentrations.

Dust storms form when wind passes over a dust source containing loose particles such as dirt, clay, silt and debris, which are picked up and transported elsewhere. Dust storms can carry large quantities of dust that may contain chemicals, bacteria, fungi and a host of other debris that pollute the atmosphere and reduce air quality. They can spread over hundreds of miles and rise over several thousand feet. Dust storms also reduce visibility which can have adverse impacts on aircraft and road transportation. Remote sensing algorithms employ a variety of approaches such as spectral and spatial variability tests, to try and distinguish dust from other types of aerosols and clouds.

The DAI algorithm takes advantage of the spectral dependence of Rayleigh scattering, surface reflectance, and dust absorption to detect airborne dust. The DAI is particularly useful for evaluating dust forecasts, and monitoring and documenting dust outbreaks. The algorithm was developed for MODIS observations but is now being applied to the observations from VIIRS. This will continue the MODIS legacy and extend the dust detection to NOAA’s next generation satellite sensors.

The figure below shows a matchup between detection from MODIS DAI-based dust identification algorithm and CALIOP VFM product in one MODIS granule. The RGB image on the left shows a dust storm outbreak in the Saudi Arabia and Iraq desert. On the right is the DAI algorithm, which successfully captured this event.



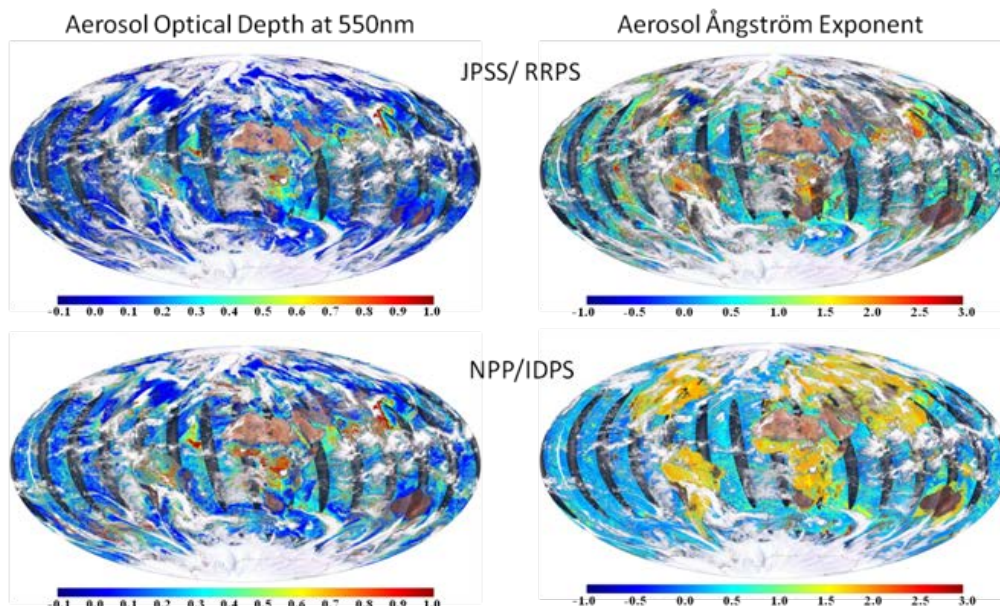
Comparison of dust detected with DAI-based algorithm with aerosol types in CALIPSO Vertical Feature Mask (VFM) on May 25, 2008 at 10:15 UTC. RGB image (left), DAI (right).

Aerosol Optical Depth

Aerosols deteriorate air quality and are detrimental to human health and the economy. High concentrations of aerosols, when inhaled can significantly affect respiratory health, and lead to upper respiratory diseases such as asthma. From a pollution monitoring perspective, it is important to investigate the key parameters that help provide an understanding of the spatial extent and regional transport of pollutants. Another important initiative is the use of a common algorithm to estimate the amount of atmospheric aerosol (liquid or solid particles suspended in air) from radiation measured at multiple wavelengths by instruments aboard satellites. The technique applied utilizes the fact that the intensity and color (wavelength) of the radiation are changed in the presence of aerosols relative to an atmosphere without aerosols. The degree of this change depends on the amount, size, shape and chemical composition of the aerosols. Because even a small volume of air usually contains particles of different sizes, shapes and chemical composition, and because multiple combinations of these properties can lead to very similar change in the intensity and color of the radiation “seen” by satellite instruments retrieval of aerosol is quite challenging. The retrieval is further complicated by the

interference of radiation originating from the surface that must be accounted for, and can overwhelm the aerosol “signal” over bright surfaces. Satellite retrievals often characterize the amount of aerosol in the atmosphere in terms of the Aerosol Optical Depth (AOD). AOD determines how much of the incident radiation is reflected and absorbed, and consequently how much energy reaches the Earth’s surface. AOD indicates areas of high particulate matter in the atmosphere associated with smoke plumes, haze, and blowing dust. The larger the AOD the larger the effect of aerosol is on radiation. AOD varies with wavelength. Typical AOD values at 550 nm are between 0.1-0.2, but in thick smoke or dust plumes they can be as high as 3-5. At shorter wavelengths the AOD is larger for most aerosols, and it is smaller at longer wavelengths. This feature is related to the size of aerosol particles, and is used to calculate a parameter, the Ångström exponent, that broadly characterizes particle size. Large values (2-3) of this parameter indicate small size, while small values (<2) represent large particles.

The common enterprise algorithm developed for AOD retrieval adopts techniques developed for MODIS, VIIRS and ABI. It retrieves AODs for a finite set of aerosol models that prescribe the size, shape and composition of aerosol, and selects the pair of AOD and aerosol model that results in radiation best matching the magnitude and color of observed radiation. The retrieval uses only daytime observations, and is not performed in the presence of clouds, or when the underlying surface is bright (desert, snow, sunglint).



Example of Aerosol Optical Depth retrieval using VIIRS input from 09/17/2013. The retrievals are overlaid on the VIIRS RGB image for the same day to show the absence of retrievals due to cloud, sunglint and bright surface.

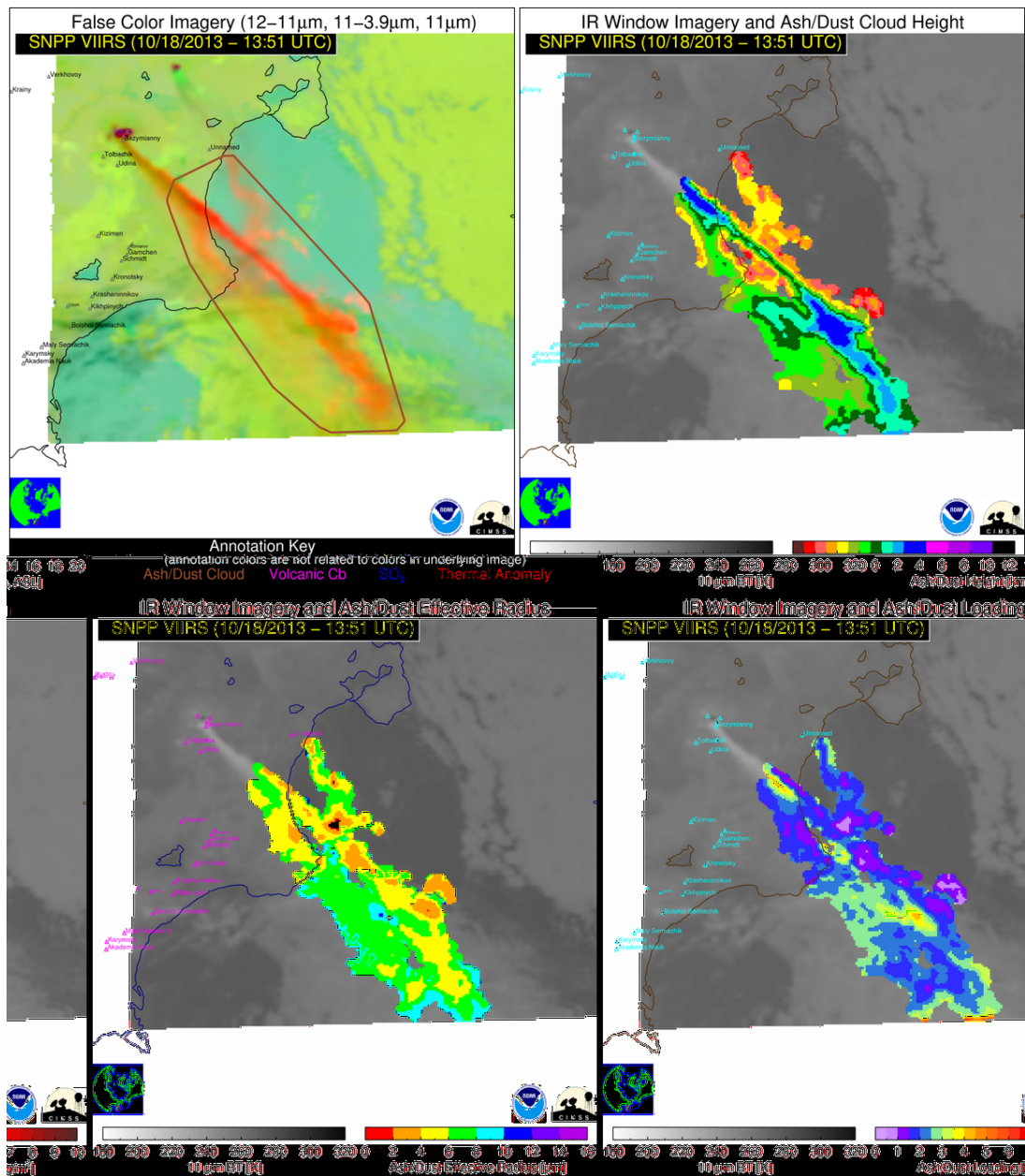
The figures show retrievals of the aerosol optical depth on the left and the Ångström exponent on the right. A VIIRS RGB image (constructed from radiation measured at red, green and blue wavelengths) is used as a background to show the absence of retrievals due to cloud, sunglint and bright surface. The retrievals in top panel are from the enterprise aerosol algorithm by applying it to VIIRS measurements (identified as JPSS/RRPS in the figure). AOD is generally higher over land than over ocean, and show

elevated values (in red) associated with significant pollution (dust, smoke). The bottom panel shows the corresponding retrievals from the VIIRS IDPS retrievals (identified as NPP/IDPS in the figure). In spite of some regional differences, by and large, the two AOD retrievals are very similar; that is the enterprise algorithm adopted for VIIRS is capable of retrievals similar in quality to those obtained from the current NPP/IDPS algorithm. The Ångström exponent fields in the two retrievals are quite different. Part of this difference comes from the difference in the technique used over land. In addition, the JPSS/RRPS (enterprise) algorithm filters out more bad values that are left in by the NPP/IDPS algorithm. However, neither of the algorithms have enough skills to make reliable retrievals over land. The over-ocean Ångström exponent used AODs at different pairs of wavelengths and thus cannot be directly compared.

Volcanic Ash Algorithm

Researchers at STAR have built a sophisticated set of computer algorithms that automatically detect volcanic eruptions and analyze atmospheric ash clouds. Airborne volcanic aerosols are major threats to transportation, health and infrastructure. Volcanic eruptions can eject ash into the atmosphere to great heights, and potentially threaten the safety of any flight in their path. When volcanic ash is ingested into jet engines it can cause severe damage, and even cause them to stall. In addition, volcanic ash particulates pose significant health and infrastructure threats to the local communities in the areas where they occur. But more than that, the effects from volcanoes erupting in remote and sparsely populated places can be felt in areas hundreds or thousands of miles away. The ash clouds produced from these volcanoes are able to transport great distances from their source, which can create a serious hazard thousands of miles from an eruption.

The Volcanic Ash algorithms are currently built for GOES-R, but are also being adapted for JPSS. They extract data on ash clouds from the satellite to produce vital information such as cloud height, mass loading and particle size. This information is important for dispersion forecasting and aviation safety. The figure below illustrates the information that is retrieved by the GOES-R/NDE (enterprise) approach. The results have been shown to be consistent with lidar measurements.



The ash cloud height (top, right), effective particle radius (bottom, left), and mass loading (bottom, right), determined using the GOES-R/NDE algorithm, are shown for an ash cloud produced by eruptions of Klyuchevskoy and Shiveluch (Russia) on October 18, 2013 as imaged by VIIRS. For reference, a false color image is also shown in the top, left panel.

Summary

As NOAA's satellite programs transition from heritage satellite systems to next generation satellite systems, there is a high value in adopting an integrated processing approach which takes advantage of the multiple sensors that are available on NOAA's geostationary and polar-orbiting satellites. Integrated processing ensures that the same algorithms process similar data streams from different sensors, and therefore reusable software is employed across platforms. Integration also simplifies the complexity of building products using multiple instruments on one platform, which allows for data between multiple

satellites and sensors in different orbits to be evaluated and calibrated. This utilization of cross-calibrated, collocated data sets leads to the development of enhanced products. STAR has been developing common algorithms for several years. These uniform multi-sensor algorithms allow for improved integration of products from NOAA's geostationary and polar-orbiting satellites.

The application of uniform retrievals is beneficial as it provides consistency in retrieved products across different satellite and field measurement campaigns, thus allowing the direct comparison of products for the numerous weather applications. Various NOAA researchers, including those whose work has been highlighted in this article, are adapting their algorithms and software so that they can be applied to a large variety of LEO and GEO instruments, ultimately laying the ground work for fully integrated multi-sensor processing systems.

In addition, the algorithm work supported by the JPSS PGRR Program exploits the strength of LEO and GEO sensors through the development of multi-satellite and multi-sensor algorithms to generate uniform data and products for users of NOAA's satellite data, including the National Weather Service (NWS), National Ocean Service (NOS), NASA, NRL, NMFS, and so forth.

JPSS USER PERSPECTIVE
What the users are telling us about JPSS

Section 5

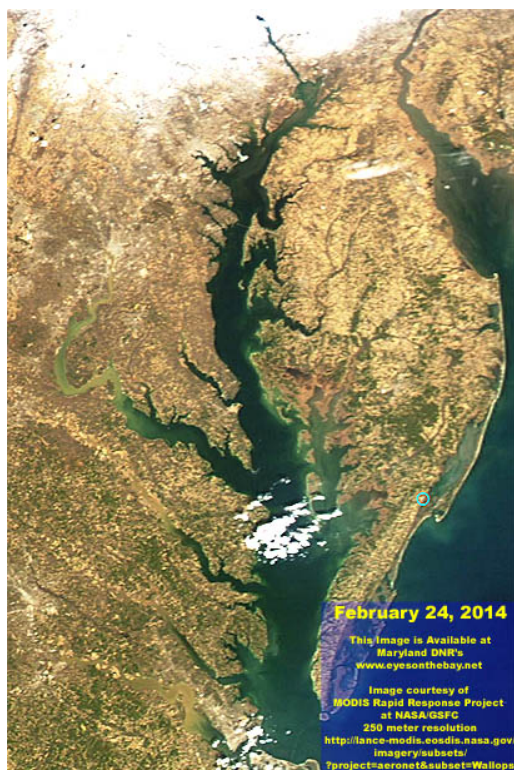
**Development of Algorithms for Retrieval of Chlorophyll-A in
the Chesapeake Bay and other Coastal Waters Based on JPSS-
VIIRS Bands**

*This article is based in part on the **March 21, 2014 JPSS science seminar** given by Dr Alex Gilerson, City College of the City University of New York (CCNY).*

Contributing editors: Alex Gilerson, Mitch Goldberg, Julie Price, William Sjoberg, and Kathryn Shontz

Coastal waters are some of the most valuable natural resources on Earth. They provide environmental services that range from food, habitats, and coastal protection, to transportation and recreation. In addition, they generate billions of dollars in revenues from activities such as tourism and fishing. Coastal ecosystems are also home to some of the most diverse and valuable natural resources including, coral reefs, mangroves, and estuaries, which serve as habitats for marine animals and sanctuaries for endangered species. Poor water quality in coastal areas can have many negative ecological, social, and economic effects on the health of marine systems, including the plant, animal, and marine life that depend on these waters. For example, phytoplankton, which are microscopic organisms or algae that live in the ocean's surface waters, form the base of the marine food web. However, they can sometimes grow explosively, creating what is referred to as a "bloom", and produce harmful impacts on marine ecosystems. Case in point, when masses of algae die and decompose, they can deplete oxygen in the water, leading to a condition known as hypoxia, which occurs when oxygen concentrations fall below the level necessary to sustain most animal life. Furthermore, even a small percentage of algae produce powerful toxins that can kill fish, shellfish, marine mammals and birds, and may directly or indirectly cause serious and potentially life-threatening symptoms in humans.

Therefore, it is important to take measurements of the indicators that provide the overall picture of coastal water quality, and to keep our coastal waters healthy by maintaining good quality.



Chlorophyll is the pigment that enables plants to use sunlight to convert simple molecules into organic compounds via photosynthesis. Chlorophyll-a concentration [Chl] is one of the key parameters derived from the Ocean Color (OC) satellite imagery. Concentrations of [Chl] are measured to determine ocean productivity, water quality, bio-optical and ecosystems modeling, optimization of fishing conditions, and detection of algal blooms, amongst other applications. [Chl] is usually estimated from the ratio of reflectances in the blue-green bands, using commonly named blue-green ratio algorithms. However, these algorithms are currently formulated for open ocean areas. Due to the complexity of the coastal waters and surrounding atmospheric parameters, estimations of the water contents in the coastal areas are quite difficult to obtain with a high accuracy. Even though satellite observations provide a broader picture for the distribution of parameters retrievable through these OC algorithms, they have to be verified with in-situ data.

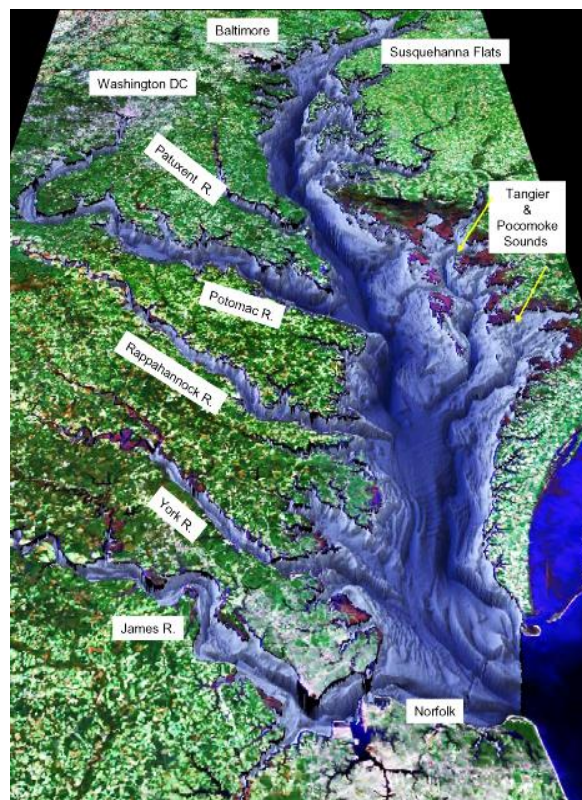
Dr Alex Gilerson and his team from the City College of the City University of New York (CCNY) are developing specialized algorithms to retrieve [Chl] in the Chesapeake Bay and other coastal waters. Their work is based on the bands available on the Visible Infrared Imager Radiometer Suite (VIIRS) sensor, onboard the Suomi National Polar-orbiting Partnership (SNPP) satellite. This article will discuss

current enhancements that Dr Gilerson and his team have made to these robust VIIRS based Neural Network (NN) algorithms that use synthetic datasets that were generated through bio-optical modeling and Hydrolight radiative transfer simulations. The NNs were utilized to relate the water leaving radiances to [Chl] with these algorithms and tested on the NASA bio-Optical Marine Algorithm Data (NOMAD) set and also on field data from the 2013 Chesapeake Bay summer field campaign. Also included in the article are atmospheric correction issues drawing from multi-year in situ observations of satellite performance at the Long Island Sound Coastal Observatory (LISCO) – a unique heavy coastal site that provides continuous multi and hyperspectral data from collocated instrumentation in coastal water area and the WaveCIS site, which is closer to the open ocean.

Chesapeake Bay Study Motivation

The Chesapeake Bay is the largest estuary in the US with an approximate surface area of 4480 square miles and average water depth of 21 feet (Chesapeake Bay Program, <http://www.chesapeakebay.net/discover/bay101/facts>). Estuaries are partially enclosed bodies of water where saltwater from the ocean mixes with freshwater from rivers, and streams. They are one of the most productive ecosystems on earth. The Chesapeake Bay is home to numerous animals and plants, and provides almost 80 to 90 percent of America's recreational fish catch and more than 75 percent of the commercial fish catch. In addition, its estuaries support several marine industries such as recreational fishing, commercial fishing, and tourism, which contribute billions of dollars to regional economies.

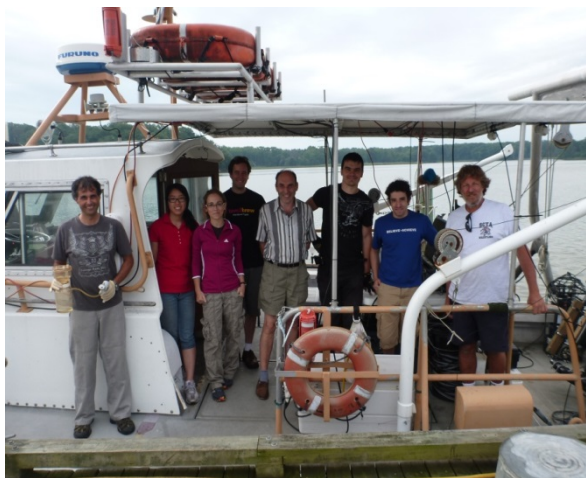
Multiple water parameters are monitored by the Chesapeake Bay Program including [Chl], a key measurement that demonstrates attributes such as ocean productivity and water quality. Retrieval of chlorophyll concentration is performed using algorithms which are based on the correlation between chlorophyll concentration and the ratio of the remote sensing reflectance (Rrs) measured by the satellite sensor at two or more wavelengths (also referred to as bands). Standard blue-green ratio algorithms provide reasonable accuracy for the open ocean waters, typically ± 50 percent. However, this accuracy decreases significantly in the coastal waters because of mineral scattering and contamination of the blue and green reflectance signals from colored dissolved organic matter (CDOM) absorption. CDOM is a component of water that naturally occurs due to decaying organic matter, such as leaves, within a water body. It contains chromophores that absorb UV and visible light. Special algorithms therefore need to be developed for the retrieval of [Chl] in coastal waters. As the Chesapeake Bay is a key natural, socio-



NOAA image of the Chesapeake Bay

economic and recreational resource, detection and monitoring of [Chl] levels are necessary as they help determine the bay's productivity and water quality. In addition, they help track and predict nuisance algal blooms. Monitoring [Chl] levels is also useful in management applications, which include making decisions on optimal fishing conditions in the region.

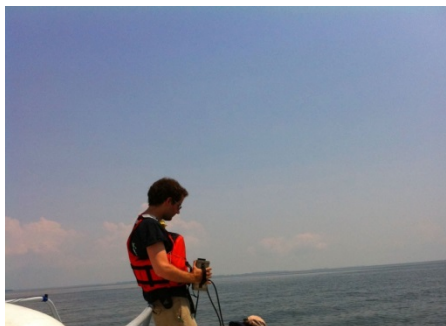
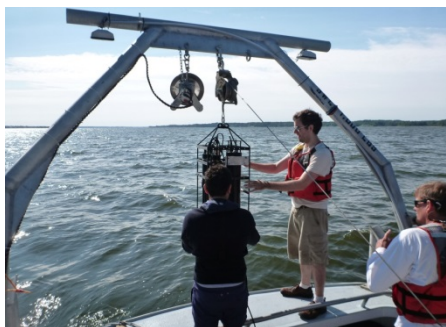
Chesapeake Bay Study Details and Results



Group picture of the Chesapeake Bay campaign research cruise team

To address the challenge of retrieving [Chl] in coastal waters, a science team from CCNY, NOAA, University of Maryland, and Columbia University conducted a research cruise in the Chesapeake Bay where they collected numerous data that would help them better understand coastal ocean biogeochemical processes, and evaluate satellite retrievals of ocean color in this complex and diverse estuarine environment. They used the data for algorithm development and validation. In addition, the field data was validated against satellite data, used for intercomparisons of measurement techniques, and also used in the development and testing of new instrumentation.

The research cruise team took measurements of optical properties of in-water constituents including absorption, scattering and backscattering, in-water light polarization, water physicochemical properties, concentrations of coastal water biogeochemical variables, total suspended sediments, and atmospheric aerosol optical thickness. These field data collected at 43 stations together with NOMAD data and data on [Chl] from the Chesapeake Bay program matched with data from the NASA's Moderate Resolution



Top left – Deployment of IOP package, top right – deployment of HyperPro, bottom left – deployment of the GER spectroradiometer for water reflectance measurements above and below the water surface, and bottom right – filtering water samples for Chl, TSS and mineral concentrations, and CDOM absorption.

Imaging Spectroradiometer (MODIS) aboard the Aqua satellite were used to evaluate the performance of available and newly developed algorithms. For the field data the team found that the algorithm

previously developed by the group which uses the red and NIR bands (665 and 708 nm) for the estimation of chlorophyll-a concentration [Chl] gave very consistent results but 708nm band does not exist on the VIIRS sensor, so this algorithm is not directly applicable to the satellite data.

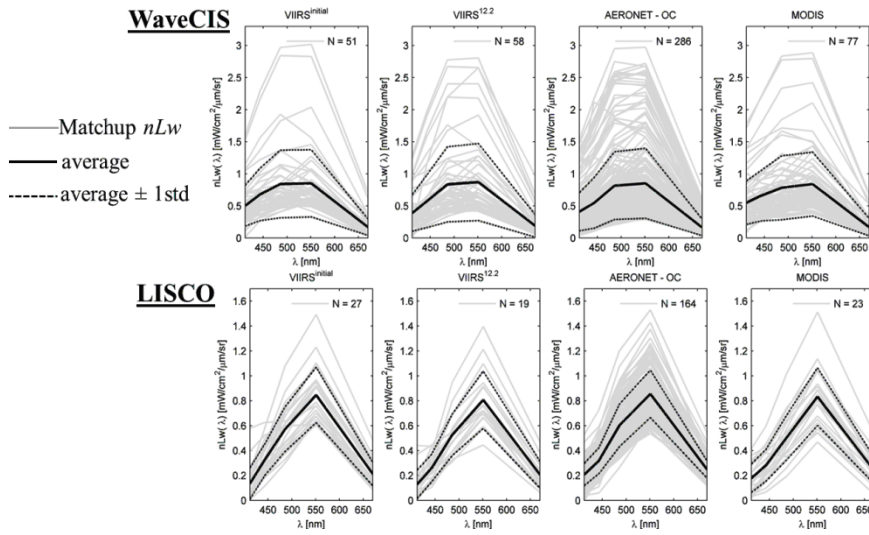
Atmospheric Correction

Retrieval algorithms are usually inaccurate in coastal waters due to an imperfect atmospheric correction procedure, which generally eliminates the contribution of the light scattered by atmospheric molecules and aerosols as well as light reflected from the ocean surface to the total signal measured by the sensor. Tuned for the best performance in the open ocean with relatively clear atmospheres by so called “vicarious gain adjustment” for the sensor, the atmospheric correction performs worse in the coastal areas due to their more complex atmospheric composition. To address atmospheric correction issues, Dr Gilerson and his team analyzed multi-year observations of satellite performance at two coastal Aerosol Robotic Network–Ocean Color (AERONET-OC) sites in Long Island Sound (LISCO) with atmosphere similar to the Chesapeake Bay and WaveCIS in the Gulf of Mexico with clearer atmosphere.



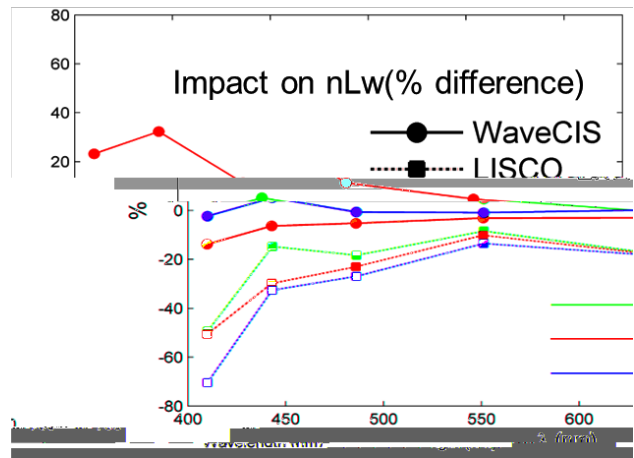
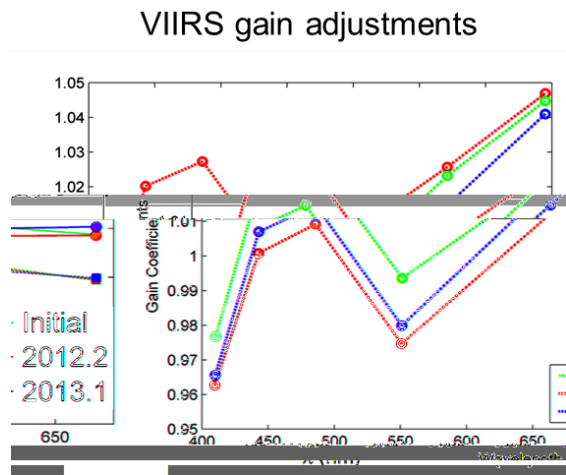
The AERONET-OC consists of worldwide distributed autonomous sun-photometers that are used to measure atmospheric aerosol properties. It was established to support marine applications. Measurement sequences from the AERONET-OC sites are executed every 30 minutes. The LISCO site is particularly unique because it combines multi-spectral (SeaPRISM) and hyperspectral (HyperSAS) radiometer measurements, for comparisons with satellite and in situ measurements and radiative transfer simulations for coastal waters. The instrument configuration at this particular site makes it possible to accurately assess the bi-directionality correction of the water leaving radiances.

nLw spectral consistency analysis



Variation ranges of match-up spectra, and their averages & standard deviations for both the LISCO and WaveCIS sites. This indicates qualitative agreement between the satellites and in-situ nLw data.

As shown in the figure on the left, both sites exhibited a strong consistency between the data from VIIRS and MODIS sensors and in-situ normalized water leaving radiance nLw data for both sites, however, the impacts of the vicarious gain change for the sensor was not the same for the two locations. For the LISCO site and similarly for the Chesapeake Bay nLw retrieved at 412nm is often very inaccurate and cannot be used in the reliable algorithms, which leaves the bands of VIIRS at 443, 486, 551 and 671 nm for application in coastal waters.



Neural Network algorithms

Neural Networks consist of many interconnected parts or “neurons” that work together, using a set of known inputs and outputs, to model a desired function. They learn by example, and they are configured for a specific purpose. Neural networks are effective methods of replacing traditional chlorophyll retrieval algorithms that are based on blue-green reflectance ratios and are generally inefficient in coastal waters due to spectral interferences from organic and inorganic components in the water, which don’t necessarily correlate with chlorophyll in the coastal waters. The neural network can be designed and optimized to basically derive together all optical parameters, therefore deriving better estimates. Based on the team’s previous experience with OC NN models, they developed new NN algorithms which they tested on field data from the 2013 Chesapeake Bay field campaign, NOMAD, and matchups of

MODIS satellite with in-situ [Chl] from the Chesapeake Bay Program (USF data – provided by the University of South Florida group, Drs C. Le and C.Hu). NN algorithms were trained on the datasets which included VIIRS bands in the visible without 412nm. The team also evaluated retrievals of [Chl] using more conservative methods like a blue-green ratio (OC3) and the more recently proposed algorithm which utilizes bands in the red and green part of the spectrum and seems to be more robust in coastal waters than OC3.

R ²	CCNY field (N=43)	NOMAD (N=247)	USF data (N=889)
OC ₃ V	0.64	0.1	0.079
671/486	0.73	0.37	0.29
671/551	0.51	0.20	0.22
Multi-band	0.88	-	0.31
NN VIIRS	0.71	0.22	0.34

Comparison of several inversion techniques on different datasets

Summary

Satellite ocean color imagery derived from [Chl] provides key information that is used to assess ocean productivity, water quality, bio-optical and ecosystems modeling, optimization of fishing conditions, and detection of algal blooms, amongst other applications. However, ocean color satellite validation is particularly challenging in coastal waters due to their complexity and also the complexity of their atmospheric conditions. More specifically, the standard blue-green band ratio algorithms used for satellite retrievals of chlorophyll concentrations in the open ocean are extremely inaccurate in coastal waters because of the complexity of these waters and difficulties with satellite atmospheric correction. This is especially true for the Chesapeake Bay, one of the main US estuaries, with very high spatial and temporal variability of the in-water parameters and complex atmospheric composition. Thus, for coastal waters, special algorithms for the retrieval of [Chl] and other water parameters need to be used, and the satellite data used in these waters must be validated with in situ measurements.

Data obtained from the LISCO site have become a key element of the AERONET-OC network, and are used continuously in coastal area applications including water monitoring and algorithm development, and calibration/validation of sensors on current and future ocean color remote sensing satellites. The team’s assessments of the vicarious and atmospheric correction procedures done at the two coastal AERONET-OC sites revealed that the impacts of the vicarious calibration procedure on the OC data retrievals were not the same given that each had different atmospheric and water properties. Further studies at the two sites, and also at the Chesapeake Bay showed that the impact of the atmospheric correction can be critical on retrieval accuracy and needs to be properly addressed. In these studies the team evaluated the accuracy of retrievals of water parameters such as chlorophyll concentration and CDOM absorption from satellite remote sensing reflectances using satellite data from VIIRS and MODIS, and field data. Dr. Gilerson and his team refined their neural network algorithms to get to one that works best in coastal areas, however, the atmospheric correction issues they encountered signifies that more experiments and more studies remain to be done. Nonetheless, the findings from this study are still very valuable to various user groups, including NOAA NMFS fisheries modelers currently spinning up

the Chesapeake Atlantis Model, and coastal managers, such as the Maryland Department of Natural Resources. These user groups can utilize the data obtained through ocean color radiometry (OCR) to measure parameters such as phytoplankton biomass and sediment, which are useful in estimating the constituents of Ocean and coastal waters. These measurements also make it possible to quantify the atmosphere-ocean interaction, and monitor sediments, pollutants fluxes and ecosystem monitoring.

JPSS USER PERSPECTIVE
What the users are telling us about JPSS

Section 6

**VIIRS Active Fire Data for Fire Weather Applications: JPSS
and GOES-R Activities Supporting 2013 Fire Incidents**

Joint JPSS/GOES-R Science Seminar

This article is based in part on the April 21, 2014 joint JPSS-GOES-R Science Seminar given by Dr Ivan Csiszar, NOAA NESDIS Center for Satellite Applications and Research, Evan Ellicott, University of Maryland, Department of Geographical Sciences, and Christopher Schmidt, University of Wisconsin – Madison.

Contributing editors: Ivan Csiszar, Evan Ellicott, Christopher Schmidt, Mitch Goldberg, Julie Price, William Sjoberg, and Kathryn Shontz

Each year millions of forest and grassland acreage are destroyed by wildfire resulting in loss of life, property and ecosystems.



Damages from wildfires, such as the one depicted in the image above, are not only environmental but economic as well.
Photo: NOAA

While fire is an integral component of many ecosystems, previous management (i.e. suppression) strategies have left these ecosystems in degraded health and vulnerable to potentially destructive fire events that create a myriad of adverse environmental, social, and economic impacts. Such impacts include water quality degradation, damage to or destruction of property, compromised public health, and disruption to transportation and tourism. Climate is another factor, not completely understood, but likely influencing increases in fire frequency. Knowledge of both short and long-term impacts of fires is essential for effective risk assessment, policy formulation, disaster and resource management, and other purposes.

This article describes the activities of the Joint Polar Satellite System (JPSS) and the Geostationary Operational Environmental Satellites-R (GOES-R) Active Fire (AF) Proving Ground and Risk Reduction (PGRR) projects to help their user community prepare for the applications of the active fire products that will be available on NOAA's new-generation JPSS and GOES-R satellites. In particular, the article presents highlights from outreach efforts and interactions between team members from the Visible Infrared Imaging Radiometer Suite (VIIRS) AF PGRR and the wildland fire incident community, including Fire Behavior Analysts (FBANs) and Incident Meteorologists (IMETs), in relation to new and upcoming fire detection capabilities. IMETs provide weather monitoring and forecast support during major wildfires, while FBANs provide critical information about what they expect the fire to do over the coming hours to days based on fuels, terrain, and weather. The importance of the interaction between the VIIRS AF team and IMETs and FBANs was validated during site visits to the West Fork Complex fire in Colorado and Rim fire in California during the 2013 fire season. These site visits provided an opportunity for the team to experience firsthand the pressures and hurdles faced when out in the field responding

to an incident. Furthermore, the team's interaction with IMETs, FBANs, and other wildland fire cadre end-users provided insight to data needs as well as gaps in data knowledge and use.

Satellite Derived Active Fire Data for Fire Management and Fire Weather Applications

The National Oceanic and Atmospheric Administration's (NOAA) polar-orbiting and geostationary satellites collect and provide consistent long-term observations that are critical to weather forecasting, and atmospheric and oceanic research. These observations are used to measure key indicators of the Earth and its environment. In addition, they support a large number of applications, including the near-real time detection and monitoring of wildfires, fire management and control in protected areas, biomass burning emissions modeling, and air quality forecasting, modeling, and monitoring. Over the years, emerging needs such as the early detection and constant monitoring of wildfires have triggered the demands for satellite-derived fire information.

In response to these needs, satellite-derived active fire data from NOAA have become one of the primary inputs in applications that support the prediction, detection, monitoring, and assessment of wildfires. Active fire data from heritage sensors including the Advanced Very High Resolution Radiometer (AVHRR) onboard the NOAA family of Polar-orbiting Operational Environmental Satellites (POES) and the current imagers on GOES have been used to monitor fire activity worldwide. On the polar-orbiting platforms, these fire observation capabilities were extended to the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Earth Observing System (EOS) Terra and Aqua satellites. MODIS was the first sensor designed to detect and characterize actively burning fires, also known as hot targets, on a global and systematic basis. Building on the success of MODIS, observations from VIIRS, onboard the Suomi National Polar-orbiting Partnership (S-NPP) satellite, were made available for the first time during the 2012 fire season. When S-NPP products are combined with the expected active fire capabilities on the new GOES-R satellite, the nation can expect new products with higher accuracy and more frequent measurements for fire and smoke monitoring and other hazards.

Approaching a New Era in Fire Detection and Characterization with NOAA's Next-Generation Polar-orbiting and Geostationary satellites

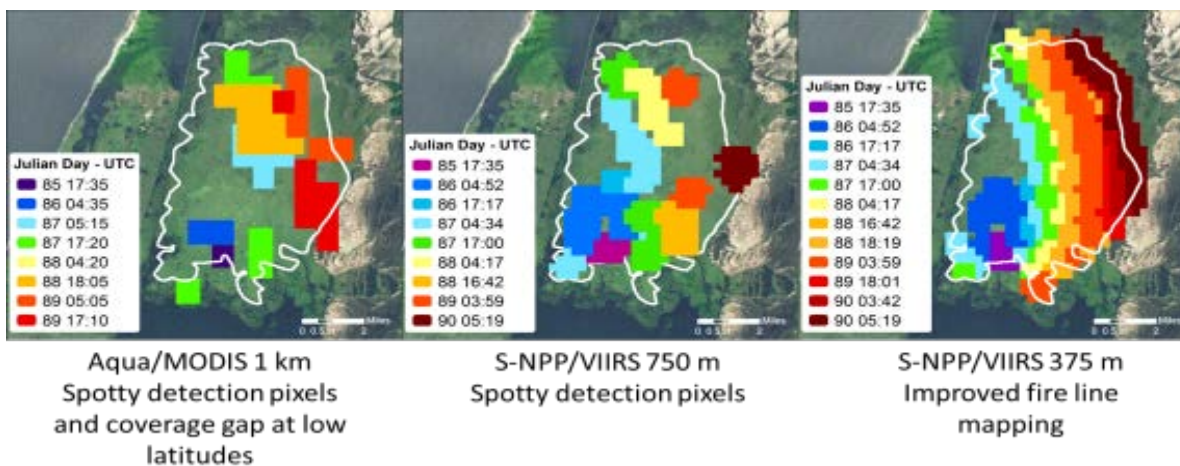
The timely detection of active fires from ground-based or airborne platforms can be quite challenging, especially when there are multiple fires over large areas. In these situations, satellite-based systems are the most practical and feasible means for accurate and consistent large-scale fire monitoring. With sensors that are extremely sensitive to the radiative signal, satellites are able to spot the areas where a fire is occurring and differentiate them from the non-burning background. In addition to detecting and providing the location of fires, the VIIRS sensor and the Advanced Baseline Imager (ABI) on GOES-R have the capability to indicate fire intensity through a variable called Fire Radiative Power (FRP). This information can help identify the most intense regions of the fire, which might not be evident from other ground-based or airborne observations. The standard VIIRS Active Fire (AF) product generated by the S-NPP Interface Data Processing Segment (IDPS), processes radiometric measurements from the VIIRS 750m moderate resolution bands using a heritage algorithm from MODIS. The GOES-R ABI Fire Detection and Characterization Algorithm (FDCA) is the GOES-R implementation of the Wildfire

Automated Biomass Burning Algorithm (WFABBA) used with GOES-8/15 and other geostationary satellites.

NOAA is poised to replace its current suite of Polar-orbiting satellites with the JPSS series. JPSS consists of three satellites: the on-orbit S-NPP, and the future JPSS-1 and JPSS-2 missions. The GOES-R series, with its first launch expected in early 2016, is set to replace the current GOES. The new sensor capabilities from NOAA's next generation polar-orbiting and geostationary satellites including better spatial, spectral, and temporal resolutions will provide significant improvements over the heritage sensors. More importantly, they will provide continuity of a key legacy of Earth observations, particularly to the real-time resource and disaster management community for situational awareness such as fire location, smoke plume spread, and air quality monitoring. Furthermore, they will enable early detection and characterization of fires, and provide critical decision support tools that will give fire managers a leg up in responding to fire events. The JPSS and GOES-R proving grounds therefore offer the best opportunities to prepare the active fires user community to use the new fire products from JPSS and future GOES-R missions.

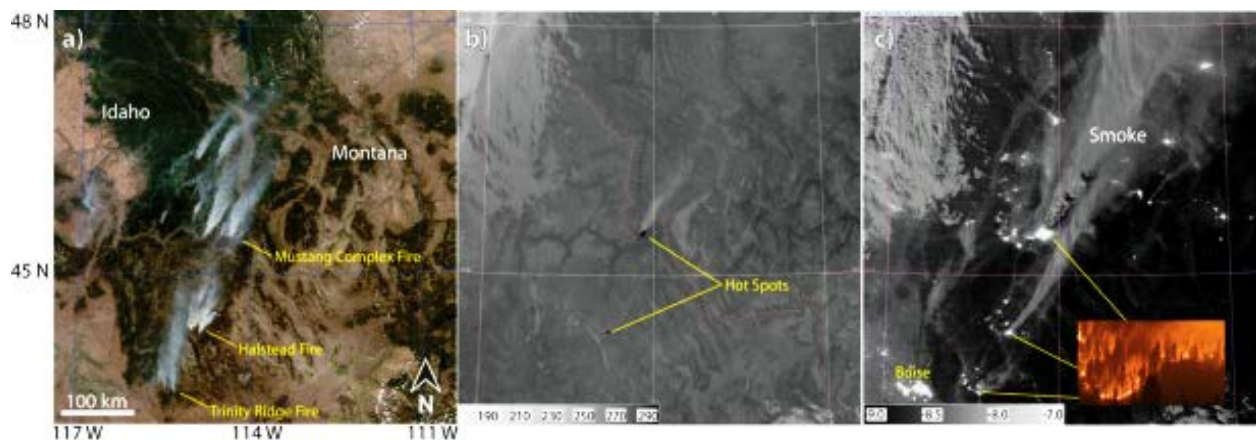
Active Fire Monitoring Capabilities from Polar Platforms

VIIRS AF incorporates technological advances from previous sensors, such as the AVHRR on the current suite of NOAA's polar-orbiting satellites. It also represents a continuation of high quality fire monitoring capabilities that started with MODIS on the NASA EOS Terra and Aqua satellites. With the 750m resolution moderate resolution "M" bands, including a band specifically designed for fire detection, and the even higher resolution of 375m from the imager "I" bands, and using more channels as inputs, the VIIRS AF is a significant improvement over the AVHRR fire product. Its design allows for radiometric measurements to detect and characterize active fires over a wide range of observing and environmental conditions. The image on the right (below) is generated with the spatially refined experimental I-band product, which offers much higher resolution fire detection than the standard M-band product (375m vs. 750m). The 750m AF product is available on the Interface Data Processing Segment (IDPS), which consists of high-speed, multi-processing computers that rapidly convert large streams of sensor data from JPSS to produce Environmental Data Records (EDRs).



Grass fire in Southern Brazil, 26-31 March 2013
Image credit: Wilfrid Schroeder (UMD)

VIIRS also features the Day/Night Band (DNB), a fully calibrated low-light visible-band sensor that builds upon the heritage of the Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS). With its spatial and radiometric resolutions, and quantitative applications, the DNB has overcome many of the challenges faced in nighttime environmental sensing. It leverages reflected moonlight, light emitted from cities, fires, gas flares, and other sources never before considered, to sense clouds, fog, and surface features such as snow cover. In addition, the DNB's sensitivity to very low levels of visible light at night allows it to produce a form of visible imagery often providing excellent continuity to track fires from daytime visible and infrared imagery. For example, the image below of the Mustang Complex Fire in Idaho, 2012, shows (a) daytime true color imagery of numerous fire locations across the state. Imagery from the thermal infrared (M15) and DNB, of the fires as they burned through the same location at night, are shown in (b) and (c), respectively. Even though thermal infrared imagery reveals some portions of the largest plumes, the DNB brings out a lot more detail. As shown in the DNB image (c) below, the bright white glow reveals the most intense parts of the actively burning fire, while smoke appears pale gray.

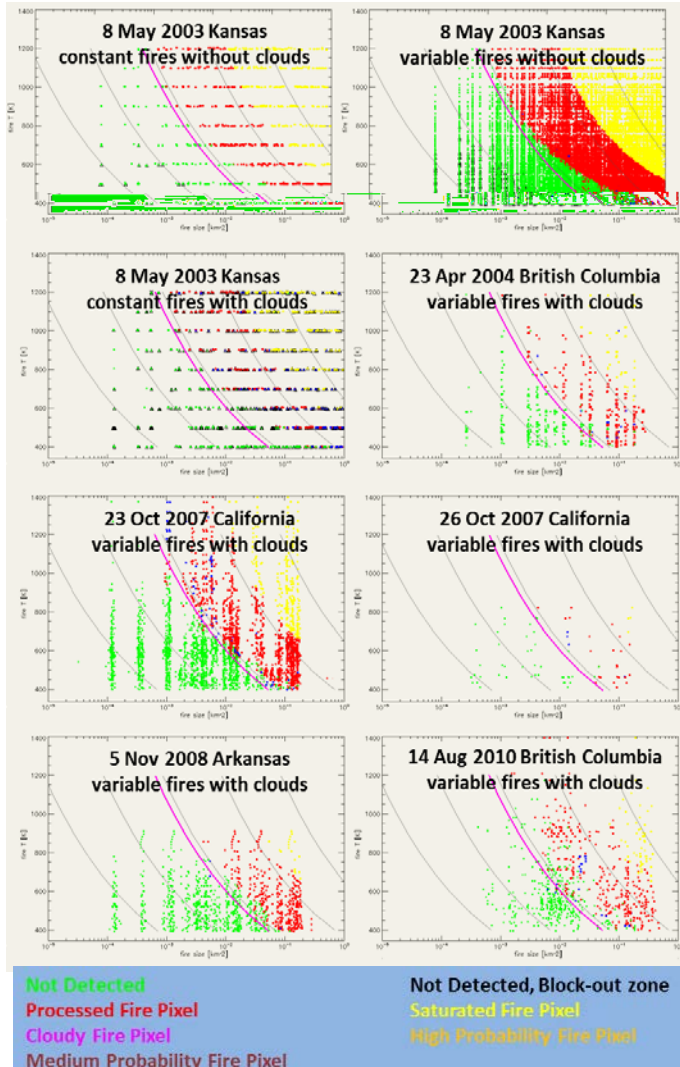


(a) Daytime VIIRS true color imagery showing a large outbreak of fires across Idaho on 28 August 2012, 2016 UTC. (b) Nighttime VIIRS M15 thermal infrared imagery (K) from the following evening (29 August 2012, 0832 UTC) depicts significant hot-spots from a subset of the fires, but with little discernible smoke plume information. (c) Corresponding VIIRS DNB radiance imagery ($\log_{10}[W\text{-cm}^{-2}\text{-sr}^{-1}]$) reveals the smoke plumes via lunar reflectance, as well as bright light emission from the flames (Inset photograph of Trinity Ridge fire courtesy of Kari Greer).

Image and caption obtained from: Miller SD, Straka W, III, Mills SP, Elvidge CD, Lee TF, Solbrig J, Walther A, Heidinger AK, Weiss SC. Illuminating the Capabilities of the Suomi National Polar-Orbiting Partnership (NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night Band. *Remote Sensing*. 2013; 5(12):6717-6766.

Active Fire Monitoring Capabilities from Geostationary Platforms

NOAA's geostationary satellites monitor the Western hemisphere continuously. This makes it possible for them to detect short duration fires, and also gives them a much greater advantage over polar orbiting satellites to closely survey fire development and progression, albeit at a coarser spatial resolution. Improved quality detections are expected from the GOES-R ABI FDCA. ABI provides sixteen spectral channels, 500 m resolution for the visible bands and 2 km for the infrared bands, compared to five channels on the current GOES 8/15 series Imager, which provides 1 km resolution for the visible bands and 2 km for the infrared. ABI will scan at a faster rate than the current GOES. These advances



The FDCA is quite successful detecting fires with FRP > 75 MW (purple curved line, gray curved lines are on a log scale of MW). Fire cluster detection rates >95%. For individual pixels the detection rates are >80%.

Engaging the User Community

For the VIIRS AF and GOES-R ABI FDCA teams, user engagement is a key component of product evaluation and development. It is also one of the ways in which the teams can gauge their user community's readiness for their products. To help the AF user communities achieve user readiness, the team members engage them in various training, outreach and education activities, including meetings and workshops; they also establish user-focused teleconferences, product training sessions, and on-site visits. Through these activities, the teams provide information about the sensors and products and help ensure end users understand the new capabilities being demonstrated. Finally, these activities enable the PGRR team members to gain insight into the user community's wants and needs.

will allow for faster detection and characterization of fires. The ABI FDCA is a dynamic, multi-spectral algorithm that uses the visible (when available) and the 3.9 and 11.2 μm bands to locate fires and characterize sub-pixel fire characteristics. The 12 μm band is used along with the other bands to help identify opaque clouds. It is built upon the current operational WFABBA. The ABI FDCA provides continuity in fire detection while utilizing the new capabilities offered by the ABI compared with current GOES. ABI will perform better than any previous geostationary sensor for fire detection and characterization.

The charts shown on the left depicts the GOES-R FDCA fire detection and classification as a function of the model-simulated ABI fire size and fire temperature. Fire detection case studies of simulated ABI data were developed at the Cooperative Institute for Research in the Atmosphere (CIRA).



VIIRS data visualization and dissemination portal

which provides a rolling archive of all VIIRS fire observations across the globe. The website provides background information on the AF product, which includes a searchable archive of data. It provides access to data covering the continental US (CONUS), which has now been extended globally. The site also serves as a product evaluation portal for evaluating enhanced and experimental products while allowing the AF team to gather user-feedback which helps with VIIRS active fire algorithm improvement and evaluation.

The VIIRS AF teams engage user communities through interagency and international coordination. For example they have established several key partnerships with end-users such as the U.S. Forest Service (USFS), National Weather Service (NWS), and National Interagency Fire Center (NIFC) to improve data services and user outreach. They also participate in international outreach activities through the Global Observation of Forest and Land Cover Dynamics (GOF-C-GOLD), a panel of the Global Terrestrial Observing System (GTOS), regional networks.

GOES-R ABI FDCA user engagement activities have been much more limited and have not developed any training and infrastructure similar to the VIIRS AF team.

VIIRS AF Team Supporting the 2013 Fire Season

A second highly successful approach to user engagement has been the deployment of VIIRS AF Team members to fire locations that have fire Incident Command Posts (ICP) set up to lead the multi-agency response to fighting the fire. This in-place presence allows for the evaluation of the use of satellite data by the firefighting teams and assist them in determining how new capabilities can be quickly transitioned to operations. The following sections discuss these initiatives in more detail.

The on-site visits were a result of outreach efforts from teleconferences that prompted dialogue between PGRR AF project investigators and members of the user community, including IMETS. These discussions focused on topics relating to the dissemination of VIIRS data and information, latency of the

The VIIRS AF team, for example, is engaged in several initiatives, including the development of a near-real-time enhanced VIIRS AF product delivery system to NOAA end users. The team is making improvements to and evaluating VIIRS AF algorithms, providing support to the operational fire management and corresponding NOAA operations, and providing outreach to the international user community of direct-readout VIIRS fire data.

The team has developed a web-based data visualization and distribution system: <http://viirsfire.geog.umd.edu/>,

delivery system, and the user community’s wants and needs. After several of these discussions among the team members, it was determined that site visits during active fires would provide a window of opportunity to observe and understand what the response cadre dealt with at a wildfire incident. Through these on-site visits, AF team members were witness to the kind of pressures and hurdles the end user faces when responding to an environmental event out in the field. These visits also provide the team members with a hands-on opportunity to see how their fire data is used in the field. These visits also allowed team members to assess and evaluate their end users’ needs and applications.

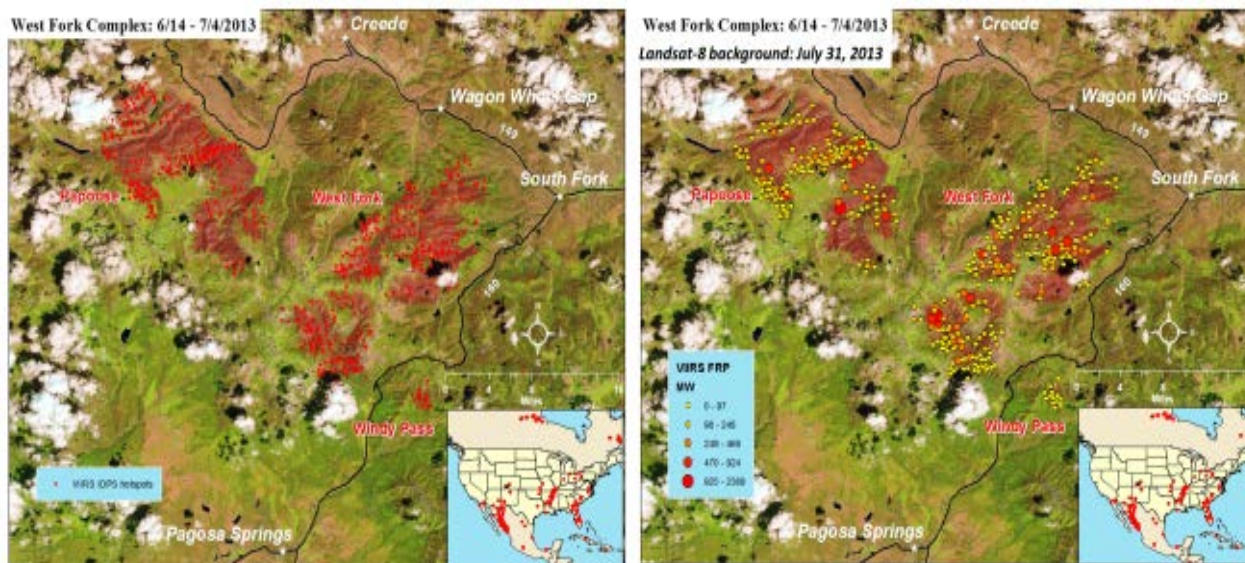
West Fork Complex

On Monday, June 24, 2013, Evan Ellicott, member of the S-NPP VIIRS AF product development and evaluation team, landed in Denver Colorado. His plan was to visit the West Fork Complex in southern Colorado, and to get as close to the front line as possible and meet with the key people fighting the fire. The West Fork Complex consisted of three lightning-caused wildfires, West Fork, Windy Pass, and Papoose, which burned on the San Juan and Rio Grande National Forests and private lands in southern Colorado.

Evan’s goal was to evaluate their use of remotely sensed data and determine how the new JPSS VIIRS capabilities could make a difference.

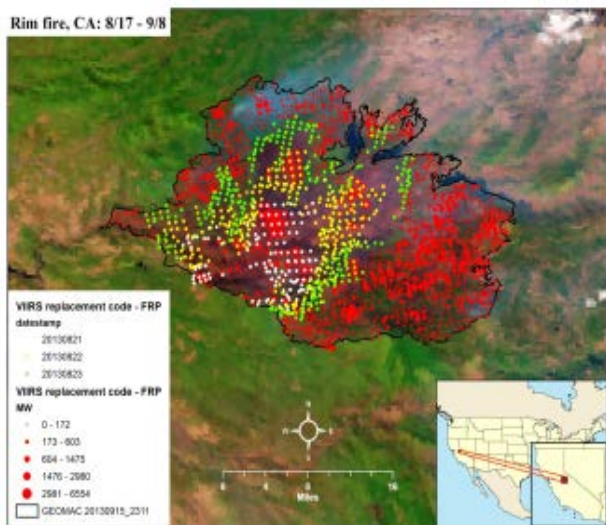


Eric Morgan and Chris Johnson (FBANs)



This site visit offered first-hand insight to the operational structure, work and information flow, as well as an opportunity to demonstrate the benefits and performance of S-NPP data while getting user feedback. All of these directly relate to the VIIRS AF PGRR project. While at the ICP he met with many of the Incident Command (IC) cadre and worked with them to understand their roles and

responsibilities, the data they needed, wanted, and were unaware of, and the hurdles they faced in terms of data access, processing, and analysis.



Example of the Fire Radiative Power (FRP) together with the timestamp.

Rim Fire, California

The Rim fire started on August 17, 2013 and grew steadily for the first several days under dry and windy conditions. In early September, at the time of Evan’s conversations with Robyn Heffernan, National Fire Weather Science and Dissemination Meteorologist at the National Interagency Fire Center (NIFC), the Rim fire reached 80% containment, which was an ideal opportunity for him to engage IC cadre, specifically the Planning Section members, as they could allocate more time to talk about the hurdles they had faced in terms of situational awareness, their data and information needs/wants, and how these resources could allow them to more effectively meet their goals on the incident.

Applying Lessons Learned from the 2013 Fire Season

The visits to the West Folk Complex and Rim fires highlighted the issues associated with data latency and connectivity. For example, the delivery of remotely sensed (RS) data to the Situation Unit Leaders and others in the planning section, as well as command cadre, as quickly as possible is a critical component to operational management of an incident. Currently the RS data used – primarily nighttime infrared images from airborne sensors (the program is referred to as NIROPS), is provided only once a day and at night. Evan explained to the site crews how VIIRS (and MODIS) provide an additional “look” at the fire around the same time NIROPS flights are imaging the fire (~12-2am) and thus would offer additional sampling points to confirm heat sources and fire perimeter. In addition, the timing difference between NIROPS, VIIRS, and MODIS could offer insight to direction of spread. Moreover, using MODIS-Terra (~10:30am/pm) along with VIIRS and MODIS-Aqua (~1:30am/pm) fire information, would offer a sense of the fire’s diurnal activity, progression, and intensity. The fires revealed that VIIRS detection data needs to be available in time for the two daily meetings and integrated into the suite of information used for the planning and decision making process. In addition, timely updates during the day can provide valuable information to support decisions on specific firefighting actions. This can be achieved by ensuring access to direct broadcast data from various receivers across the country, typically 30 minutes or less after the satellite overpass.

The format of the data was a consistent theme with the end-users of both VIIRS and GOES data. They indicated that they were interested in receiving data in a format that could be easily ingested into a Geographic Information System (GIS) or Google Earth. In terms of obtaining data, they recommended a straightforward process, that would clearly show where the data was located and available, and what type of data was being provided (i.e. a metadata file with clear, concise descriptions should be provided). The information regarding the fire needs to be available in a compressed format that can be

easily downloaded through low-bandwidth cell phone and wireless networks, which then can be combined with other geospatial information on-site. Until a robust data access system is set up, the S-NPP VIIRS AF team is planning to provide ad-hoc remote support to end users for select fire events through partnerships established in part through Evan's visit to the West Fork Complex.

Latency is a critical component to the operational management of an incident. Therefore, it is crucial that remotely sensed data is made available to the decision makers on the ground as quickly as possible. For GOES-R, the fundamental function of the WFABBA and FDCA is low latency, and real-time detection of fires. And, as fire detection must be at a high temporal resolution to provide emergency management services with as much lead-time on new fires as possible, the WFABBA and FDCA are steps towards that goal.

Further work is needed to ensure utilization of the full capabilities of the VIIRS and ABI sensors to provide fire information at various spatial details during daytime as well as nighttime. Continuous interaction with the end users also helps identify shortcomings of the fire detection algorithms and thus support further product improvements by the product development teams. For VIIRS, options for various data products, data formats, and background material are provided through the Active Fires Product Data and Evaluation Portal at <http://viirsfire.geog.umd.edu>.

Summary and Forward Path

The VIIRS AF products currently available on S-NPP build upon the fire algorithms developed for heritage imagers. They are providing key active fire information to the AF user community. The JPSS PGRR is a framework for NOAA to conduct testing of advanced operations, services, and science and technology capabilities that address the needs of both internal and external users. Successful testing of data products and services demonstrates readiness to implement into operations. To familiarize end users with the applications of S-NPP AF products, and prepare them for the applications of the AF products that will be available on JPSS-1, members of the AF teams embarked upon projects that established pathways for the user community. Among them is a web-based data visualization, analysis, and distribution system that provides timely data and a rolling archive of all VIIRS fire observations. These pathways allow the user community, including operational forecasters, to achieve user readiness through the application of AF products and data from NOAA's current polar-orbiting satellite systems. These data are used to improve and/or develop products, conducive to different applications and time scales.

Coordination and assessment efforts have been done by the JPSS AF PGRR team, to address the user community's wildland fire data needs. The team's evaluations revealed that information gaps still exist including end-user capability improvements (i.e. training interfaces), limited observations and measurements near fires, and latency. The capabilities and activities developed through the PGRR efforts and other related activities are instrumental in reducing these specific gaps. Furthermore, site visits provided an opportunity to witness firsthand the challenges related to data connectivity, latency, format, and availability. In addition, feedback from IMETs and other fire support personnel helped the team better understand when the product was of most utility.

NOAA's polar-orbiting and geostationary satellite platforms offer different spatial/temporal detection capabilities to the AF user community. Since no sole satellite system has the perfect fire monitoring capabilities, the AF PGRR teams should leverage the capabilities of JPSS and GOES-R, and their respective heritage systems, to generate complementary active fire data sets.

On S-NPP, VIIRS provides useful information for daytime and nighttime detection and characterization of active fires. GOES-R will provide ABI coverage over most of the western hemisphere at spatial resolutions of 2 km, continental US coverage every 5 minutes, and full disk coverage every 15 minutes that will allow monitoring of the diurnal cycle. For end users this means the delivery of high frequency fire detection and characterization data. Soon, JPSS and GOES-R will be the nation's primary operational environmental observation systems. The PGRR teams will continue to characterize their satellite data attributes, engage NOAA end users to optimize their use of data from the next generation systems, and prepare end users through education, training and outreach.

JPSS USER PERSPECTIVE
What the users are telling us about JPSS

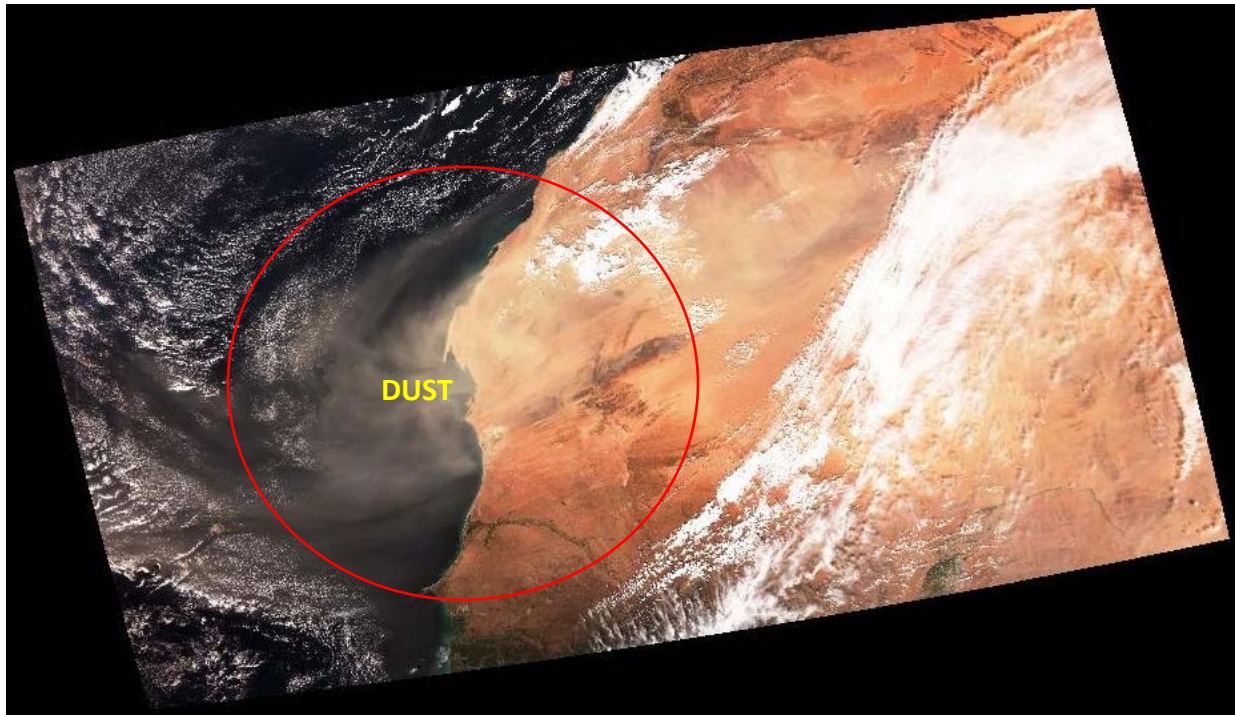
Section 7

**The Suomi National Polar-orbiting Partnership (S-NPP)
Ushers in the Next Generation of Aerosol Products for Air
Quality Applications**

*This article is based in part on the **May 19, 2014 JPSS science seminar** given by Dr Shobha Kondragunta, NOAA NESDIS Center for Satellite Applications and Research, and Amy Huff, Pennsylvania State University, Department of Meteorology.*

Contributing editors: Shobha Kondragunta, Amy Huff, Mitch Goldberg, Julie Price, William Sjoberg, and Kathryn Shontz

This article describes the new Aerosol Optical Depth (AOD⁵) products for air quality (AQ) applications that are available from the Suomi National Polar-orbiting Partnership (S-NPP) – the National Oceanic and Atmospheric Administration’s (NOAA) first next-generation polar-orbiting satellite, which launched in October 2011. This is important since NOAA satellites provide the AQ user community with observations over large spatial domains not available from ground monitoring stations. The AQ community utilizes satellite-derived aerosol products for a variety of applications, including daily AQ forecasting and research. The Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the S-NPP provides high definition imagery on a global scale. VIIRS high-resolution imagery are used in the detection and amount of atmospheric aerosols. VIIRS products for AQ applications include suspended matter (e.g., dust and smoke), aerosol optical depth (AOD), and true color imagery (RGB). AOD is useful for identifying and tracking areas of high particulate matter (PM₁₀/PM_{2.5}) concentrations that correspond to an AQ event, such as a wildfire, dust storm, or a haze episode. RGB serves as a complement to AOD measurements by providing visible information about areas of smoke, haze, and dust.



Dust storm off the West Coast of Africa captured by the VIIRS instrument on December 14, 2013. These African dust storms can travel thousands of miles across the Atlantic Ocean, and often reach the Gulf of Mexico. In addition to causing hazy skies, which reduces visibility and results in poor air quality, dust storms have been found to impact tropical cyclone activity in the North Atlantic.

This article also includes a discussion on the relative pros and cons of VIIRS pixel level product (Intermediate Product AOD) and aggregate product (Environmental Data Record AOD), which offer a

⁵ Also called Aerosol Optical Thickness (AOT)

substantial increase in spatial resolution over the standard Moderate Resolution Imaging Spectroradiometer (MODIS) AOD products – still widely used by the AQ community. This article provides some AOD imagery examples from MODIS and the GOES Aerosol and Smoke Product (GASP), and VIIRS from the Infusing satellite Data into Environmental Applications (IDEA) website (<http://www.star.nesdis.noaa.gov/smcd/spb/aq/>). In addition, the article mentions some future outreach activities, including training events designed to build the capacity of users, and outlines the potential improvements to VIIRS aerosol products based on feedback from the user community.

Atmospheric aerosols are tiny solid or liquid particles that are suspended in the atmosphere. Examples include dust, smoke, haze, and fog. Aerosols can be derived from natural or anthropogenic sources including urban/industrial pollution, natural environmental events such as volcanic eruption, dust outbreaks, chemical reactions in the atmosphere, and biomass burning associated with agricultural land clearing and forest fires. Despite their microscopic size, their presence in the air poses significant challenges to the environment. They cause air pollution, impede visibility, and are detrimental to human health and the economy. Exposure to aerosol concentrations above the national standards set by the EPA can significantly affect respiratory health, and exacerbate existing lung diseases, such as asthma and emphysema. According to the American Lung Association's (ALA) "State of the Air 2014" report, nearly half of the nation's population — more than 147 million — live in counties where ozone or particle pollution levels make the air unhealthy to breathe⁶.

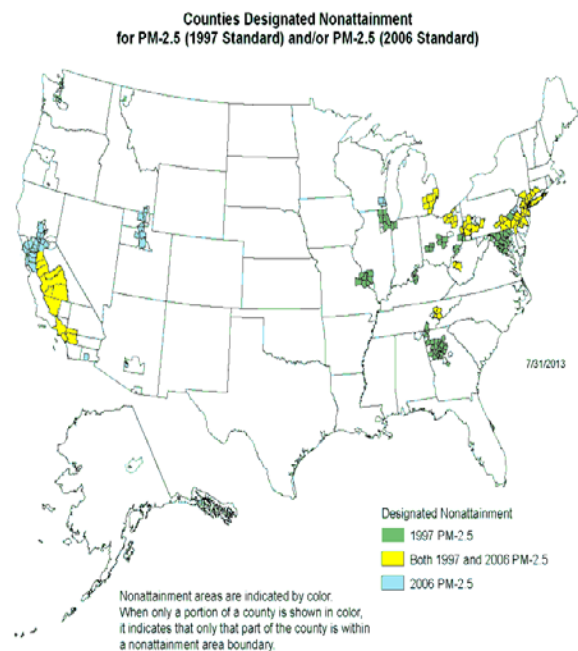
The Clean Air Act, as amended in 1990, requires the Environmental Protection Agency (EPA) to set standards to limit air pollution. NOAA and EPA, through a Memorandum of Agreement (MOA), have partnered to develop a National Air Quality Forecast Capability (NAQFC) that provides numerical air quality model guidance for forecasters at the state, local, and tribal environmental agencies that issue AQ forecasts for the public.

The user community for AQ satellite products includes the NWS and its field offices, EPA, Federal Aviation Administration (FAA), US Forest Service (USFS), academia, industry and AQ managers from federal, regional and local agencies. The NWS, for example, relies on the scientific information and tools including satellite data to generate its AQ forecast guidance. Particulate matter is one of the foci of this effort. An example of an outreach application is the UMBC U.S. Air Quality, or Smog Blog, web page <http://alg.umbc.edu/usaq>, which uses the NOAA and NASA aerosol products that are available through NOAA in near real time to document day to day AQ issues. According to section 319 of the Clean Air Act, an exceptional event is:

an event that affects air quality, is not reasonably controllable or preventable, is an event caused by human activity that is unlikely to recur at a particular location or a natural event, and is determined by the Administrator through the process established in the regulations promulgated under paragraph (2) to be an exceptional event. It does not include stagnation of air masses or meteorological inversions, a meteorological event involving high temperatures or lack of precipitation, or air pollution relating to source noncompliance.

⁶ <http://www.stateoftheair.org/2014/assets/ALA-SOTA-2014-Full.pdf>

The Air Quality Community's Mission Support



The figure above shows the non attainments as of July 2013. The areas in green, blue and yellow are not meeting the national ambient AQ standard of PM 2.5

The AQ community uses satellite products to support its wide range of activities and responsibilities, particularly for operational and retrospective analyses. AQ forecasters, analysts, researchers and modelers, utilize observations from NOAA's SNPP and NASA's Terra and Aqua, for daily AQ forecasting, fire, smoke, and dust monitoring, and ambient AQ monitoring. Scientists identify meteorological features that affect air pollutant build-up and transport, such as cloud cover, convection, and frontal boundaries. Aerosol satellite products help scientists to identify and evaluate significant air pollution events like smoke emissions from wildfires, windblown dust, and haze. Tracking the changes in these events over time allows forecasters to understand, anticipate, and prepare for potential future changes. In addition, the discoveries from these long-term studies on aerosols help the public strategize on how to deal with their societal impacts.

Furthermore, these long-term studies provide the members of the AQ community the much needed tools to develop emissions control strategies to meet the EPA's health-based National Ambient Air Quality Standards (NAAQS). Government officials use this information to establish guidelines for issuing permits for emissions sources (e.g., power plants), and determine whether industries operate within their designated limits.

NOAA's Satellite Capabilities for Measuring, Monitoring and Analyzing Aerosols

The Hazard Mapping System (HMS)

The Hazard Mapping System (HMS) was developed in 2001 by NOAA's National Environmental Satellite and Data Information Service (NESDIS) as an interactive tool to identify fires that produce smoke over North. The image on the right is a jpeg depiction of fire and smoke analysis from the HMS Fire and Smoke Product. Smoke plumes are shown in gray. Active wildfires are marked with red dots. The HMS utilizes automated fire detection algorithms from multiple satellite sensors that are currently in orbit on the geostationary and polar-orbiting satellite platforms. Geostationary data offer high temporal resolution (data



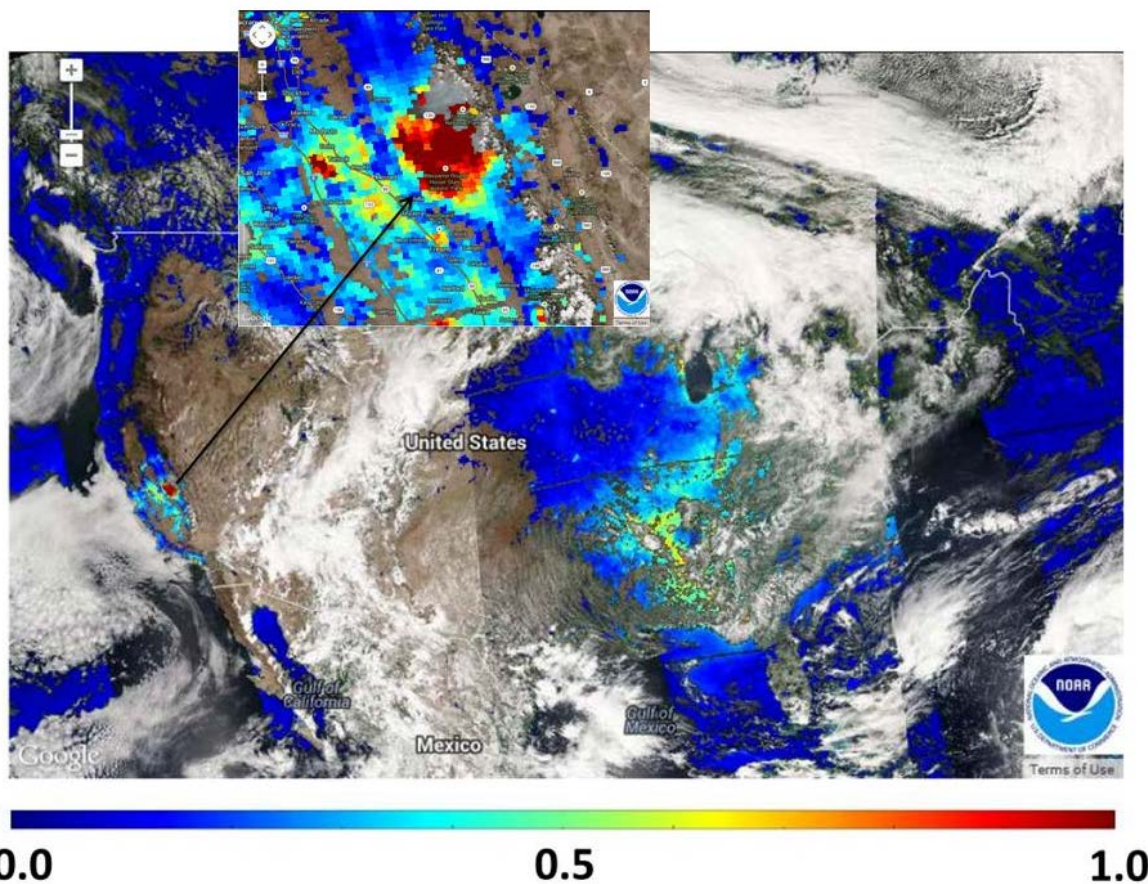
refresh of 15 minutes) but with a nominal spatial resolution at satellite subpoint of 4 km for the 3.9 μm band which is employed for hotspot detection. Visible band data, used for smoke detection, is available at 1 km resolution. Polar orbiting data are currently provided by the MODIS instrument on both the NASA Terra and Aqua spacecrafts as well as the Advanced Very High Resolution Radiometer (AVHRR) on NOAA-15/18 and VIIRS on S-NPP. The polar data provide a higher nominal resolution of 1 km for the 3.9 μm band but at lower temporal refresh rates. Low and mid latitude locations are scanned twice per day by each of the polar orbiting satellites while higher latitudes receive more passes per day. The HMS identifies fires and smoke plume extent over the US and adjacent areas of Canada and Mexico. Analysts use fire locations and visible imagery from the HMS to identify areas of smoke. As smoke and blowing dust impact PM 2.5 and PM 10 concentrations, the capability of the HMS to quickly depict areas of smoke and identify the fires that are producing the emissions for inclusion in AQ transport and dispersion forecast models makes it very useful for the AQ community.

Satellite Aerosol Optical Depth (AOD)

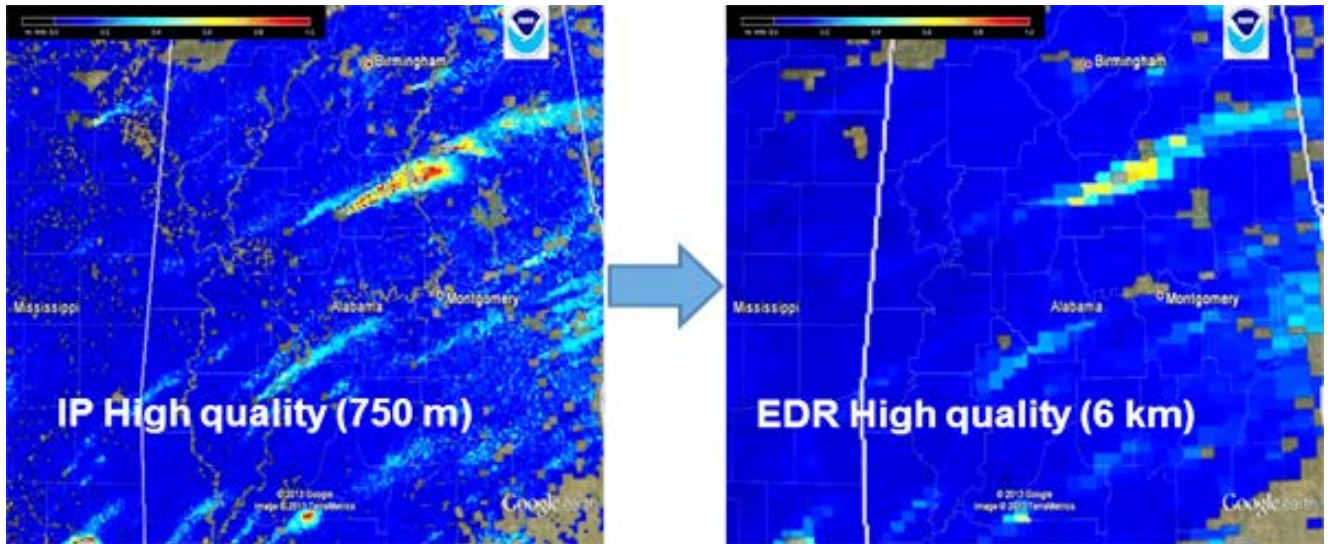


RIM FIRE – fire activity on the South Flank. Photo credit: USFS/Mike McMillan

Satellite derived AOD product is a viable tool to track areas of high particulate matter or aerosols associated with smoke, haze and blowing dust. For the past two decades, AOD data was available from the MODIS instrument onboard NASA's polar-orbiting Terra and Aqua satellites, and also from NOAA's GOES Imager. MODIS provides high accuracy retrievals at resolutions of 10 km and 3 km, while GOES is available at a 30-minute interval, and delivers retrievals at a resolution of 4 km. Satellite measured AOD has been shown to be a good proxy for pollution monitoring especially when long-range transport is involved. The image on the left shows VIIRS AOT on September 9, 2013 for Rim fire in California. The fire started on August 17, 2013 and was contained on Thursday, October 24, 2013 and fully extinguished on September 6, 2013. According to a NASA press release dated August 26, 2013, dense smoke posed serious health problems. In addition, it caused reduced visibility, which hampered both rescue and suppression efforts.

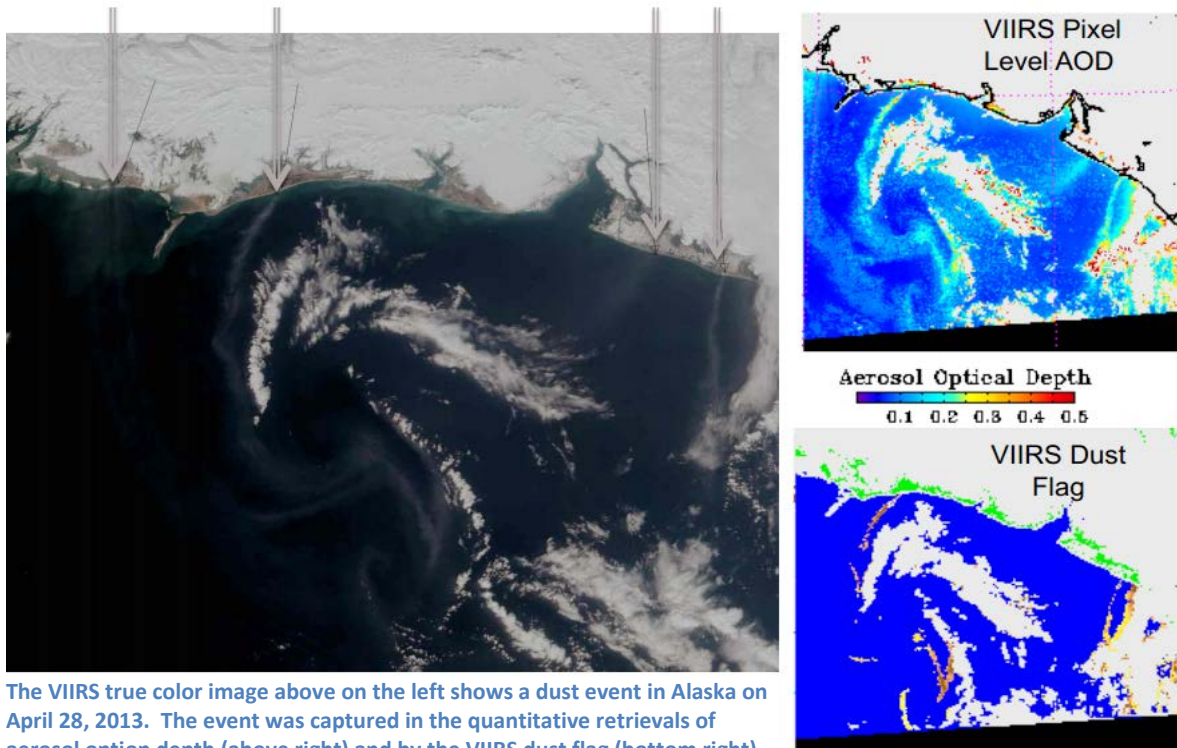


The air quality community has relied primarily on AOD imagery from MODIS and GOES. The launch of S-NPP and its VIIRS sensors, improved the AOD satellite capabilities. The VIIRS heritage comes from AVHRR and MODIS, albeit with much superior spatial resolution properties. VIIRS acquires high-resolution atmospheric imagery in 22 bands from 412 nm to 12 μ m. Moreover, its capabilities support the generation of a variety of products which are applied in areas such as detection of fires, smoke, atmospheric aerosols, and so forth. For AQ applications, VIIRS offers two high spatial resolution AOD products, a 750m nadir resolution Intermediate Product (IP) and a 6 km resolution EDR product, which is aggregated from IP measurements. Both of these products offer a substantial increase in spatial resolution compared to the MODIS AOD 10 km products, which is still widely used by the AQ community. The VIIRS 750 m IP product has a higher resolution than the MODIS Collection 6 AOD 3 km product, and resolves variations in AOD on urban scales. The 6 km resolution EDR product is at a much higher resolution than the MODIS Collection 5 AOD 10 km product, and is useful for large scale AQ events, like large wildfires. Moreover, VIIRS has wider swath (3000 km) than MODIS (2330 km), and therefore does not have any gaps between adjacent orbits. Also VIIRS spatial resolution at swath edges is much higher than that of MODIS.



Details associated with smoke plume AOT structure seen in VIIRS IP AOT (left panel) are smeared out when aggregated to EDR AOT (right panel)

VIIRS True Color Imagery (RGB)



The VIIRS true color image above on the left shows a dust event in Alaska on April 28, 2013. The event was captured in the quantitative retrievals of aerosol optical depth (above right) and by the VIIRS dust flag (bottom right)

A true color (Red-Green-Blue) satellite image can show the presence of dust (brown), smoke (gray), and haze (white), which are easy to distinguish from clouds. Thus, the VIIRS radiances in the visible bands are used in various spectral and spatial variability tests to qualitatively identify dust and smoke in the imagery. The images shown above, of dust outbreaks in Alaska, were taken on April 28, 2013. In them, the streaks of dust seen emanating from the land are captured nicely in the quantitative retrievals of

AOD and the dust flag generated from dust detection algorithm. It should be noted that AOD cannot be retrieved when there are clouds. These images are used by operational AQ forecasters in providing air quality and visibility guidance to the general public.

Spreading the Word on the New VIIRS Capabilities

The JPSS AQ Proving Ground (AQPG), a subset of the overall NOAA PG, focuses on the needs of the AQ community. As such, it is working to familiarize the U.S. AQ satellite user community with applications of the new generation of aerosol products that are available on S-NPP satellite, and also prepare them for the products that will be available on JPSS-1. The JPSS AQPG also provides its user community with training and outreach on these aerosol products. These include videos on YouTube and annual AQPG meetings for user community. In November 2013, the AQPG held a two-day Suomi NPP aerosol science and operational user workshop that was attended by 65 participants from NASA, NWS, NRL, EPA, state and local AQ forecasting agencies, and different universities. The goal of the workshop was to present the status of VIIRS aerosol products and facilitate their operational evaluation to the science community and operational users. Team members from the AQPG conducted hands-on case study analysis of VIIRS aerosol products and performed live demos of various visualization tools. Moreover, there is an advisory group of 40 AQ forecasters and analysts from federal, state, and local agencies who receive hands-on training on these aerosol products. These analysts provide feedback to members of the AQPG team, who in turn incorporate it into VIIRS aerosol product development.

The Infusing satellite Data into Environmental Applications (IDEA) Website

The screenshot shows the 'National Satellite AOD and Natural Color Images' web interface. Callouts indicate the following interactions:

- select date:** Points to the date and time selection dropdowns (2013, July, 02, 00:00).
- select satellite:** Points to the 'Choose plot type' section with radio buttons for MODIS Terra, MODIS Aqua, CASP East, CASP West, and VIIRS.
- Change AOD opacity:** Points to the 'AOD opacity' slider control.
- Click on individual regions to see regional AOD images:** Points to the main map area showing AOD over the United States.
- Download images or google earth kml file:** Points to the 'Images download links' table at the bottom.

Images download links				
MODIS Terra	MODIS Aqua	CASP East	CASP West	VIIRS
AOD png	AOD png	aerosol gif	aerosol gif	AOD png
AOD KML	AOD KML	dust png	dust png	AOD png
AOD KML	AOD KML	AOD KML	AOD KML	KML
AOD KML	AOD KML	AOD KML	AOD KML	KML

Example of the interactive web display used to stream AOD and natural color products to users, showing pull-down menu for selecting date/time, radial buttons for choosing data, and animation controls.

The Infusing satellite Data into Environmental Applications (IDEA) website <http://www.star.nesdis.noaa.gov/smcd/spb/aq/> was created through a NASA/EPA/NOAA cooperative effort with the goal to improve AQ assessment, management, and prediction by infusing measurements from multiple satellite sensors including MODIS Terra, MODIS Aqua, GOES EAST and GOES WEST imager into (EPA, NOAA) analyses for public benefit. It is a free, quick and easy way for members of the AQ community to access satellite products. In addition to delivering static images, this interactive visualization tool holds NRT and archived imagery dating back to 2008.

Although it was initially developed as a research tool for MODIS, it was later migrated to NOAA where it is run operationally, and enhanced to include VIIRS, GOES-E, GOES-W, surface PM2.5 estimations, and the aerosol product from the Ozone Monitoring Instrument (OMI). Owing to further enhancements and the capability to disseminate automated data from GOES, MODIS, and EPA ground-based PM2.5 measurements to the operational AQ community in near real-time (NRT), it has become a core product in the toolkits used by federal, state and local AQ analysts and forecasters. AOD for example, is most often accessed via the IDEA website, which provides comparisons of AOD between each different satellite sensors up to five different quality levels.

Summary and Next Steps for the AQPG/VIIRS AOT Products

Atmospheric aerosols have a profound effect on our environment including negative impacts on economic activity and human health. NOAA's role to provide 24-hr AQ forecast guidance using numerical AQ prediction models, has facilitated the provision of observations from next generation satellites such as S-NPP, which the user community utilizes for forecasting, modeling, and monitoring AQ conditions.

The AQ community, which includes the agencies responsible for monitoring AQ, forecasters, modelers, and analysts, has come to rely on environmental satellite observations generated by NOAA's polar-orbiting and geostationary satellites. These observations include optical depth, PM2.5, and true color imagery of smoke, dust, which are used in a wide range of AQ applications including detecting and predicting fine particulates, estimating emissions, and also as evidence of exceptional events.

The data from NOAA satellites is used to engage in intensive studies that enhance our understanding of the processes that produce aerosols, and the ensuing effects from these aerosols. Through the JPSS PG, the AQPG team continues to interact closely with the AQ user community through training and outreach activities to maximize the usefulness of S-NPP aerosol products. In addition, 2-3 training/informational webinars are planned for 2014 to keep Advisory Group members updated on product development.

JPSS USER PERSPECTIVE
What the users are telling us about JPSS

Section 8

**The NOAA Visualization Laboratory: Putting Satellite Imagery
into Your Hands**

*This article is based in part on the **June 23, 2014 JPSS science seminar** presented by Dan Pisut, NOAA Visualization Lab Manager.*

Contributing editors: Dan Pisut, Mitch Goldberg, Julie Price, and William Sjoberg

To create accurate visualizations of satellite data, one requires a thorough understanding of uniquely instrumented satellite sensors and their capabilities. In NOAA, the Environmental Visualization Laboratory (VizLab) plays a critical role in communicating these capabilities to scientists, operational users, and the public in general. NOAA's role on the world stage as a source for weather and climate information means the VizLab team is working hard to ensure real-time data is represented on the VizLab website, <http://www.nnvl.noaa.gov>.

Founded in 1999 to help improve the outreach capability of NOAA, the VizLab serves the communications, education, and outreach needs of NOAA in support of its mission to foster environmental literacy. Since its debut, it has become a critical source of satellite data focused on significant high visibility

environmental events. Satellite images of massive hurricanes, smoke from fires covering thousands of acres, and rapidly moving volcanic plumes, have become a staple in the US media and news. The VizLab also works closely with offices across NOAA, federal, state and local agencies, academia and industry, along with informal educational institutions such as the Smithsonian National Museum of Natural History, providing visualizations to help them meet their education, and communications needs. Most recently, the VizLab has led the way in communicating the capabilities of NOAA's current operational polar-orbiting satellite, the Suomi National Polar-orbiting Partnership (S-NPP). S-NPP, which launched on Oct 28, 2011, is the first next generation polar-orbiting satellite in the Joint Polar Satellite System (JPSS) series, and is considered the bridge between NOAA's legacy polar satellite fleet, and the JPSS constellation.

Finding interesting Earth phenomenon to visualize is one thing, understanding the complexities of the data, especially from S-NPP is another. For example, the RGB color composite shown below was

generated using S-NPP VIIRS data. Great care was taken to maximize the benefit of VIIRS channel comparisons to better identify the swirls of plankton blooms in the Baltic Sea. Some non-standard RGB composite techniques (including channel selection, gamma correction, and hue shifts) were used to maximize the contrast between land, ocean, and the phytoplankton to reveal the dynamic nature and structure of plankton blooms. Plankton – microscopic organisms or algae that live in the ocean’s surface waters – contribute almost half of the world’s total primary production, which is the process by which carbon dioxide is taken up by plants and converted to new organic matter by photosynthesis. These organisms form the base of the marine food web. However, they can sometimes grow explosively, creating what is referred to as a "bloom", which, if intense, can result in harmful impacts on marine ecosystems.

This RGB color composite uses the satellite’s SVI1, SVM4, and SVI2 bands, each sensitive to different colors of light. By combining these channels, features not apparent in normal visible imagery can be discerned.
Credit: NOAA/NASA

Transforming 1s and 0s

The VizLab captures raw data from S-NPP as well as other of NOAA’s polar-orbiting and geostationary satellites via NOAA’s operational satellite servers, repositories at the Center for Satellite Applications and Research (STAR), along with the Product Evaluation and Analysis Tools Elements (PEATE) Direct Readout and other data services from the University of Wisconsin Space Science Engineering Center (SSEC). Managing this data flow is no small undertaking, as it consumes several terabytes of storage and processing per day. However, these complex, automated processes allow the VizLab to generate images for the media with the speed of an operational analysis program.

The VizLab’s responsiveness to breaking weather disasters was especially evident on November 17, 2013, when violent tornadoes ripped through the Midwestern states of Missouri, Illinois, Indiana, Kentucky, Michigan and Ohio. These tornadoes caused loss of life and extensive damage to property

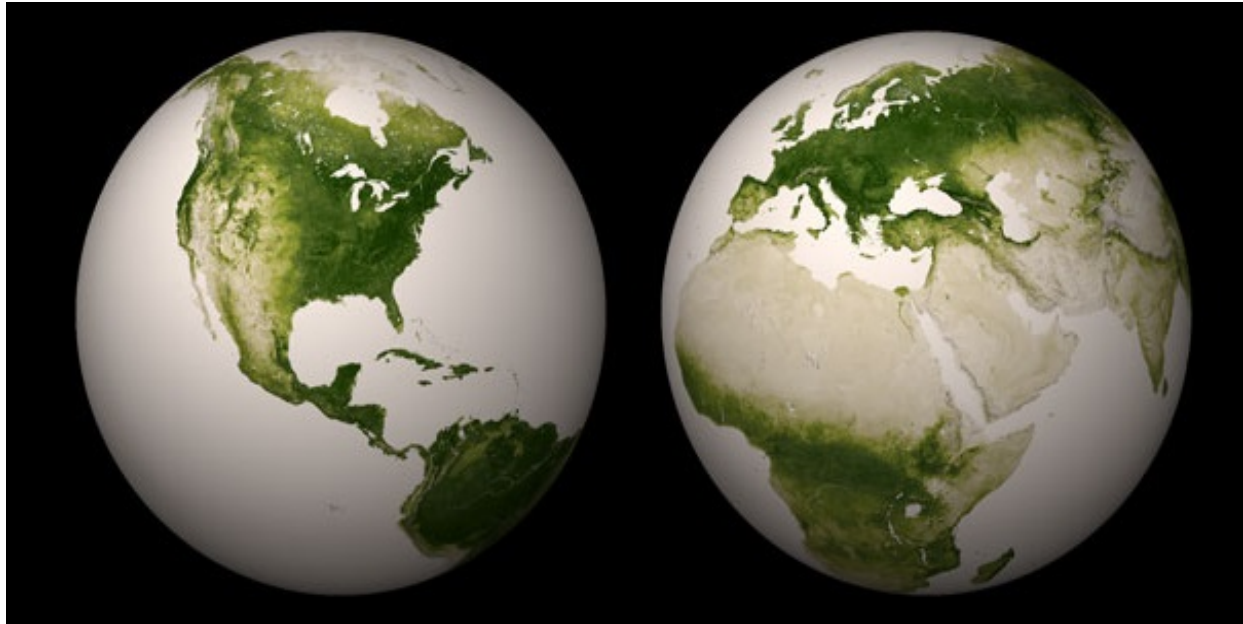
and infrastructure. By November 20, the NOAA National Weather Service (NWS) Storm Prediction Center (SPC) had documented 94 Tornado Reports, 30 of them in Indiana alone. With damages estimated in excess of \$1 billion, this outbreak was the most expensive weather disaster to occur in November in 25 years of record keeping. The image below is visualization, from the VizLab, of this severe weather event. It shows how S-NPP viewed the storms as they were beginning to strengthen, alerting forecasters at SPC of the impending danger.

This image was taken by the S-NPP satellite's VIIRS instrument around 1920Z on November 17, 2013 as the storms were beginning to strengthen. The red dots correspond to the latitude/longitude of each of the 94 Tornado Reports documented by the Storm Prediction Center.
Image credit: NOAA/NASA

To ensure such timeliness, over 150 computer scripts are running around the clock on the VizLab's server farm based in Silver Spring, Maryland at the headquarters of the NOAA Satellite and Information Services (NESDIS). Geostationary satellite data that is ingested is processed on McIDAS systems; all other data is imaged using customized IDL scripts. Additional programs then take the raw imagery and layer, map, annotate, re-project, or re-color based on the final output and use. The real-time feeds are distributed on the VizLab website, by the NOAA Science On a Sphere[®] program, and are picked up by many other museums and websites.

But these are just the automated processes. Most of the VizLab's most recognized imagery requires another level of processing and skill – transitioning from data imaging to graphic arts. Over the years, the tools have changed from custom applications to more commercial off the shelf programs. The VizLab uses a mix of products from Adobe and Autodesk Maya for their final renderings of 2D and 3D data. To grab attention and also improve understanding, the VizLab is cognizant of the need for proper use of scene composition and perspective, annotation elements, and emphasizing areas of importance through the careful application of color.

Simplifying data while preserving detail was best highlighted by the VizLab’s social media campaign for “Green: Vegetation on Our Planet.” This project, done in coordination with NOAA and NASA, involved the creation of a highly detailed set of vegetation index maps, marking the one year mark of processing VIIRS vegetation data. These maps, released to the public in several formats at full resolution, used simple shades of pale to dark green to show the subtle changes in vegetation cover over the planet from week to week. This project gave the VizLab a sense of the obstacles to come in dealing with VIIRS data on a routine basis – the sheer size in terms of data volume and processing requirements. The VizLab developed 3D fly-throughs of the data – each scene taking two weeks to render.



This image features a year's worth of data from the S-NPP satellite, which is able to detect subtle differences in greenness (above). The darkest green areas are the lushest in vegetation, while the pale colors are sparse in vegetation cover due to snow, drought, rock or urban areas.

NOAA View – A New VizLab Cornerstone

The global vegetation data was certainly “big data” but it pales in comparison to the group’s latest effort. In November 2013, the VizLab launched the NOAA View data exploration tool, an education/outreach website and web services that provides a single point for experiencing imagery and other environmental data captured by NOAA satellites and other observational and analysis platforms. NOAA View brings together more than 100 different variables, many in near real-time, along with historical data sets, some dating back to 1880, with new ones being added regularly. Content is updated on a daily, weekly, monthly or annual basis as data observations and collections permit.

One popular offering in NOAA View is a daily, full-resolution, global composite of VIIRS true color imagery. Eleven of the 21 channels on VIIRS are used to create very low noise reflectances for the red, green and blue channels (SVM5, 4, 3, respectively). The corrected reflectances are then gridded into orbits. Afterwards, and each neighboring orbit is blended to soften the edges and remove striping

artifacts. The result, after processing 2 TB of data over 20 hours, is a 16-bit, 53,376 x 26,688 pixel image of Earth.



NOAA View has been proven as an effective educational outreach tool designed to provide the public free and easy access to global environmental data. It is also demonstrating its value to the research community. Even before celebrating its first anniversary, it has received significant praise in NOAA and from external scientific and educational organizations. In addition to these accolades, it acts as a portal to official data distribution points in NOAA.

NOAA View is compatible with all major internet browsers, as well as Apple and Android mobile devices. It allows users to manipulate the display to change views of the world, data inputs and periods of time to observe the Earth. Moreover, users can browse, animate and download high-resolution imagery from the VizLab, making it an ideal instrument for delivering NOAA data imagery to audiences worldwide.

Summary

The VizLab uses data from the suite of sensors on NOAA's current polar-orbiting and geostationary satellites to create visualizations that communicate various findings of the Earth and its surrounding environment. These visualizations transform complex science into meaningful interactive visual displays such as NOAA View that allow us to observe and understand the underlying patterns and relationships contained within the data.

S-NPP produces approximately 3.5 terabytes of data a day, its follow-on, JPSS-1, is expected to generate 4.5 terabytes of data each day. Similar amounts are expected from GOES-R, the next generation geostationary satellite. As the volumes of data generated will only be bigger, the challenges for the VizLab will now include extracting interesting and useful information from more massive and complex datasets containing dozens of variables to create visuals. The NOAA VizLab is on the cutting edge of

representing big data with visuals displays that inform and educate the public about the atmosphere, oceans, clouds, ozone, snow, ice and vegetation. With access to a constant stream of new data from NOAA's weather satellites always, the VizLab team continues to find new ways to make it available to the public for years to come.

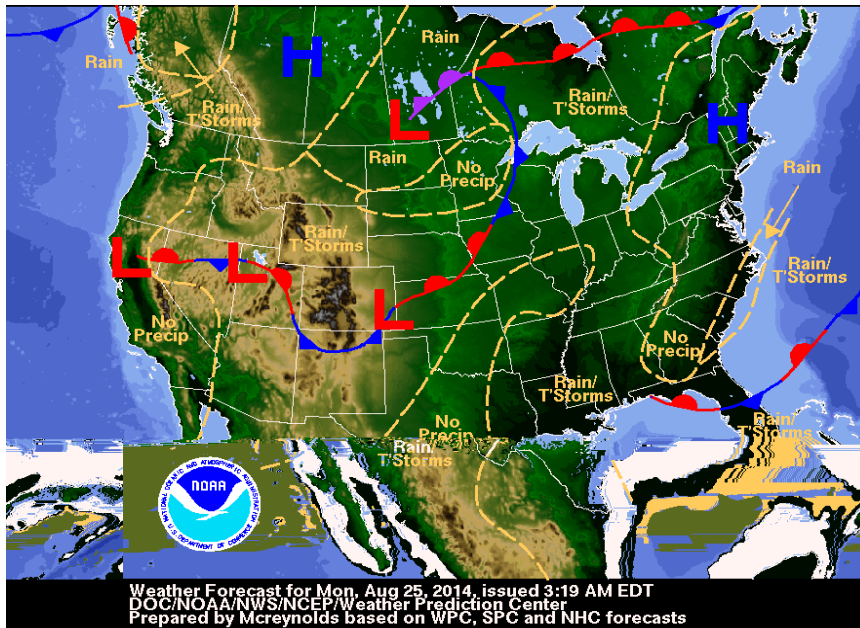
JPSS USER PERSPECTIVE
What the users are telling us about JPSS

Section 9

**The Proactive Quality Control (PQC) in Ensemble Data
Assimilation: An Innovative Approach to Detecting Bad
Observations**

This article is based in part on the July 21, 2014 JPSS science seminar presented by Daisuke Hotta (Japan Meteorological Agency), with additional contributions from Professor Eugenia Kalnay (University of Maryland, College Park.).

Contributing editors: Eugenia Kalnay, Daisuke Hotta, Mitch Goldberg, Julie Price, and William Sjoberg



Satellite Data Assimilation (DA) is the process of incorporating atmospheric observations into Numerical Weather Prediction (NWP) models to accurately describe the state of the atmosphere. Gridded datasets of satellite observations are key for weather analysis and forecasting. Operational NWP models, such as the Global Forecast System (GFS) run at the National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Prediction (NCEP), rely heavily on data assimilation techniques to ensure accurate techniques to improve forecast accuracy. Accordingly, the Joint Polar Satellite System (JPSS) Proving Ground and Risk Reduction (PGRR) funds various science teams to develop and augment the satellite DA schemes and systems used today.

Improved computerized prediction models, more powerful computers and better observations have each provided significant advances in NWP on both regional and global scales. Attention has now turned to sophisticated methods for assimilating data into these forecast systems. Incorporation of advanced DA methods, such as variational techniques and Ensemble Kalman Filtering (EnKF), have played important roles in enhancing NWP forecasts through more comprehensive assimilation. NWP systems have improved to such an extent that today's 5-day forecasts are approximately as accurate as the 3-day forecasts in the 1980's.

Despite this progress, some challenges remain. One such challenge is the sudden drops in the skill levels of the operational NWP forecast models of some NWP centers, referred to as "forecast skill dropout." In the past, observation locations, model dynamics and physics or bad analyses would have been considered primary suspects for these "dropouts." Some recent studies are pointing to a different problem, linking these dropouts to degraded or "bad" observations. More specifically, studies have revealed the inability of the operational NWP quality control (QC) system to (1) detect the bad observations, and (2) filter them out. As these observations go undetected they are assimilated into prediction models, and in turn deteriorate the forecast by perturbing and biasing the background truth state. However, minimizing the impact of these observations on forecast models presents a number of

challenges. The flawed observations would first need to be detected and then removed once they are found. As shown in the figure below, when the NCEP model is experiencing degradation due to the assimilation of “bad” observations, other models, such as the European Centre for Medium-range Weather Forecasts (ECMWF), continue to operate with much less impact to forecasts.

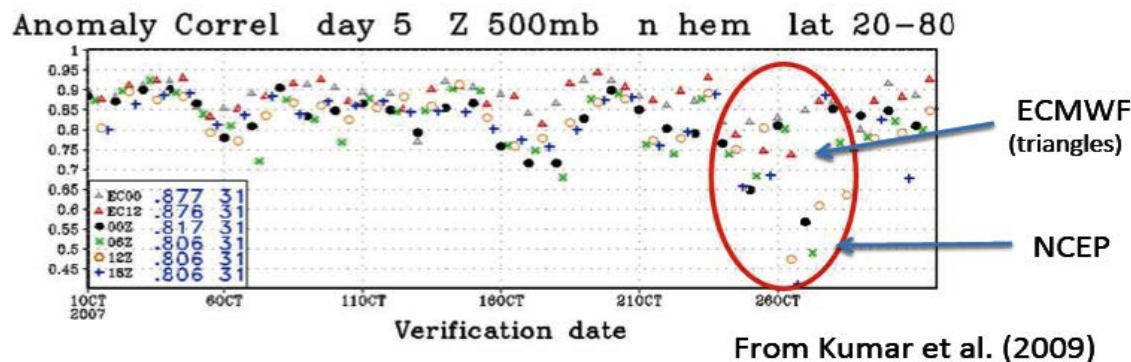


Figure 1: Time series of 500 hPa 5-day Anomaly Correlation for the Northern Hemisphere for various operational models including NCEP GFS (green), and ECWFM (red)

A group of researchers at the University of Maryland in College Park, led by Dr. Eugenia Kalnay, formulated an innovative Proactive Quality Control (PQC) scheme. This scheme exploits the Ensemble Forecast Sensitivity to Observations (EFSO) capability to detect the flawed observations and mitigate the impact of their assimilation into the models. The PQC technique has demonstrated significant improvements to the NWP forecasts in the presence of a “data dropout” case, showing that this scheme can be adapted to the NCEP operational environment.

The innovative PQC scheme is discussed in this article. But first, to provide a better sense of why and how this research is being carried out, the article will begin with a brief discussion of previous research and experiments that were performed on NWP forecast sensitivity to assimilated observations.

Previous Efforts to Estimate the Impact of Assimilated Observations

Traditionally, the impact of any given assimilated observation(s) on NWP forecast skill has been assessed with Observing System Experiments (OSEs) which are then used to quantify the importance of conventional and satellite data sets within NWP systems. The information from OSEs is used to demonstrate how effective the Data Assimilation System (DAS) is with incorporating the observed data but it also can be used to the utilization of the data within the DAS. OSEs, however, are performed independent from the whole DA and forecast system and, because they take several months to perform, require a substantial amount of computational resources.

To avoid the resource expenditure associated with an OSE, the Forecast Sensitivity to Observation (FSO) approach has been established to provide insight to the impact of observations onto forecasts. The FSO approach – first designed for a variational DAS using the adjoint method by Langland and Baker (2004) – requires a diagnostic technique to quantify how much the assimilation of each observation has improved or degraded a forecast. In 2008, Liu and Kalnay adapted the FSO to the Local Ensemble Transform Kalman Filter (LETKF) without using the adjoint model. In 2012 Kalnay et al. introduced a simpler, easier to implement and more accurate formula to estimate FSOs within an ensemble data

assimilation cycle wherein this approach is applicable to any formulation of EnKF. It was successfully implemented to a quasi-operational global ensemble DAS coupled with the NCEP GFS model. In 2013, Ota et al. applied the method (of Kalnay et al. 2012) to the GFS serial Ensemble Square Root version of EnKF (EnSRF) DAS that is used at NCEP. Their study demonstrated that in some cases the “bad” observations responsible for regional forecast skill dropouts could be detected with 24-hour forecast lead-time. They also found that resultant forecasts could be improved by excluding the degrading observations from the DAS within 7 cases of regional forecast skill dropout. Ota et al. reran the analyses and the 24-hour forecast without the 7 selected observation sets, and found that the regional forecast errors were substantially reduced, as shown in table 3 below.

Table 3. List of local 24-hour forecast failure cases (initial time from 00 UTC, 8 January 2012, to 18 UTC 7 February 2012)

Initial	Area	Size	Rate	N	Denied observation (denied number/total number)	Change (estimate)
06 UTC JAN 12	50N–80N 145E–175W	1.99	1.36	5	AMSUA ch4, 5, 6 (2735/125063)	–8.7% (–19.5%)
00 UTC JAN 16	30N–60N 20W–0	2.71	1.35	6	GPSRO 600–950 hPa (50/4918)	–0.6% (–4.3%)
18 UTC JAN 27	30S–0 105E–120E	2.40	1.21	1	AIRS (19908/670041)	–0.2% (–6.0%)
00 UTC JAN 30	70S–40S 165E–165W	2.00	1.25	6	AMSUA ch1, 3, 4, 5, 15 (3822/164934)	–4.7% (–12.8%)
06 UTC FEB 2	50N–80N 150W–110W	3.01	1.22	5	GPSRO 250–400 hPa, 600–850 hPa (407/13092)	–11.7% (–8.7%)
06 UTC FEB 4	30N–60N 150W–130W	1.81	1.26	3	IASI (57950/1177256), HIRS ch3, 4, 9, 11, 12, 14, 15 (785/73419), Aircraft 950 hPa ~, 125–600 hPa (5794/100896)	–25.5% (–81.6%)
18 UTC FEB 6	60N–90N 40E–100E	1.71	1.38	2	MODIS_Wind (10970/43452)	–28.4% (–47.7%)

In the case of MODIS Winds, the regional forecast errors were reduced by nearly 30%, constituting a major forecast improvement. The spatial pattern of the forecast errors for the MODIS winds case is

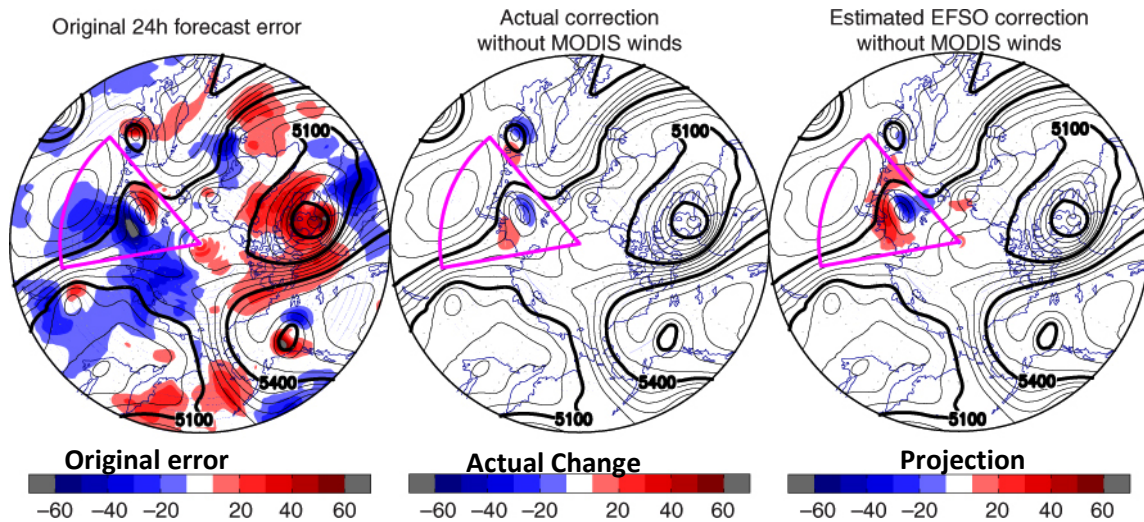


Figure 2: (from Ota et.al 2013, Fig. 9) Twenty-four hour forecast error of 500 hPa geopotential height (unit: m, 18 UTC 6 February 2012 initial) from original analysis (left), forecast change due to the removal of the MODIS polar wind observations in the data-denial experiment (middle) and a linear estimation for it based on EFSO (right). Black contours show the analysis. Magenta cones show the target area of the observation impact estimate.

shown in the left panel of Figure 2. The forecast initialized from the analysis that assimilated the “bad” observations shows a dipolar structure inside the target domain (magenta cone). A linear estimation of forecast changes based on EFSO (Fig.2, right panel) “predicts” that this dipolar error can be partially

cancelled by not using the flawed observations, which matches the actual (nonlinear) change of the forecast (Fig. 2, middle panel).

Sifting Through the Treasure Trove of Data

To find out whether the PQC was ready to be assimilated into the operational system, Dr. Daisuke Hotta (Hotta, 2014) took a few considerations into account. These included:

- Which is the best-suited DAS (ensemble/variational hybrid) for the PQC to run?
- Whether a shorter lead time was enough to capture meaningful signals of the forecast errors: This would be particularly useful because operational systems usually have early analyses for short-range forecasts, and “final” analyses that include delayed observations. A readily available early analysis would allow an essentially “no cost” PQC for the final analysis.
- The values to reject and the cutoff criteria: Rejecting too many observations which are noted as potentially “bad” can lead to forecast degradation as there is not enough data to initialize the model, but rejecting too few would make little difference to the forecast improvement.
- Confirming whether excluding the “bad” observations improved analyses and forecasts.

Given the considerations above, Hotta (2014) explored the EFSO diagnostics tool by applying it to NOAA quasi-operational systems with essential help from Dr. Sid Boukabara (JCSDA) and Dr. Jim Jung (NCEP). The PQC scheme was applied to a lower-resolution version of the operational ensemble/ three-dimensional variational (3D-Var) hybrid Gridpoint Statistical Interpolation (GSI), and tested over three different forecast lead-times of 6, 12 and 24 hours.

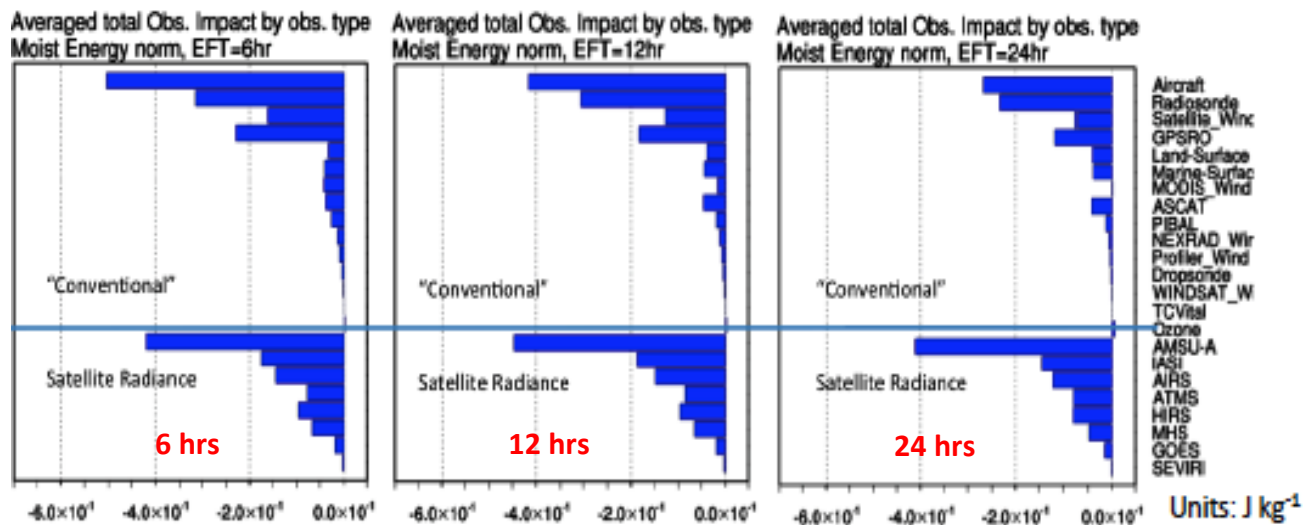
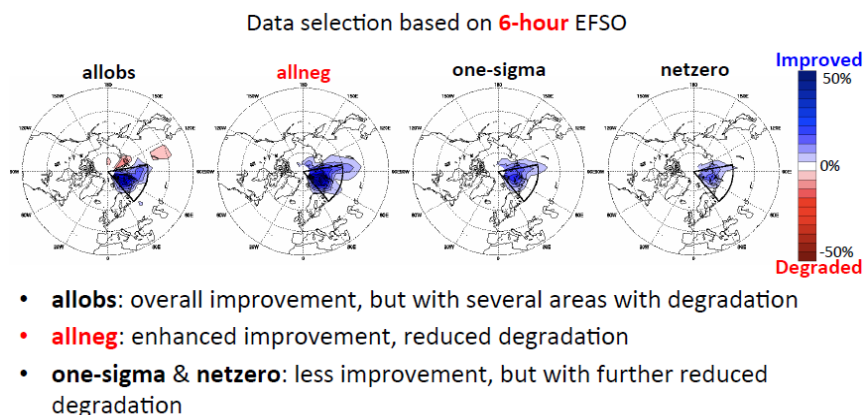


Figure 3: Average net observation impact for each observation type for lead-times of (left) 6 hours, (middle) 12 hours and (right) 24 hours. The forecast errors are measured with the moist total energy norm (unit: $J\ kg^{-1}$).

They found that EFSO results were not very sensitive to the choice of verification used, i.e., pure ensemble or hybrid, and that the evaluation lead-time as 24, 12 and 6 hours gave similar results. This meant that the EFSO scheme can be applied to any sort of NWP system and moreover can be used on operational DA cycle timeframes.

Next Hotta (2014) ran a series of data denial experiments to help them determine how to best implement the PQC scheme. They analyzed which platform-specific observations to reject, how many of those observations should be thrown out and, more importantly, whether the exclusion of the “bad” observations identified by the 6-hour EFSO improved the forecast. They ran experiments on 20 selected forecast failure cases, in which the analysis and forecast were repeated for various scenarios which removed the flawed observations. As shown in the figure below, when they excluded all observations, they noted an overall improvement in the forecast albeit with several areas of degradation. When they excluded very few observations, it made little to no difference on the forecast. However, when the researchers excluded all of the negative impact observations, i.e., the MODIS wind observations which were flagged as “bad”, the forecast greatly improved.



Future Directions

Recent findings suggest that “bad” observations often go undetected and end up being assimilated into forecasts; this was shown to be a major cause of the abrupt drop in performance in NCEP’s 5-day forecast skill. The EFSO could detect the observations that caused degraded 24-hour forecasts, an achievement which generated a lot of excitement among members of the DA research community. Recent work has shown that by using PQC methods, flawed observations could be detected in as few as 6 hours after the analysis by EFSO and that 24-hour forecasts could be improved by using information retrieved from a mere 6 hours of analysis. Therefore, if implemented into operations, the early analyses for short-range forecasts can be employed as a “no cost” PQC for the 24-hour forecasts and may avert the need for more costly and time consuming OSEs.

The research team at the University of Maryland (UMD) is now undertaking the final steps towards the operational implementation of PQC into the NCEP NWP system. If it is implemented to the operational system, PQC will allow NWP centers more sophisticated and effective utilization of satellite observations, further maximizing their benefit to society and economy through minimizing uncertainty of weather predictions.

Moreover, a detailed database can be created from all the flawed observations that will be stored in the PQC. Such a database would be of high value to algorithm developers who can utilize it to identify and rectify the problem that produced the “bad” observations, avoid future occurrences, and also to make improvements to their algorithms.

Sources:

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JPSS USER PERSPECTIVE
What the users are telling us about JPSS

Section 10

**NOAA Satellite Training: Preparing the End-User Community
for New Data and Products from the Nation's Next Generation
Environmental Satellites**

Joint JPSS/GOES-R Science Seminar

*This article is based in part on the **August 18, 2014** Joint JPSS-GOES-R science seminar presented by Brian Motta – NWS Training Division/Forecast Decision Training Branch, Wendy Abshire – UCAR/COMET, Chad Gravelle – Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the NWS Training Center.*

Contributing editors: Brian Motta, Wendy Abshire, Chad Gravelle, Mitch Goldberg, Julie Price, and William Sjoberg

**“Tell me and I forget, teach me and I may remember,
involve me and I learn.”**

– Benjamin Franklin

Training is critical in any industry, or organization, and especially a technical one, where it is necessary for new capabilities to transition from research to operations. Training is put in place to improve or sustain excellence in performance. This is a challenge in both of the National Oceanic and Atmospheric Administration’s (NOAA’s) primary satellite programs, the Joint Polar Satellite System (JPSS) and Geostationary Operational Environmental Satellite R-Series (GOES-R). The first of these next-generation satellites – the Suomi National Polar-orbiting Partnership (S-NPP) – launched in October 2011. Its next generation sensors deliver critical environmental data to key users including NOAA’s National Weather Service (NWS) and others around the world. The JPSS Proving Ground and Risk Reduction (PGRR) Program has provided the necessary technical details of the S-NPP sensors, and current and proposed applications of its capabilities to user training cadres to encourage the effective operational application of these capabilities. The next generation geostationary weather satellite, GOES-R, will carry significant improvements and technology innovation on board. GOES-R will be able to deliver a full disk (hemispheric) scan in only 5 minutes, compared to the 25 minutes needed for the same task with the current GOES satellites. Training will again be a critical component of the successful operational application and exploitation of the new JPSS and GOES-R capabilities.

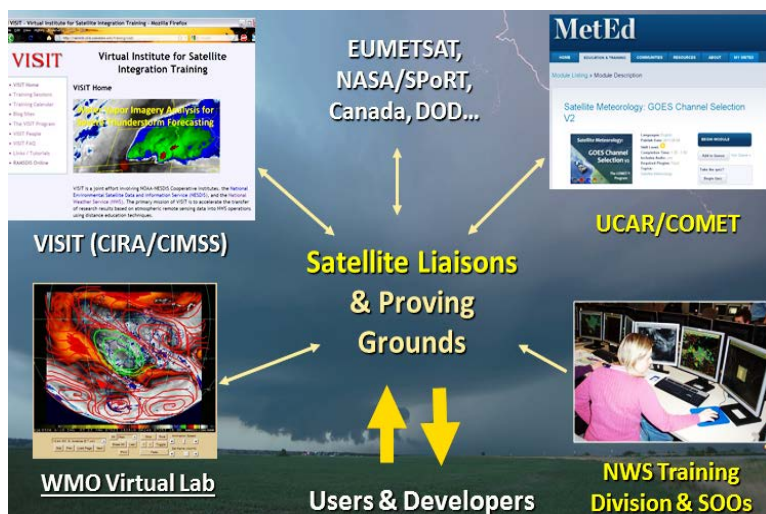
NOAA’s Satellite Training Community

If user communities are not in a position to properly exploit the wealth of NOAA’s satellite data, products and services, how can they realize the full benefits of its operational satellite systems? For NOAA and its agencies, training is necessary to ensure that the users, and especially operational forecasters, have access to the full range of NOAA’s satellite data, products and services, and are able to transition these capabilities into their operational missions as quickly and effectively as possible. The need for this type of training has been recognized as an essential ingredient in NOAA’s vision for a world-class workforce to support NOAA’s mission of "Science, Service, and Stewardship". The integral role that training plays within the agency and to its programs and goals are outlined in NOAA’s Next Generation Strategic Plan (NGSP) (<http://www.ppi.noaa.gov/ngsp/>) and other planning documents.

NOAA has established a collaborative multi-agency satellite training program involving a base of community participants including training developers, operational forecasters, and scientists from several organizations and external agencies. International partners like Canada, Japan, and EUMETSAT

have also become involved. The NOAA training community works collaboratively with its partners to ensure that operational forecasters know how to use the currently available satellite products, and to stimulate use of future satellite observations and products in operational environments. This fosters the ability of NOAA users not only to understand the basic science underpinning satellite capabilities, but how to integrate this science into their operations, in order to gain the most important operational benefits.

Joint JPSS-GOES-R Training Science Seminar



On August 18th, JPSS and GOES-R held a joint science seminar on the satellite training efforts currently taking place in NOAA. This seminar is part of an ongoing series of joint science seminars between JPSS and GOES-R. The presentation provided details of NOAA’s satellite training program and its key partners including: the NWS Training Division and Operations Proving Ground (OPG); federal agencies such as NASA Short-term Prediction Research and Transition Center (SPoRT)

(weather.msfc.nasa.gov/sport/), the Federal Emergency Management Agency (FEMA), the U.S. Department of Defense (DoD), and the Federal Aviation Administration (FAA). Additional satellite training is also provided by the University Corporation for Atmospheric Research (UCAR) Cooperative Program for Operational Meteorology, Education, and Training (COMET) satellite education resources (www.meted.ucar.edu/), the Cooperative Institute for Research in the Atmosphere (CIRA) Virtual Institute for Satellite Integration Training (VISIT) (<http://rammb.cira.colostate.edu/training/visit/>), and the Cooperative Institute for Meteorological Satellite Studies (CIMSS). International organizations such as the World Meteorological Organization (WMO) Space Programme Virtual Laboratory for Training and Education in Satellite Meteorology (VLab) (www.wmo-sat.info/vlab/) are also involved. Seminar presenters provided examples from the aforementioned elements, to show how they help users of NOAA satellite data prepare for the changes that will be brought upon by the Nation’s next generation weather satellites.

Delivering Training to NOAA’s Satellite User Communities

As it is of utmost importance that NOAA’s user communities are able to apply the capabilities from its satellite data, products and services in their operational environments, the agency’s satellite training community has developed a variety of satellite training resources. These resources are full of valuable material, which are delivered through various training mechanisms and levels, including:

- ❖ Foundational Training, which underpins basic concepts of the operational uses of satellite sensors and imagery. Foundational Training describes the satellite programs, the satellites,

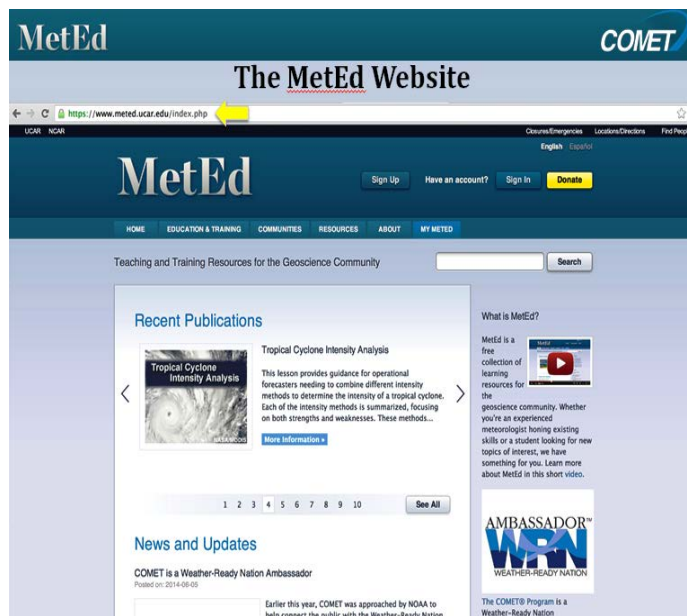
sensors, imagery and their uses is offered, and is offered by a number of enterprises including the Cooperative Program for Operational Meteorology, Education, and Training (COMET), the Virtual Institute for Satellite Integration Training (VISIT), and some specialized training centers and satellite operators known as Centres of Excellence (CoEs).

- ❖ Satellite Applications Training, which focuses on the application of satellite data products and services to environmental challenges such as severe weather events; and
- ❖ Focused Organizational-level Training which is done by individuals in the training centers, i.e., satellite liaisons.

The organizations that are key elements of these resources are now discussed.

Cooperative Program for Operational Meteorology, Education, and Training

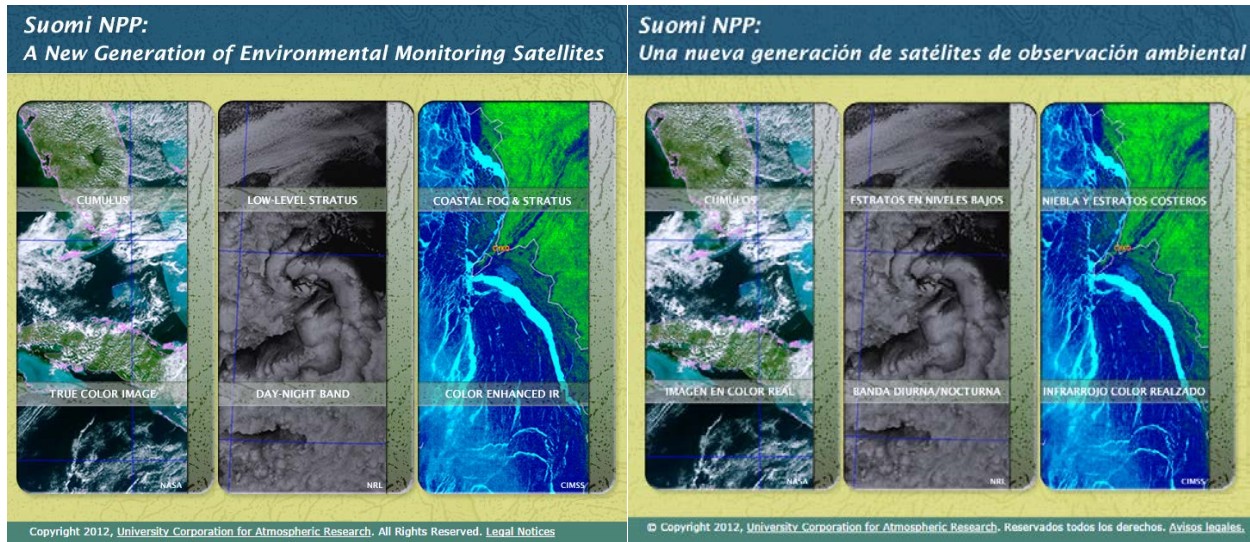
The COMET® Program is part of the University Corporation for Atmospheric Research's (UCAR's) Community Programs (UCP). COMET offers foundational and satellite applications training in weather and related sciences. As a key trainer to users of NOAA satellite data, COMET produces training modules focused on the integration of geostationary and polar-orbiting remote sensing data into operational applications and forecast processes. Through its MetEd website, COMET offers these free online self-paced training modules on a range of atmospheric and geoscience related topics. Many of these modules are uploaded to the NOAA/NWS Learning Management System (LMS) where forecasters can review them for training credit. The training materials focus on the capabilities and applications of current and next-generation satellites and their relevance to operational forecasters and other user communities including those in academia, and private industry.



The COMET program's training activities are funded by several organizations, including the JPSS and GOES-R satellite programs, U.S. Department of the Interior, NOAA National Environmental Satellite, Data and Information Service (NESDIS), NOAA's National Geodetic Survey (NGS), Commander Naval Meteorology and Oceanography Command (CNMOC), and the U.S. Army Corps of Engineers (USACE). It also receives funding from international partners, including the Bureau of Meteorology of Australia, the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT), and the Meteorological Service of Canada (MSC).

COMET's training efforts reach out to regional and global user communities. In fact, one third of COMET users are international. The MetEd website has become a popular destination for the education community making them the largest users of COMET training material globally. In response to its user

needs, MetEd offers over 100 satellite-specific modules in English, Spanish, and French. For example the module below is available in both English and Spanish. It describes the history of polar-orbiting satellites and the role and mission of S-NPP and JPSS. The first half describes its mission, products, and instruments, while the second half focuses on its role in environmental monitoring, offering examples of how it detects and monitors Earth's climate, land and ocean surfaces, atmosphere, and space weather.



Capacity building – a key element in COMET’s training program – refers to strengthening the skills, competencies and abilities of individuals, groups, organizations and societies. COMET activities related to capacity building include participation in a global network of specialized training centers, including the WMO Virtual Laboratory (Vlab). The key objective of the VLab is to improve the world wide utilization of satellite data and products throughout WMO Members. These centers – called Centres of Excellence (CoEs) – provide training on meteorological and environmental satellite systems, data, products and applications used in other regions of the world including Africa, Europe, Asia and parts of South and Central America. These centers organize workshops, training courses, expert meetings and

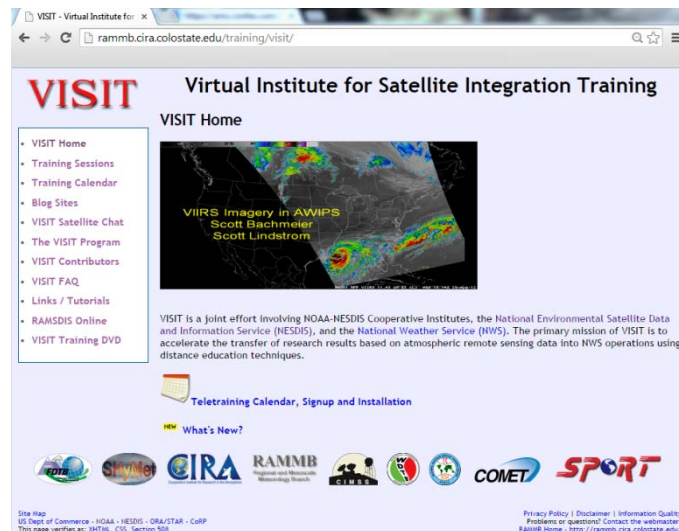


Centres of Excellence (represented by their national flag) and their supporting satellite operators (highlighted in yellow).

seminars dealing with a wide range of satellite applications within their regions. For example, a training series on African Satellite Meteorology Education and Training (ASMET) is done in partnership with COMET and forecast centers in Africa. NOAA’s satellite training program utilizes the capabilities of these centers to meet user needs for increased skills and knowledge in using satellite data within their region.

Virtual Institute for Satellite Integration Training (VISIT)

NOAA's Virtual Institute for Satellite Integration Training (VISIT) connects trainers with forecast offices remotely using teletraining—an approach that combines the use of the Internet and audio conferencing – with the goal to accelerate the transfer of research results based on atmospheric remote sensing data into NOAA operations. VISIT is comprised of staff from various institutions including, CIMSS, CIRA, NESDIS, and the NWS training division. While live sessions are limited to NOAA employees, recorded sessions are available without restriction. VISITview – a software package designed for VISIT training sessions – provides live two-way interactions.



Satellite Liaisons

Satellite liaisons provide support to NOAA's National Centers for Environmental Prediction (NCEP) and NWS Forecast Offices. They are the backbone of focused organizational-level training. At these centers, satellite liaisons maintain a consistent presence in operations to continuously promote the use of satellite data amongst the operational user community in solving specific forecast challenges. They also familiarize forecasters to the capabilities of NOAA's next-generation satellite systems. Almost all forecaster training is in person, either individually or in small groups consisting of 3-5 analysts/forecasters. Training sessions are based on the products that are considered to have immediate benefit to the respective NCEP Center. The satellite liaisons are key members of the JPSS and GOES-R Proving Ground Programs where they help establish various satellite capability demonstrations, set up seasonal focused applications, and provide training on an ongoing basis to the operational forecasters at their location. They are essentially research-to-operations liaisons, as they provide training for satellite product users, and gather and synthesize user feedback to empower product developers to consider and implement further product improvements. More than a link between the developers and users, satellite liaisons are considered the local subject matter experts (SMEs) that provide valuable input into the development and execution of the training programs.

Liaisons also provide training to operational forecasters in Weather Forecast Offices (WFOs) as the opportunity allows. Unlike at national centers, almost all forecaster training at WFOs is done remotely (e.g., live teletraining such as VISIT). This is due to the large number of WFOs (over 100). When available, live tele training, which is given by the satellite liaison or the product developer, is offered to the WFO(s). To supplement the live tele training WFOs also receive recorded training materials.

These liaisons will become even more critical in the future in response to the challenges of the operational integration of the large volume of data from NOAA next generation satellites. They will be critical in ensuring the more intelligent integration of information derived from blended satellite products (e.g., geostationary and polar satellite observations), multi-dimensional classification of severe

storm potential by combining satellite, radar, in-situ data and models, and new ways of visualizing GOES-R data within the next generation operational decision support platform known as the Advanced Weather Interactive Processing System (AWIPS-II). To serve the different needs and skills of satellite data users, liaisons employ various training tools, including COMET, VISIT, and the Proving Grounds (PGs). These tools also show how the satellite can really benefit the forecaster and how satellite data can be incorporated within tools already in use.

Proving Grounds (PGs)

NOAA's JPSS and GOES-R PGs were established to ensure user readiness in the area of satellite services, and are fundamental elements of the satellite training program. The PGs promote outreach and coordination of new products with the end users, incorporating their feedback for product improvements. In addition, they facilitate R2O by helping end-users, such as an environmental modeling center or NWS WFO, prepare for the future satellite observations, get real-world experience by leveraging existing resources, and evaluate product enhancements. Working with NWS users, PG projects assist in the application of improved products to help with decision support services (DSS), forecasts, and warnings via the research-to-operations (R2O) and operations-to-research (O2R) process. Conversely, R2O allows for operational readiness evaluations through forecaster endorsement, validation of usability, usefulness for decision making, and workflow impact. The R2O and O2R synergy is essential to maximize the benefit of NOAA satellite systems to the NWS and for the algorithm developers to take advantage of the meteorological expertise of the NWS to help validate their work. By creating a streamlined R2O and O2R process, an iterative, two-way interaction between science and technology (S&T) development and NWS operations is optimized. With an effective O2R/R2O environment, this knowledge will continue to lead to better weather predictions.

National Weather Service Training Division: Integrating S-NPP and Getting Ready for GOES-R

Since its inception, the NWS has provided forecasts of severe weather threats and issued warnings to communities across the U.S. Technology, and the rapid pace at which it develops, is a major factor contributing to the need for education and training within the NWS. Equally important, majority of the data used in the Numerical Weather Prediction (NWP) models at the NWS come from satellite observations. Therefore, to acquaint operational forecasters with satellite data, it must be understandable, accurate and at the very least be proven superior to (or at least equal to) the other options in helping solve their specific forecast challenges.

The NWS recognized the need to capitalize on training to help its forecasters effectively use the new technologies and data to better predict severe weather events. To this end, it has developed a diverse portfolio of activities, which include a training program that offers satellite training development activities to its operational forecasters and end-users of NOAA's satellite products and applications. It is intended to ensure that they are better able to integrate science into their operations. The NWS training division provides training in variety of formats to meet needs of learners. These include the traditional COMET modules, S-NPP data sets, videos, quick guides, the VLab, and etc., in addition to test bed experiments, OPG operational readiness evaluations, and satellite Proving Ground/User Readiness meetings. Examples of some training activities that are in place or are being considered include:

Pre-launch information teasers

Pre-launch information training courses often begin six months before a satellite is launched. They include 1-2 minute information “teasers” or Youtube videos that build upon existing satellite videos. These videos feature some introductory examples that are used to set a baseline understanding, along with examples on applications of satellite data.

Just-In-Time Training (JITT)

JITT incorporates web- and intranet-based applications. These are scheduled to start once GOES-R data become available on AWIPS II. Real-time access to an expert will also be available 24 hours a day, seven days a week.

Science Infusion Week

Science Infusion Week is a new concept slated to start after the launch of GOES-R. It is a one-week in-residence workshop, for the Science Operations Officer/ Development and Operations Hydrologist (SOO/DOH). It will focus on integrating new data and emerging science into the forecast and warning process. The SOO and DOH provide guidance in technical areas (e.g., the use of technologies and tools in local studies), ensure scientific rigor is maintained, and safeguard data integrity in the conduct of office activities.

Summary

NOAA’s next-generation satellites will continue providing valuable data to support high impact weather warnings as well as key inputs for global and regional NWP models. They will also continue to support NOAA’s warning and prediction operations, its operational forecasters and other user communities, and applications in environmental analysis. However, the data from these satellites cannot be employed in the absence of the necessary scientific knowledge, experience and technical skills. An effective training program is critical to creating and maintaining the required knowledge and skill levels to optimize the use of these new capabilities.

As NOAA’s satellite programs, dissemination systems and forecast and warning operations continue to evolve, the agency is taking several steps to prepare its staff and partners for the ensuing changes. The first in line of new generation satellite systems, S-NPP is already delivering data in unprecedented amounts and speeds. Its follow-on, JPSS-1, is expected to generate even more data. Once launched, GOES-R will add even more data to the NOAA’s burgeoning environmental database. NOAA’s satellite training programs are taking several steps to ensure that new satellite products are easily understood and accepted as they become available. Increased familiarity with COMET’s training program, VISIT training material, and effective satellite liaison one-on-one training sessions will be key to encouraging greater use of current and future satellite observations and products in operational weather forecasting. These training efforts are expected to continue bringing researchers and forecasters together to use and evaluate products and applications that will allow them to create better forecasts and timely warnings.

JPSS USER PERSPECTIVE
What the users are telling us about JPSS

Section 11

**Infusing S-NPP PMW Retrievals to CMORPH Precipitation
Estimates for Improved Weather, Climate, and Hydrological
Applications**

*This article is based in part on the **September 29, 2014 JPSS science seminar** presented by Pingping Xie, NOAA Climate Prediction Center (CPC).*

Contributing editors: Pingping Xie, Mitch Goldberg, Julie Price, and William Sjoberg



Storm near Elko, Nevada. NOAA image obtained from <http://water.usgs.gov/edu/watercycleprecipitation.html>

Precipitation – rain, sleet, snow, freezing rain, hail and other variants are –key components of the water cycle. Precipitation replenishes the Earth’s water supply. Moreover, the condensation heating associated with precipitation drives large-scale atmospheric circulation, which is critical to weather forecasting and climate prediction. Extreme precipitation events, such as floods, blizzards, ice storms, etc. have substantial impacts on society which can include extensive property damage and loss of life. On longer time scales, precipitation effects are crucial to atmosphere-ocean interactions in climate variability, which is critical to climate monitoring and prediction. Needless to say, precipitation plays a dominant role in the development and decay of droughts. While the effects of precipitation are felt at local scales, understanding its role in the water cycle requires an accurate documentation of its global distribution. Therefore, it is important to develop tools that can provide precipitation measurements for the whole globe at a high time/space resolution.

Precipitation Measurements

Historically, precipitation measurements have been given by surface-based rain gauges and weather radars. Although they produce high quality surface measurements of precipitation, there are several problems and limitations associated with them. Rain gauges are widely scattered offering only limited spatial coverage. Furthermore, gauge observations are subject to errors (e.g. during snowfall and high wind speed, evaporation) and sampling biases as the observations represent local conditions. Surface-based radars are unavailable in many parts of the world. Moreover, their capabilities can be limited by beam blocking due to buildings and mountainous terrain. Moreover, radar data are not exchanged globally. Satellites, however, provide consistent coverage over large parts of the globe. Their observations provide precipitation estimates which are used by weather agencies such as the U.S.

National Weather Service (NWS) to complement the surface-based measurements and fill in the large observational gaps in regions with poor or no surface-based measurement coverage. The earliest methods for estimating precipitation relied on infrared sensors on geostationary satellites. More accurate estimates can be obtained using microwave observations, which at certain wavelengths, are sensitive to the radiation emitted from liquid cloud / rain droplets and that scattered by ice particles and large water droplets inside a cloud. However, these measurements are available only from low earth orbit (LEO) satellites which circle the Earth only a few times per day, potentially missing precipitation events. Thus, geostationary (GEO) IR is more complete but has poor accuracy, while passive microwave from LEO satellites is more accurate but has sparse sampling. For this reason, many data sets combine observations from multiple satellite platforms that carry passive microwave and/or infrared (IR) sensors. The IR sensors on GEO platforms produce cloud top temperature estimates which are used to derive precipitation estimates. The microwave sensors on LEO satellites derive the precipitation signal from both scattering and emission.

There is a pressing requirement for adequate observation and estimation of precipitation on a global scale stemming primarily from the paucity of such information over the vast majority of the Earth's surface.

*Global Precipitation Assessment: A Project of the GEWEX Radiation Panel, WCRP-128 (May 2008),
<http://www.gewex.org/reports/2008AssessmentGlobalPrecipReport.pdf>*

NOAA Climate Prediction Center's (CPC) MORPHing technique (CMORPH)

The NOAA Climate Prediction Center (CPC) MORPHing technique (CMORPH), was created to provide a single suite of unified precipitation products for global / regional applications. It does so by integrating passive microwave retrievals from LEO satellites with features from GEO satellite infrared data, to provide the best possible precipitation estimates for weather, climate and hydrological applications. In the original version of the CMORPH technique developed in 2002, the integration is carried out in two big steps. First, motion vectors of precipitating clouds are computed through comparing the two consecutive GEO IR cloud images that are 30 minutes apart. Precipitation retrievals derived from PMW measurements from individual LEO satellites are then propagated along the motion vectors from their respective observation times toward the target analysis time. This propagation is performed in both the forward and backward directions and the weighted mean, with the weights inversely proportional to the length of the propagation time, is defined as the final CMORPH integrated precipitation analysis. The CMORPH precipitation analysis is constructed on an 8kmx8km grid over the globe from 60°S to 60°N and in a 30-minute interval from January 1, 1998 to the present. The real-time update is performed twice at latencies of 3 and 18 hours, respectively.

Shortcomings in the Old Version CMORPH

CMORPH achieves best possible accuracy through integrating information from measurements from multiple LEO and GEO platforms. Shortcomings, however, exist in the old version CMORPH described above. These include:

- Limited spatial coverage (60°S-60°N) due to the use of GEO IR data to derive cloud motion vectors;
- An 8km spatial resolution that does not fully take advantage of the information from multiple sensors especially those from GEO platforms;
- Poor representation of cold season precipitation, especially snowfall due to the problems in the PMW retrievals used as inputs to the CMORPH integration system;
- Long latency times. The quick version – QMORPH – is produced three hours after the target analysis time, while the regular version is produced 18 hours after the target analysis time. While such latencies may suffice for operational climate monitoring and research purposes, they are not ideal for weather and hydrological applications. The ideal time to produce these estimates would be 1 hour, particularly for operational forecasters who require shorter latencies, and especially for potential life threatening events such as severe and flash floods, blizzards, ice storms and so forth; and
- A lack of uncertainty estimation. The uncertainty of a measurement provides information about its quality. There are two groups of users that rely on uncertainty estimations. One is modelers, who need uncertainty estimates in their ensemble assimilations. Therefore, the CMORPH uncertainty estimates would serve as some sort of index to help them determine how large the spread should be. The other group is NOAA weather forecasters who use uncertainty estimates as the ground truth. They need to know how reliable the information is at certain points, seasons or locations.

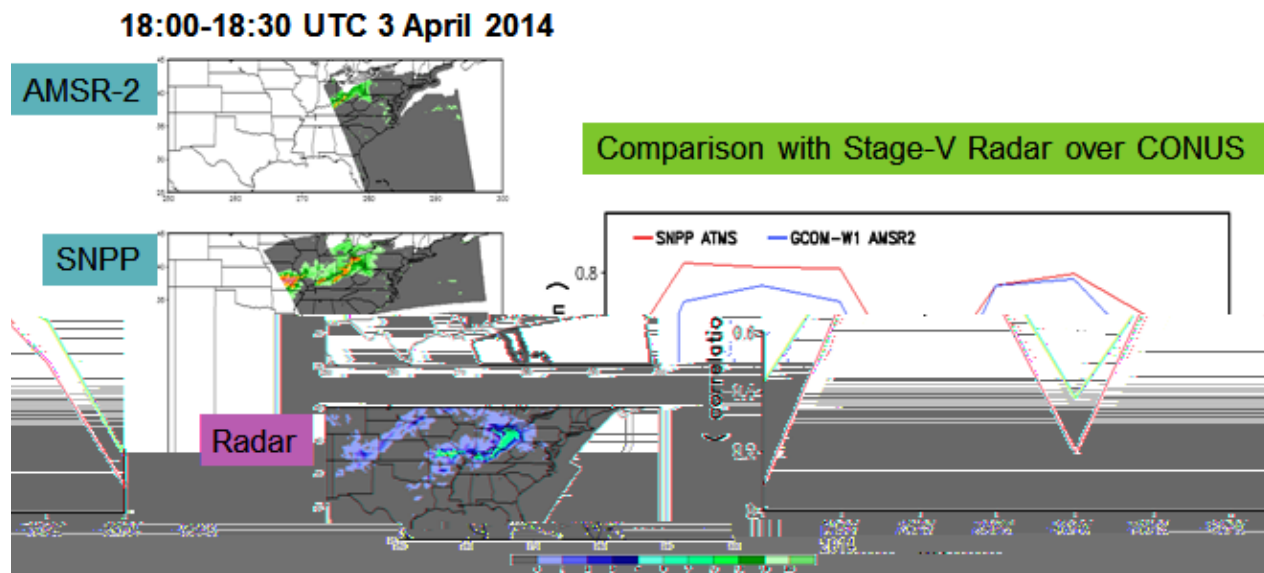
CMORPH Revamped! Using Multi-Sensor Data from NOAA Satellites to Deliver Improved Weather, Climate and Hydrological Products

Given the shortcomings with the current CMORPH, scientists at CPC, in close collaborations with developers of the satellite retrievals at NESDIS and users of the final products at several NOAA operational centers and universities, are making improvements that will lead to pole-to-pole precipitation analyses with complete global coverage, and at a more refined spatial resolution. This will be accomplished through the infusion of PMW precipitation retrievals from the current S-NPP ATMS, the GCOM/AMSR-2, and future JPSS and GPM satellites. The new CMORPH is expected to improve the representation of snowfall and cold season rainfall, shorten the latency of the real-time CMORPH, and include an uncertainty estimate. Since CMORPH is an integration technique, the first step in its development is an examination of potential sources of information for the definition of precipitation. These include:

PMW retrievals

Retrievals from space borne PMW sensors provide estimates of instantaneous precipitation rates and are the backbone of modern satellite-based global precipitation data sets. PMW precipitation retrievals are derived from measurements of two types of the sensors. Retrievals from PMW imagers, such as

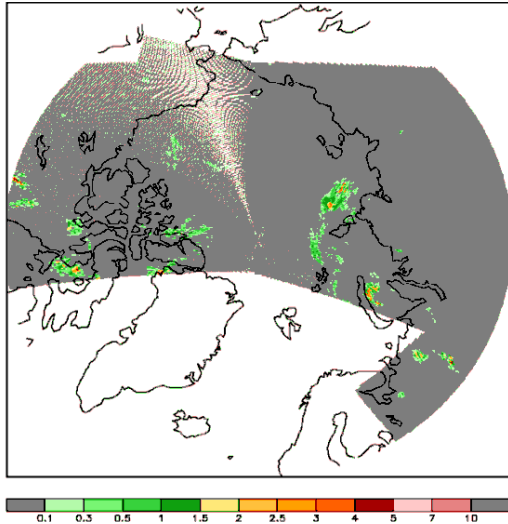
AMSR-2, present high quality in depicting precipitation distribution. The second source of information comes from PMW sounders like ATMS. The key benefit from PMW sounders is that they provide precipitation estimates over a wider region compared to imagers, which helps improve spatial and temporal sampling. S-NPP/ATMS precipitation retrievals derived by the NESDIS Microwave Integrated Retrieval System (MiRS) present excellent skills in capturing precipitation and its variations.



As shown on the left side of the figure above, a heavy precipitation event associated with a large-scale synoptic system is well captured by the S-NPP/ATMS based retrievals, with a wider spatial coverage than that for the retrievals from a PMW imager (AMSR-2). Further quantitative comparisons against the Stage-V radar estimates over CONUS (the right side of the figure above) demonstrate the superior quantitative accuracy of the MiRS ATMS retrievals compared to that of the AMSR-2. These results have given CPC scientists enough confidence to infuse it into the CMORPH system.

IR-based estimates

One huge shortcoming with the current generation techniques used to retrieve microwave precipitation estimates is that during the cold season if there is snow/ice on the ground, PMW retrievals cannot separate the rainfall/snowfall signals away from cold land surfaces and ice-covered or snow-covered areas which means that there will always be gaps. Therefore, alternate techniques that can provide precipitation estimates are necessary to cover those gaps. One such technique, developed by the CPC, derives precipitation estimates using IR measurements from the Advanced Very High Resolution Radiometer (AVHRR) onboard NOAA's polar-orbiting satellites. While the AVHRR measurements provide useful updated information a few times per day, they are not as good as microwave estimates. Below is an example of precipitation estimates derived from polar-orbiting satellite IR. These estimates were obtained from geostationary and polar-orbiting satellite IR based precipitation estimates, which are generated through calibration against PMW retrievals including those from the S-NPP. They were found to perform reasonably well compared to PMW based retrievals over high latitudes at least during warm seasons.

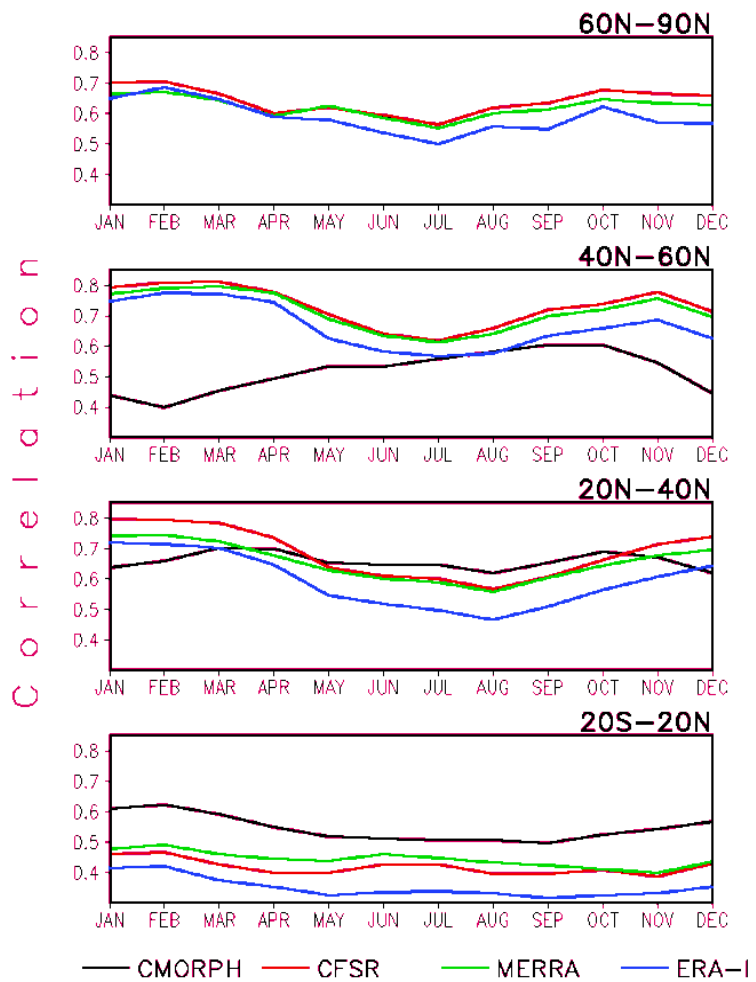


Correlation with Finland Radar 30-min Precipitation

Satellite Estimates	Land	Ocean
PMW retrievals from NOAA 18	0.380	0.353
IR-based estimates from NOAA 18	0.227	0.318

Numerical Model Simulation

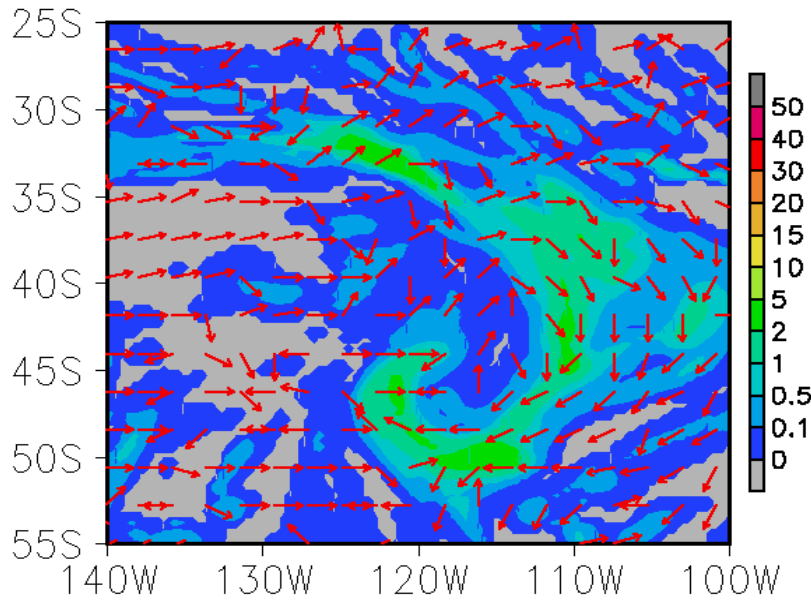
The scientists also examined the performance of the precipitation fields generated by three sets of high-resolution global reanalyses from the National Centers for Environmental Prediction (NCEP) Climate Forecast System Reanalysis (CFSR), NASA’s Modern Era Reanalysis for Research and Applications (MERRA), and ERA-I. These were compared against a daily gauge analysis covering a 12-year period from 1998 to 2009. The scientists found that even though CMORPH outperforms the reanalyses in capturing precipitation over tropics and during warm seasons over sub-tropics, the reanalyses precipitation fields perform very well over mid- and high latitudes, and over cold seasons in the sub-tropics.



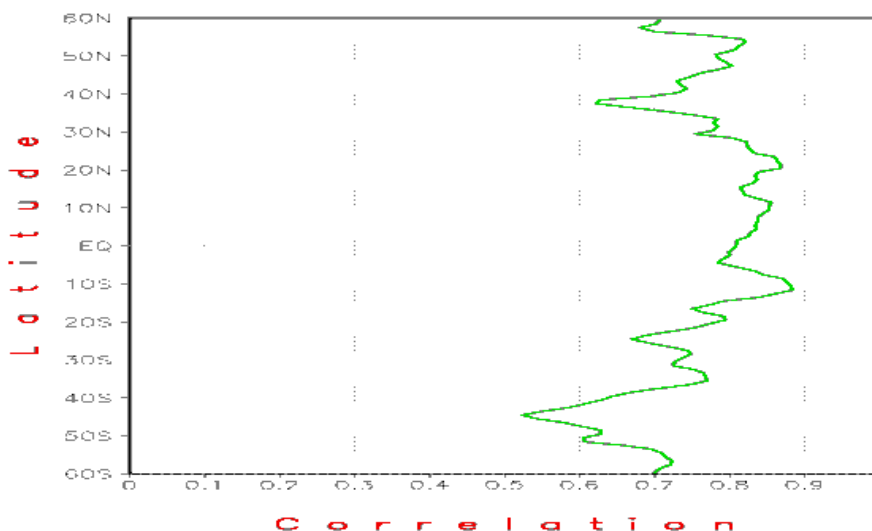
Computing cloud motion vectors over the entire globe

After examining the potential sources of information, CPC scientists are developing a technique to compute cloud motion vectors, which are an important input to the CMORPH system. The CPC scientists plan to modify this technique so that they can obtain motion vectors from pole to pole. Cloud

Vectors from CFSR Model Precipitation



Correlation between propagated and observed GEO-IR precipitation



motion vectors are computed from consecutive fields of precipitation through the cross-correlation method. First, motion vectors of precipitating clouds are derived from the CFSR precipitation fields (see top figure on the left). This serves as a first guess covering the entire globe. Next, the vectors are derived from geostationary IR based precipitation estimates. Retrievals of instantaneous precipitation rates from individual polar-orbiting satellite platforms including the S-NPP are then propagated from their respective observation times to the target analysis time using the motion vectors. The propagated PMW retrievals are then blended with the precipitation estimates derived from the geostationary IR data through the Kalman filter framework, in which the propagated PMW and the geostationary -IR based estimates are utilized as the prediction and observation, respectively. These vectors derived from PMW and AVHRR IR estimates will be included to improve the vector definition, especially over high latitudes.

Improving Snowfall Representation

The operational production of snowfall rate retrievals from PMW sounders including those from S-NPP/ATMS has enabled CPC scientists to develop an integrated snowfall rate analysis under the

CMORPH framework. The figure on the right is an application example of an improved snowfall representation from the new CMORPH.

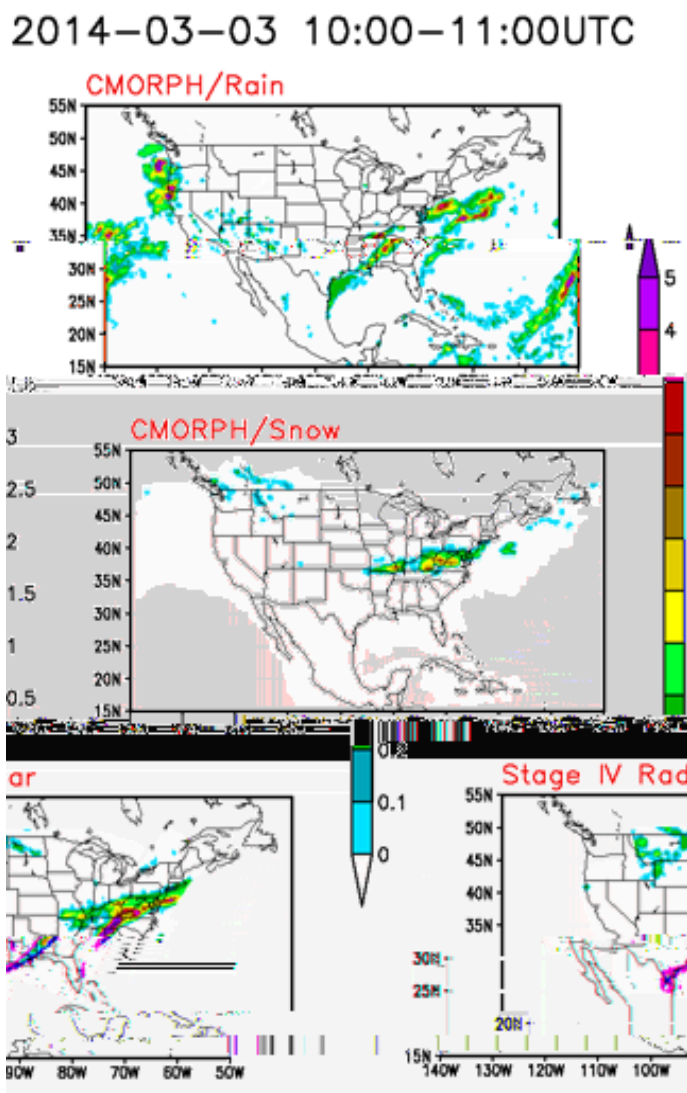
On March 3, 2014, a powerful snow storm hit the U.S. East Coast with freezing rain, snow and frigid temperatures. Most computer models foresaw a widespread heavy-snow event, and this storm did not disappoint them. While the old CMORPH captured the event, the results it generated, which are illustrated in the figure on the right, pointed out some deficiencies within the system. The top image shows the traditional CMORPH, which picked up the rainfall in the warm part of the system but missed the snowfall. The middle image shows the improved product, CMORPH/Snow, which captured the snow in the cold part of the system. The bottom radar image illustrates two bands of precipitation (rain/snow) associated with the warm and cold part of the frontal system. By combining the traditional CMORPH, with the improved product, they produce an excellent match with radar.

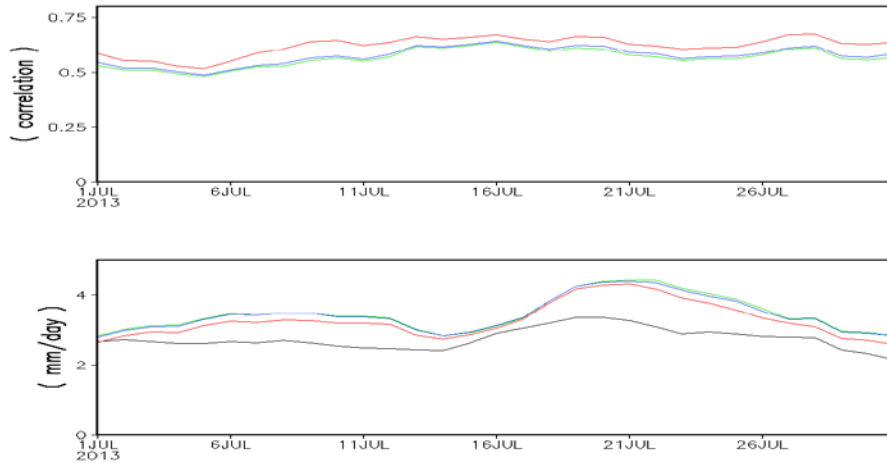
Where Does the CMORPH Latency Come from?

CMORPH is produced twice – the quick version at a delay of 3 hours, and the regular version at a delay of 18 hours. Its current operational schedule was determined over 10 years ago based on the data availability at the time. The CMORPH latency is caused primarily by the availability of Level 2 PMW retrievals, which depend on the temporal intervals between two consecutive satellite orbits, and the delay in Level 2 retrievals production. However, in the recent years an increase in the availability of PMW retrievals from polar-orbiting satellites including S-NPP, and more timely production of the Level 2 retrievals at the NESDIS Operation, has greatly improved the situation.

Importance of S-NPP/ATMS retrievals

The availability of PMW retrievals from polar-orbiting satellites including S-NPP, and more timely production of the Level 2 retrievals, has made it possible to create a quick version CMORPH at a reduced latency of 1 hour for potential applications in real time monitoring. Preliminary experiment results have shown it to present quite good skill and overall quantitative consistency with that generated at the 3 and 18 hour latencies, demonstrating the importance of the contributions from the S-NPP retrievals.

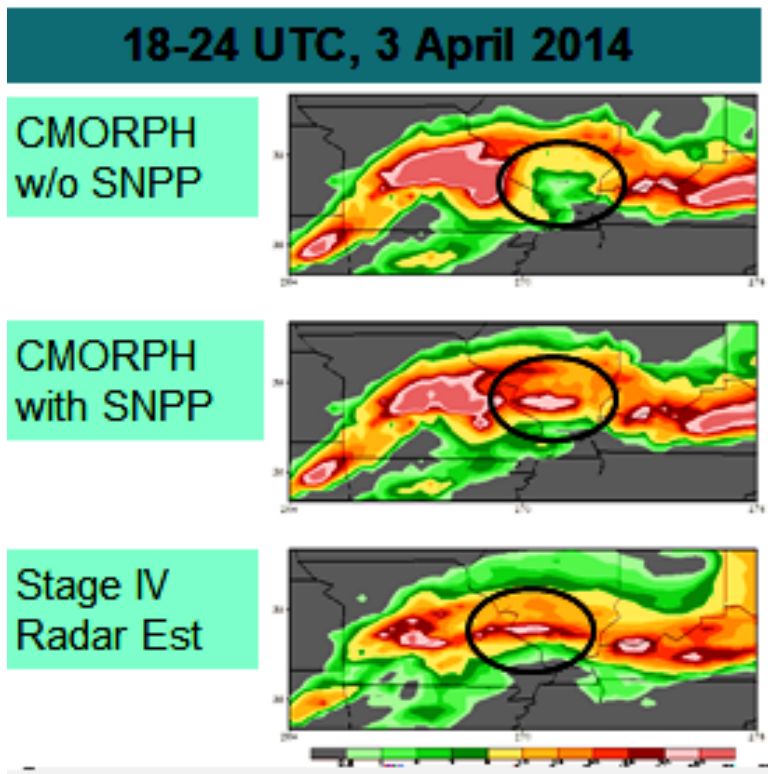




Comparison with radar over CONUS

- Red: CMORPH 18-hour
- Blue: CMORPH 3-hour
- Green: CMORPH 1-hour

First, the MiRS ATMS retrievals provide high quality precipitation estimates and also at a much wider spatial coverage along the satellite orbits. Secondly, MiRS ATMS retrievals improve the quality of combined PMW estimates used to calibrate the geostationary and polar-orbiting satellite IR based precipitation estimates that are also used as input to the new CMORPH. The example on the right, of a precipitation event on April 3, 2014, shows how the quality of CMORPH improves with the infusion of MiRS ATMS retrievals from S-NPP. In the top image S-NPP retrievals were excluded. However, with the infusion of S-NPP retrievals (middle image), CMORPH picked up the heavy precipitation, which correlated much better with the radar estimate (bottom image).



Summary

Ground-based precipitation measurements are usually inadequate, and not always readily available, due to a variety of challenges. Moreover, our ability to predict and monitor the occurrence, location and duration of precipitation events on a global scale cannot be accomplished without satellites. In poorly gauged regions, satellite precipitation products may be the only input data timely enough to allow flow predictions downstream with enough lead time to implement management and response actions based on such predictions. The 2nd generation CMORPH provides an effective and flexible platform for precipitation information integration. Moreover, the S-NPP/ATMS Level 2 retrievals of rainfall and

snowfall rate play a key role in the production of the CMORPH integrated precipitation estimates. This has led to products such as the CMORPH blended snowfall analysis, which utilizes retrievals from S-NPP and other polar-orbiting satellite sensors. In addition, the availability of global IR data on a half-hourly basis makes CMORPH data attractive to use as a means to propagate PMW derived precipitation, producing spatially and temporally complete global precipitation analyses. With these capabilities CMORPH has been recognized as the first successful blended analysis of snowfall rate in the world.

