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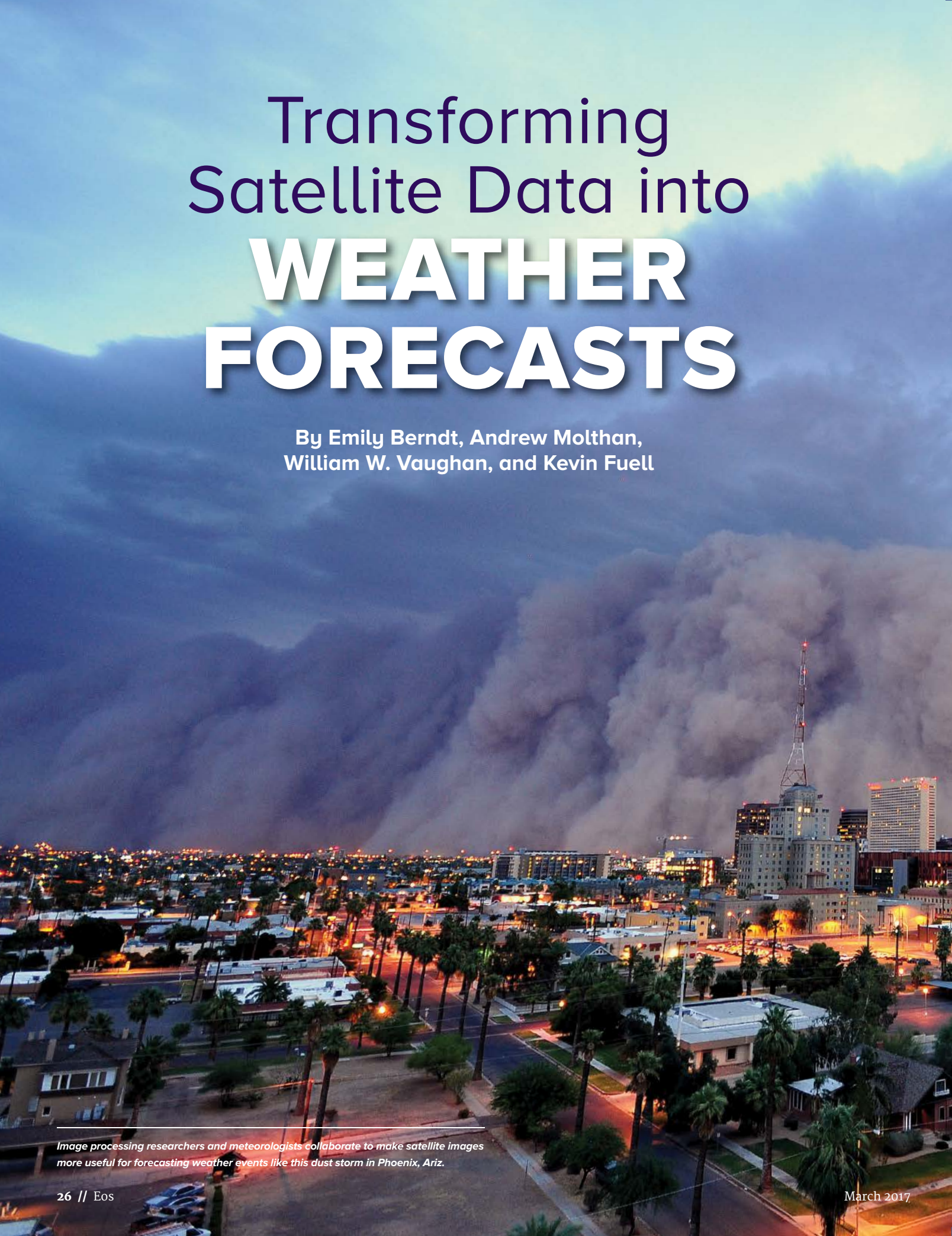
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SATELLITE DATA for Weather Forecasting



Transforming Satellite Data into **WEATHER FORECASTS**

By Emily Berndt, Andrew Molthan,
William W. Vaughan, and Kevin Fuell

Image processing researchers and meteorologists collaborate to make satellite images more useful for forecasting weather events like this dust storm in Phoenix, Ariz.



Satellite imagery has been of immense benefit to weather forecasters. With it, they can assess aviation hazards such as low clouds, monitor thunderstorms, and track the evolution of dust plumes.

Satellite sensors are continually evolving to provide ever greater imaging capabilities, and researchers continue to develop advanced techniques to identify hazards in satellite imagery. However, barriers can prevent experimental products from reaching forecasters in the operational environment.

A NASA project has developed an interactive process whereby weather forecasters learn to interpret the latest satellite imagery and apply it to their operations. Forecasters then provide feedback to the researchers who are developing algorithms and products to further improve future products. This effort has taken on greater importance with the anticipated launch of a new series of satellites that

will provide substantially greater amounts of data than are currently available.

Visualizing a Wealth of Data

Multispectral composites combine satellite data collected at different wavelengths of the electromagnetic spectrum and present them as red-green-blue (RGB) images, which serve as enhanced representations of specific phenomena such as low clouds and fog. With the launch of the Geostationary Operational Environmental Satellite-R Series (GOES-R, now called GOES-16) on 19 November 2016 and the first of the Joint Polar Satellite System (JPSS) series in 2017, U.S. National Weather Service (NWS) forecasters will have access to a wider array of imagery than is available with the current GOES satellites.

The current GOES satellites collect data from only five ranges of wavelengths in the electromag-

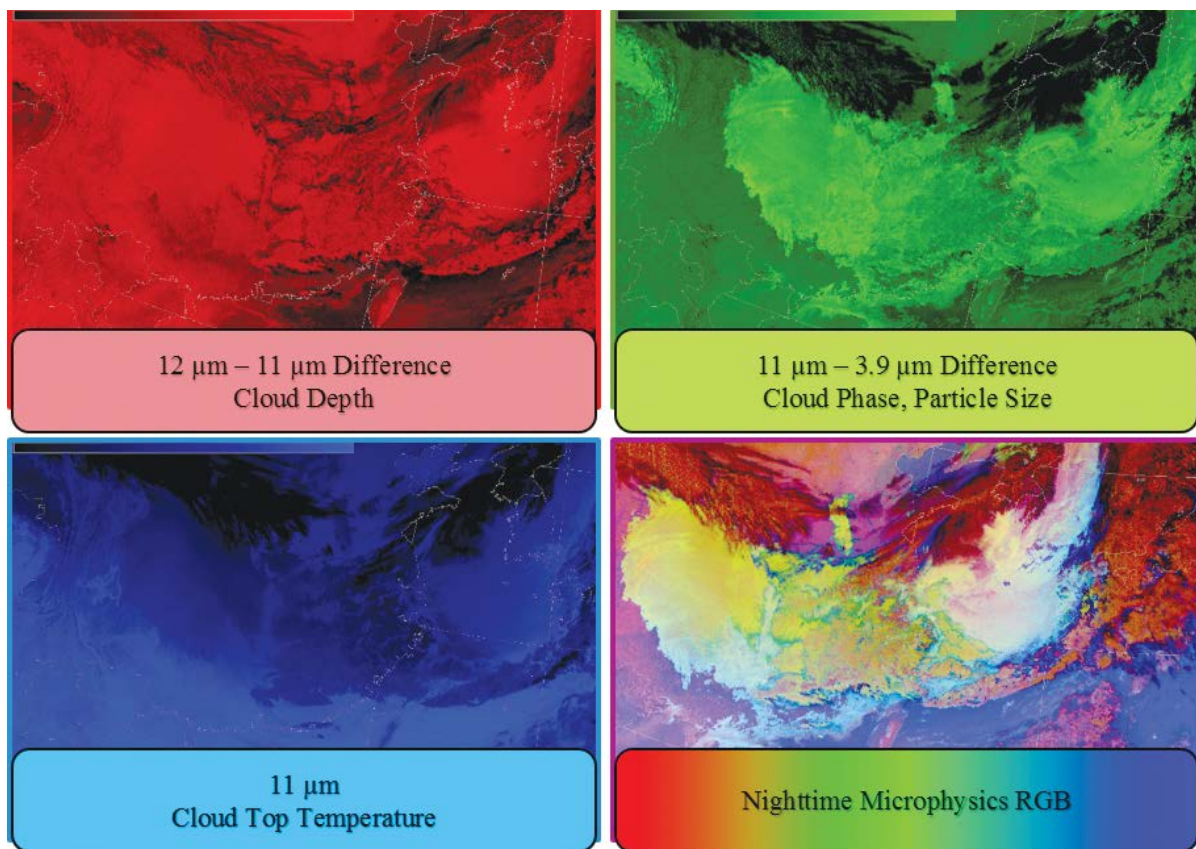


Fig. 1. Red, green, and blue components for the Nighttime Microphysics (NtMicro) RGB imagery and the resulting composite image. Imagery was derived from the Himawari-8 satellite using channels similar to those that will be available on GOES-16.

netic spectrum, called bands. GOES-16 will have a total of 16 bands. The increased number of bands, and the resulting increase in the data richness of imagery, creates an even greater need for RGB images, which provide the ability to synthesize information from several bands into a single image for rapid interpretation.

The NASA Short-term Prediction Research and Transition Center (SPoRT; <http://go.nasa.gov/2j5GgKF>) has used a research-to-operations/operations-to-research (R2O/O2R) paradigm to introduce RGB imagery to NWS forecasters to prepare them for new capabilities that will be available in the future.

Application and Feedback

Keys to this paradigm are active collaboration with end users (the weather forecasters), distribution of experimental products for use in end user display systems, creation of applications-based training materials, and evaluation of experimental products to gather end user feedback. SPoRT has applied its R2O/O2R paradigm to support the introduction of RGB imagery to NWS forecast offices since the early 2000s, when SPoRT worked with partner NWS forecast offices to introduce Moderate Resolution Imaging Spectroradiometer (MODIS) true-color and false-color RGB imagery to forecasters.

As a result of close collaboration with partner NWS forecast offices, weather forecasters now routinely use various types of RGB imagery in their operations. For example, the

Nighttime Microphysics (NtMicro) RGB is widely used to differentiate between fog and low clouds, which is useful for assessing aviation hazards. The Dust RGB, which monitors the evolution of dust plumes, has been adopted into daily operations at the Albuquerque, N.M., NWS forecast office [Fuell *et al.*, 2016]. Forecasters at the NWS Ocean Prediction Center routinely use the Air Mass RGB, which highlights differences between tropical and polar air masses, to assist with forecasting strong midlatitude cyclones [Zavodsky *et al.*, 2013; Berndt *et al.*, 2016].

Over the past 7 years, SPoRT has played an integral role in introducing RGB imagery and applications-based training to NWS forecasters. These efforts also serve to develop innovative solutions to display imagery in the operational environment to prepare forecasters for advanced imagery available with next-generation satellites.

History and Best Practices

In 2002, the European Organization for the Exploitation of Meteorological Satellites (EUMETSAT) led an effort to develop RGB products from the data collected by newly launched satellites. The effort produced a set of best practices that included recipes for a suite of standard RGB products [Lensky and Rosenfeld, 2008; EUMETSAT, 2009]. The World Meteorological Organization later adopted these RGB best practices to develop a set of standard products among international partners.

Best practices ensure that RGB products are developed with a defined recipe and that each product is well adapted to its intended use so that forecasters know what they are looking at in a given RGB product. Because RGB images are designed to enhance a specific phenomenon, individual spectral bands or differences between pairs of bands are chosen for an RGB image on the basis of the use of specific satellite bands to detect particular features.

For example, the NtMicro RGB was designed to enhance low-cloud and fog features. This RGB recipe (Figure 1) incorporates the well-known brightness temperature difference (ΔBT) between 11 micrometers (μm) and 3.9 μm . This quantity represents the difference in the intensity of the long- and short-wave infrared radiation at these two wavelengths that travels upward from the atmosphere to the satellite, and it is traditionally used to differentiate between water and ice clouds. The 12- and 11- μm ΔBT helps to distinguish between high, thick clouds and high, thin clouds by delineating cloud phase (ice or liquid water) and cloud particle size (small or large). The 11- μm brightness temperature is included to enhance low, warm clouds and distinguish them from colder, higher clouds.

Once the purpose for the RGB image (e.g., monitoring low clouds and fog) and the bands and/or band differences are chosen, the images are preprocessed to improve contrast and sharpen features of interest. The images are then assigned to the red, green, and blue components to create a single RGB image, as depicted in Figure 1.

From 2009 to 2011, SPoRT focused its efforts on developing a technique to display EUMETSAT RGB products derived from polar-orbiting satellites in NWS display systems. They also developed training materials and introduced the RGB imagery to NWS forecasters.

Because the current generation of GOES does not have enough bands to create the EUMETSAT RGB products, imagery from research instruments was used to introduce NWS forecasters to the new imagery that would be routinely available in the future with GOES-16. For example, by 2012, SPoRT was using data from MODIS and the Visible Infrared Imaging Radiometer Suite (VIIRS) to mock up the RGBs that could be created with GOES-16 bands.

Interaction with the End Users

Today, partner NWS forecast offices across the United States use the NtMicro RGB most widely. The Alaska region especially benefits from this satellite imagery. In Alaska's vast expanse of remote, complex terrain, low clouds and fog are a frequent hazard. The NtMicro RGB has become a part of daily operations in the Alaska NWS forecast offices as a result of an interactive partnership in which SPoRT conducted targeted product assessments of a variety of RGB products with forecasters.

Alaska NWS forecast offices participated in an assessment during the 2013–2014 winter, and SPoRT obtained feedback about the use of RGB from individual forecasters with a short online survey. The survey results indicated that the NtMicro RGB was valuable for distinguishing fog from low clouds beyond the traditional 11- and 3.9- μm ΔBT and that use of the RGB products gave them more confidence when issuing aviation forecasts [SPoRT, 2014].

With the extreme range in hours of day and night unique to the high latitudes, the NtMicro RGB is most

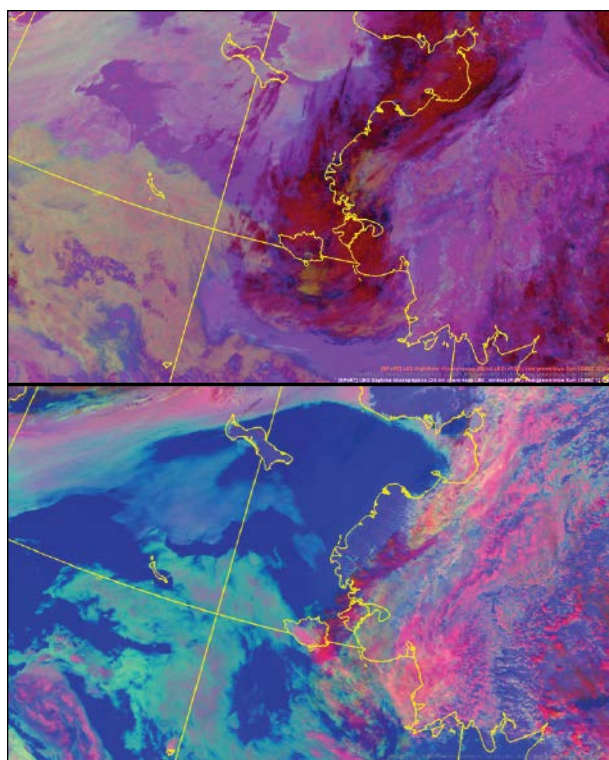


Fig. 2. VIIRS data display for (top) nighttime and (bottom) daytime low clouds and fog over the Bering Sea, using NtMicro and DtMicro RGB composite images, respectively. NASA SPoRT processed satellite imagery for 12 June 2016 at 12:59 coordinated universal time. Low-cloud and fog features are dull aqua and gray in the NtMicro images and aqua in the DtMicro images.

useful during periods of extended nighttime during the Alaskan winter. Therefore, forecasters inquired about a similar product for use during the summer. SPoRT recently developed the capability to derive the EUMETSAT daytime microphysics (DtMicro) RGB [Rosenfeld and Lensky, 1998; Lensky and Rosenfeld, 2008; EUMETSAT, 2009].

The DtMicro RGB is specifically designed to complement the NtMicro RGB for tracking low clouds and fog during the day (Figure 2). Alaska region partners assessed the utility of the DtMicro RGB during the 2016 summer, and they provided feedback that the imagery had a positive impact on operations and influenced aviation forecasts similarly to the NtMicro RGB. In addition, forecasters found the DtMicro RGB valuable for identifying strong thunderstorms and low-level rain clouds.

This example of the success of the SPoRT R2O/O2R paradigm involves the EUMETSAT microphysics RGB products and the Alaska region partners. Additional NWS partners across the United States are interacting with SPoRT to integrate RGB imagery into operations and prepare for the wealth of new imagery available with GOES-16 in the near future.

The Future of Multispectral Imagery

SPoRT continues to apply its successful research-to-operations paradigm to prepare forecasters for the capabilities that will be available from next-generation satellites. Forecasters soon will have access to all 16 spectral bands

International Ocean Discovery Program



CALL FOR APPLICATIONS



Apply to participate in *JOIDES Resolution Expedition*

Application deadline: 1 April 2017

Brothers Arc Flux Expedition (376)

Gateway to the Sub-Arc Mantle: Volatile Flux, Metal Transport, and Conditions for Early Life 5 May – 5 July 2018

Expedition 376 will investigate the fundamental, interrelated processes governing seafloor hydrothermal activity at Brothers volcano, southern Kermadec arc (IODP proposal 818-Full2). The primary objectives are to (1) Characterize the subsurface, magma-derived volatile phase for testing models predicting the existence of either a single-phase gas or a two-phase brine-vapor; (2) Explore the distribution of base and precious metals and metalloids at depth as well as the reactions that have taken place during their precipitation along fluid migration pathways to the seafloor; (3) Quantify the mechanisms and extent of fluid-rock interaction, and what this implies for the mass flux of metals and metalloids to the ocean as well as the role of magma-derived carbon and sulfur species in acting as agents for those fluxes; and (4) Assess the diversity, extent, and metabolic pathways of microbial life in an extreme, acidic, and metal-toxic (sub)volcanic environment.

The ultimate scientific goal of Expedition 376 is to discover the key processes that distinguish submarine arc-hosted hydrothermal systems from those linked to spreading centers, which results from the flux of magmatic fluid commonly being much higher in volcanic arcs. As a consequence of their shallow water depths and high volatile contents, the magmatic-hydrothermal arc signature gives rise to different fluid compositions and thus mineralization compared to submarine extensional settings. This likely also has consequences for the associated biota. Additionally, given the very acidic fluids and high metal concentrations, submarine arc hydrothermal systems are thought to be important analogs to porphyry copper, epithermal gold, and various volcanic rock-hosted massive sulfide deposits mined on land. Drilling Brothers volcano will provide essential information for understanding the formation of those mineral deposits and will also reconstruct the volcanic stratigraphy of this arc volcano.

Operations will focus on discharge zones of geochemically distinct fluids in and around the caldera of Brothers volcano by drilling and logging to 100s of m. The drill sites show variable impact of magmatic volatiles, which will enable the expedition to directly study the implications of magma degassing for the transport of metals to the seafloor and how this affects the functioning of microbial life.

For more information about the expedition science objectives and the *JOIDES Resolution Expedition Schedule* see <http://iodp.tamu.edu/scienceops/> - this includes links to the individual expedition web pages that provide the original IODP proposal and expedition planning information.

WHO SHOULD APPLY: Opportunities exist for researchers (including graduate students) in specialties including (but not limited to) sedimentologists, petrologists (igneous/metamorphic/sulfide), structural geologists, paleomagnetists, petrophysicists, borehole geophysicists, microbiologists, and inorganic/organic geochemists.

WHERE TO APPLY: Applications for participation must be submitted to the appropriate IODP Program Member Office – see <http://iodp.tamu.edu/participants/applytosail.html>

observed by the new GOES-16 satellite via their display system, known as the Advanced Weather Interactive Processing System (AWIPS; <http://bit.ly/AWIPS-support>). SPoRT worked with a team of AWIPS programmers to develop the capability to generate RGB products directly within the AWIPS workstation, which provides greater flexibility in product generation and improved color quality.

In addition, SPoRT developed a plug-in for AWIPS that allows forecasters to review quick-reference material. This is ideal for accessing short refresher training for moments when a forecaster needs to quickly look up information about a product. This new capability allows forecasters to view reference material and real-time imagery at the same time to reinforce concepts without interrupting workflow.

The NWS Operations Proving Ground evaluated these new innovative capabilities during March and April of 2016. In particular, forecasters were excited about the possibility of accessing training material directly in AWIPS.

SPoRT continues to lead the community in providing multispectral composites to NWS partners through interactive partnerships, innovative training approaches, and targeted assessments tailored to specific forecasting challenges. More information and updates on this project are available on the blog *The Wide World of SPoRT* (<https://nasasport.wordpress.com>), the NASA SPoRT Center Facebook page (<http://bit.ly/NASA-Sport-FB>), and Twitter at @NASA_SPoRT.

Acknowledgments

SPoRT works in close collaboration with the GOES-R and JPSS Proving Grounds, National Oceanic and Atmospheric Administration (NOAA) NWS Operations Proving Ground, and NOAA Cooperative Institutes.

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