Operations Plan

for the
GOES-R Proving Ground
portion of the
High Latitude Testbed and
Alaska Experiment

Program overview by:
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Product developers contributed the material regarding their respective products.

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1 Introduction

1.1 Plan Purpose and Scope

The Alaska Experiment activity at National Oceanic and Atmospheric Administration's (NOAA's) National Weather Service (NWS) Alaska Region and University of Alaska Fairbanks (UAF) High Latitude Testbed (HLT) provides the GOES-R Proving Ground (PG) with a pre-operational environment in which to deploy and demonstrate algorithms associated with its next generation GOES-R geostationary satellite system. These products are to include both GOES-R baseline products and operational readiness trials of products transitioning from Risk Reduction, but with the main focus on demonstrating the official GOES-R Baseline and Option-2 products. The availability of GOES-R products will demonstrate, pre-launch, a portion of the full observing capability of the GOES-R system, subject to the constraints of existing high latitude data sources to emulate the satellite sensors.

1.2 Overview

The Alaska Region Weather Forecast Offices (WFOs), River Forecast Center (RFC), and Alaska Aviation Weather Unit (AAWU) will receive early exposure to GOES-R PG products during the 2010 Experiment running from September to December. Pre-operational demonstrations of these GOES-R PG data will provide the Forecast Offices the opportunity to critique and improve the products relatively early in their development. In early 2010, meetings were initiated with Science Officers in the forecast offices to discuss the project and determine their needs and applications. Four products were chosen for testing in the initial experiment. Gary Hufford (NWS) and Jessica Cherry (UAF) will be coordinating Proving Ground activities in Alaska.

2 Goals of Proving Ground Project

The 2010 Experiment will focus on demonstrating the GOES-R Baseline and Option-2 products selected for this year's activities including volcanic ash, cloud phase, cloud/snow discrimination, low cloud and fog, and SO2 detection. This strategy has the best chance of maximizing the Operations-to-Research feedback that is one of the PG goals. The most important aspect of the interactions this season will be to build relationships between each key product development team and the forecasters within the NWS Alaska region. Thus, we envision that each forecaster will participate in each of the experimental activities and discussions (in particular regarding satellite-based products) and to improve integration of GOES-R PG effort in these test bed activities for future years.

3 GOES-R product(s) to be demonstrated

There are four GOES-R products from the Advanced Baseline Imager (ABI) identified to be demonstrated during the Experiment in Alaska: (1) Volcanic Ash, (2) Cloud Phase, (3) Cloud/snow Discrimination, (4) Low Cloud and fog, and (5) SO2 Detection. These products are listed in Table 1 and described further in the following subsections.

Table 1. Products to be demonstrated during Experiment

Demonstrated Product	Category
Volcanic Ash: Detection and Height	Baseline
Cloud Phase	Baseline
Cloud/Snow Discrimination (Cloud Mask)	Baseline

Demonstrated Product	Category
Low Cloud and Fog	Option 2
SO_2 Detection	Option 2
Category Definitions: **Baseline Products** - GOES-R products that are funded for operational implementation as part of the ground segment base contract. **Option 2 Products** - New capability made possible by ABI as option in the ground segment contract.	

3.1 Volcanic Ash

The GOES-R volcanic ash algorithm utilizes infrared channels (7.3, 8.5, 11, 12, and 13.3 μm) to identify potential volcanic ash clouds (when the ash is the highest cloud layer) and to retrieve the ash cloud height, mass loading, and effective particle radius. These parameters are important for both nowcasting and forecasting purposes. The ash cloud height is needed to determine if ash is at cruising altitudes and to initialize the plume height in dispersion models. The GOES-R ash cloud height retrieval accounts for transmission of radiation through the ash cloud from below (e.g. the ash clouds are allowed to be semi-transparent to infrared radiation), so it produces high quality results even when applied to optically thin ash clouds. Validation efforts indicate that the GOES-R ash height retrieval can determine the ash cloud top height with an accuracy (bias) of -1.35 km and a precision of 1.61 km, for tropospheric clouds.

Ash concentration data are needed to determine if jet engine tolerances are exceeded (should accurate thresholds be made available by engine manufacturers). If a 1 km ash cloud thickness is assumed, the ash mass loading (ton/km^2) is numerically equivalent to ash concentration in mg/m^3. Ash loading data can also be used to initialize models. Comparisons to spaceborne lidar indicate that the GOES-R ash mass loading has an accuracy (bias) of 0.42 ton/km^2 and a precision of 1.17 ton/km^2, subject to certain microphysical assumptions.

The ash effective particle radius is not an official GOES-R requirement, but it is automatically produced in the process of retrieving the ash height and mass loading. The ash effective particle radius can be used to determine if the ash cloud is dominated by small or large particles, which is important for predicting the atmospheric residence time (small particle remain suspended longer than large particles, all else being equal). This information can also be used to initialize models. Since it is not an official GOES-R product, the ash effective particle radius information will be retained in the quality flag output.

The GOES-R volcanic ash algorithm can be applied to data from the Moderate Resolution Imaging Spectroradiometer (MODIS), which is in a low-earth orbit, and, as such, provides coverage of Alaska. Example GOES-R volcanic ash products are shown in the figure below for an Alaskan eruption (Kasatochi).

Finally, it is important to point out that while the GOES-R volcanic ash products meet all of the accuracy and latency specifications, the ash detection component of the GOES-R algorithm is not designed to be used in an automated ash alert system (the GOES-R requirements did NOT include an automated alert capability). In recognition of this shortcoming, a GOES-R automated alert capability will be developed in the coming months. This capability will be a more advanced version of the automated alert capability developed for the Advanced Very High Resolution Radiometer (AVHRR). The GOES-R automated alert system will hopefully be available for testing under the GOES-R Proving Ground in 2011 or 2012.

Questions concerning the GOES-R volcanic ash products can be sent to:
Mike.Pavolonis@noaa.gov

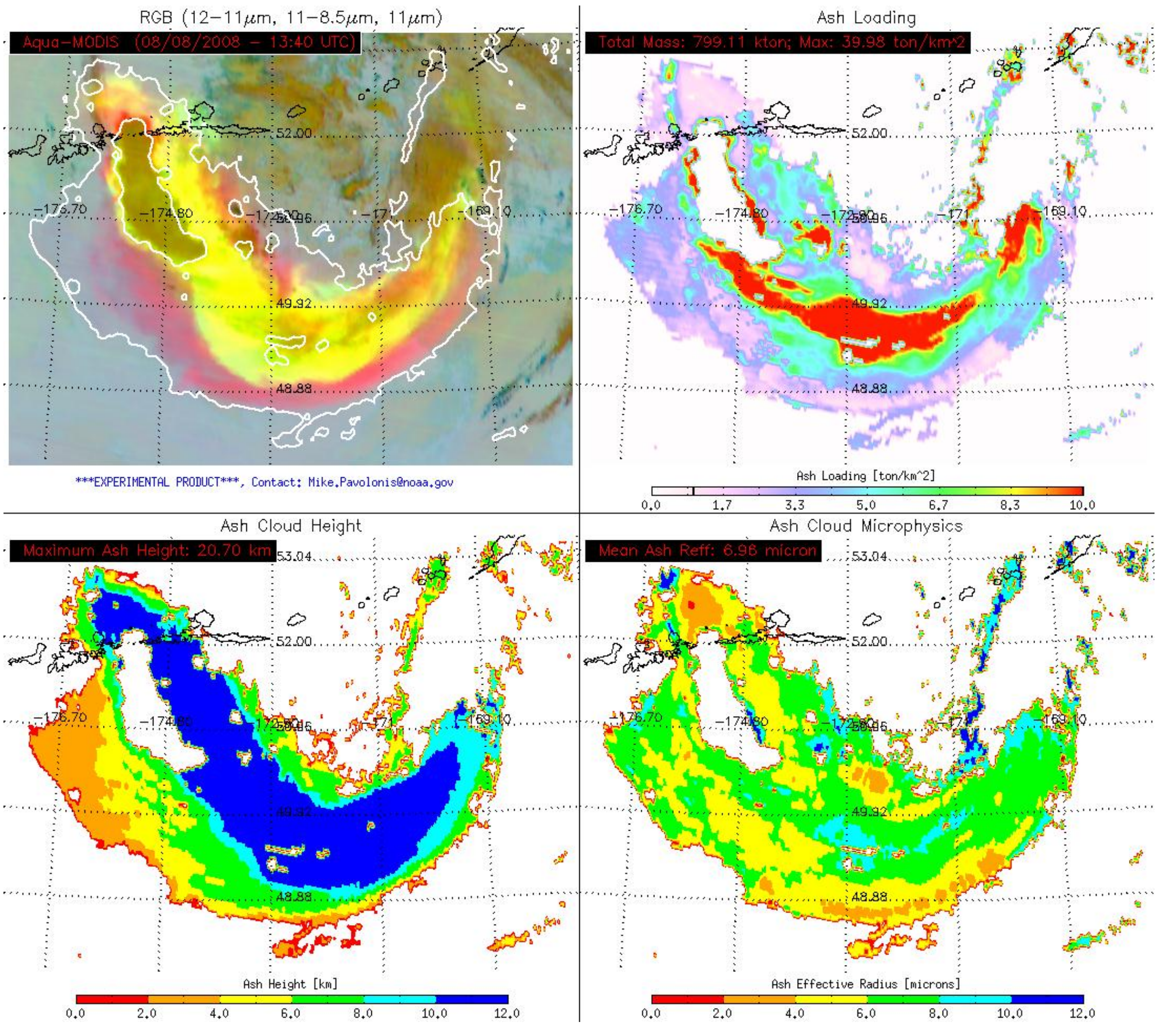

Figure 1: Example GOES-R volcanic ash products generated using *Aqua* MODIS data from August 8, 2008 at 13:40 UTC. The ash cloud present in this scene is from an eruption of Kasatochi, located in the Aleutian Islands of Alaska. A false color image (top left panel), the ash mass loading product (top right panel), the ash height product (bottom left panel), and the ash effective radius product (bottom right panel) are shown. The ash detection results are displayed as white contours on the false color image.

3.2 Cloud Phase (Cloud Type)

The GOES-R cloud top phase algorithm utilizes infrared channels (7.3, 8.5, 11, and 12 μm) to determine the thermodynamic phase of the highest cloud layer. Since the algorithm utilizes only infrared channels, the performance is spectrally independent of solar zenith angle. The cloud phase categories are: liquid water, supercooled liquid water, mixed phase, and ice. It is important to note that the cloud phase classification applies to the portion of the cloud that contributes to the measured radiances (hence the name cloud top phase). For optically thick clouds, the infrared measurements are only sensitive to the top-most portion of the cloud. For example, deep convective clouds will be classified as ice clouds since the upper-most portion of those clouds are glaciated. The "liquid water" category includes clouds that are composed entirely of liquid water at temperatures above the melting point of water (0^oC). Supercooled liquid water clouds are composed entirely of liquid water at temperatures below the melting point of water. Mixed phase clouds likely contain both liquid water and ice in the cloud layer that contributes to the measured radiances. Ice phase clouds are composed entirely of ice (in the cloud layer sensed by the radiometer).

The GOES-R cloud top phase algorithm is required to determine the cloud top phase with a classification error no larger than 20%. Our validation analysis indicates that the classification error is around 10%.

Potential applications of the cloud top phase product are (but not necessarily limited to):

1. Assessing aircraft icing potential
2. Assessing freezing rain/drizzle potential
3. Diagnosing cloud top glaciation in growing cumulus clouds
4. Diagnosing cirrus cloud cover, including cirrus which overlap lower cloud layers

Further, the GOES-R Cloud Type product provides more detailed cloud phase information, including multi-layered cloud detection and information on ice cloud opacity. The GOES-R Cloud Type product is generated within the cloud top phase algorithm module. Example GOES-R cloud top phase and cloud type products over Alaska are shown in the figure below.

Finally, while the GOES-R cloud top phase algorithm will be most accurate when applied to the ABI, it can be generated using the current GOES imager, MODIS, Spinning Enhanced Visible and Infrared Imager (SEVIRI), or Multi-functional Transport Satellite (MTSAT).

Questions concerning the GOES-R cloud top phase product can be sent to: Mike.Pavolonis@noaa.gov

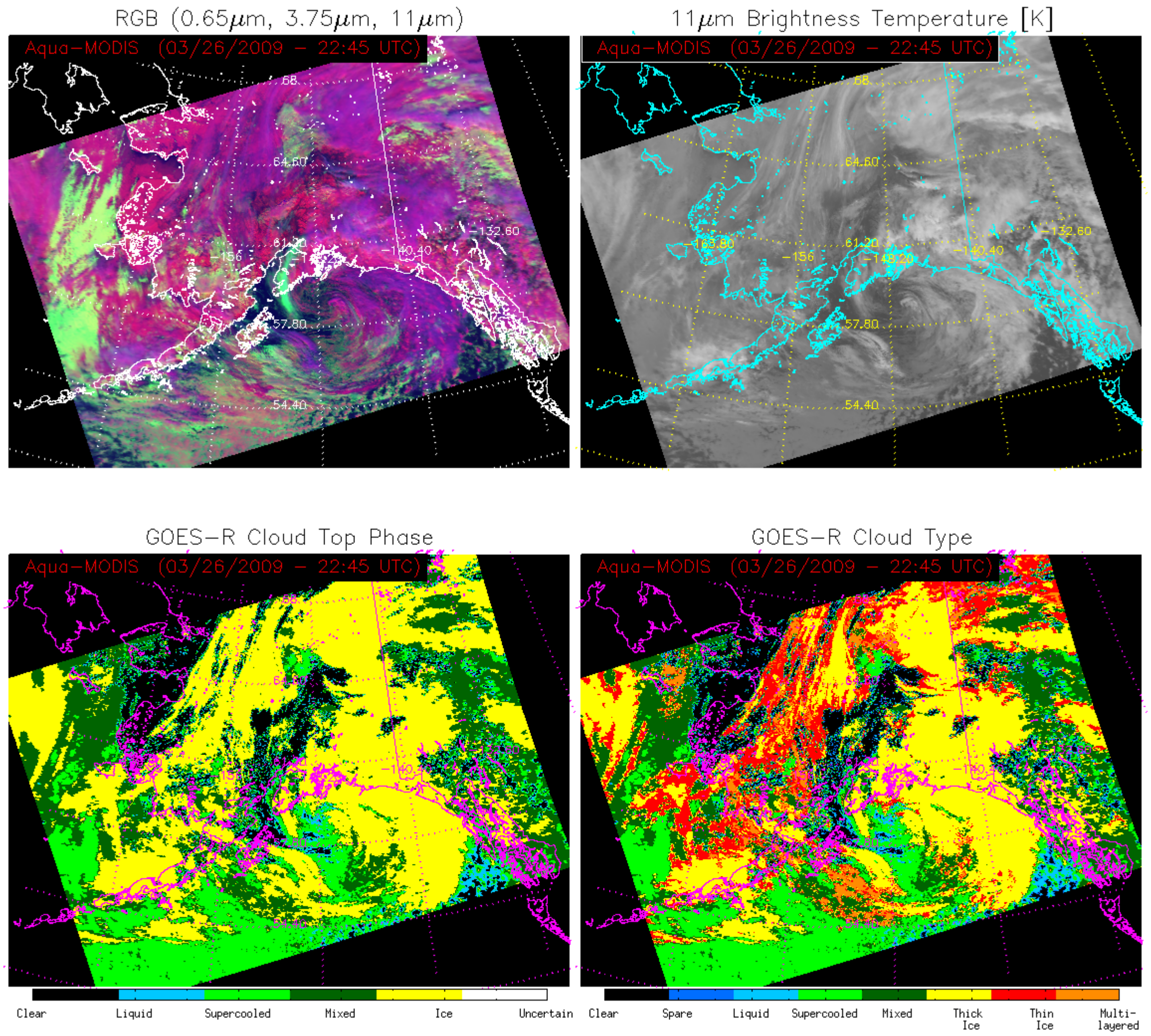

Figure 2: Example GOES-R cloud top phase and cloud type products generated using *Aqua* MODIS data from March 26, 2009 at 22:40 UTC. A false color image (top left panel), an IR image (top right panel), the GOES-R cloud phase product (bottom left panel), and the GOES-R cloud type product (bottom right panel) are shown.

3.3 Cloud/snow Discrimination

The GOES-R ABI cloud mask attempts to distinguish between cloud and snow. The philosophy employed by the mask has been to employ infrared (IR) tests that are not sensitive to the presence of snow. The initial information on the presence of snow comes currently from the Interactive Multisensor Snow and Ice Mapping System (IMS) snow product generated at NOAA/ National Environmental Satellite, Data, and Information Service (NESDIS). The IMS snow product used to process real-time satellite data is therefore one day old. Tests that function to modify the snow cover from the IMS are then applied to the IMS product. For example, pixels are reclassified as snow-free when the 11 μm brightness temperature exceeds a specific threshold. In addition, when the spectral information allows, the Normalized Difference Snow Indices (NDSI) values are computed using the 0.6 μm reflectance and the 1.6 or 3.9 μm reflectance. Thresholds are applied to these tests to reclassify IMS snow-free pixels as potentially snow covered. In the end, pixels considered to be snow covered are ignored by cloud mask tests known to be sensitive to the presence of snow. Lastly, the cloud mask performs a special daytime test over snow-covered pixels using the 1.6 or 3.9 μm reflectance with the specific purpose of detecting water-phase clouds over snow. The cloud mask does report the modified snow mask in its output, however, this mask only gives information at pixels treated as snow-covered by the mask and should not be interpreted as an improvement on the snow mask provided by the IMS. This procedure is used with the Advanced Very High Resolution Radiometer (AVHRR), MODIS, GOES and SEVIRI data.

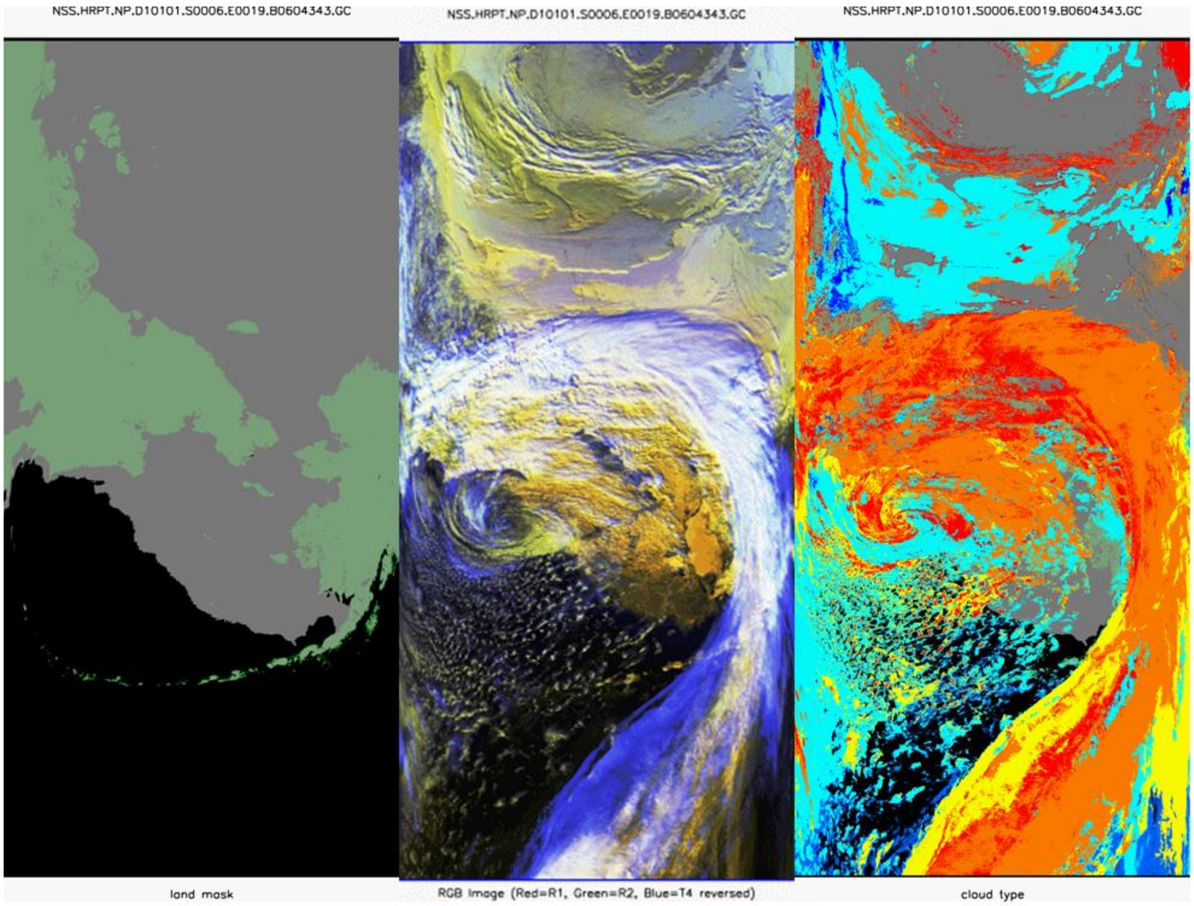

Figure 3. Example of snow/cloud discrimination in the GOES-R AWG cloud mask (here applied to AVHRR). Figure on the left shows the snow cover from IMS (grey color). The middle figure shows a false color image. Figure on the right shows a derived cloud type (water phase clouds appear in blue and green; ice phase clouds appear as yellow and orange.)

Questions concerning the GOES-R cloud product can be sent to: Andrew.Heidinger@noaa.gov

3.4 Low Cloud and Fog

The GOES-R fog/low cloud detection product is designed to quantitatively identify clouds that produce Instrument Flight Rules (IFR) or Low Instrument Flight Rules (LIFR) conditions (ceiling < 1000 ft (305 m)). The aviation flight rule categories are defined in the table below. The GOES-R fog detection is expressed as a probability. At night, the algorithm utilizes the 3.9 and 11 μm channels to assign a fog probability. Fog probability during the day is determined using the 0.65, 3.9, and 11 μm channels. The fog probability is based on textual and spectral information, as well as the difference between the cloud radiative temperature and surface temperature. An example of the GOES-R fog product is shown in the figure below.

Table 1: Aviation flight rules

Flight Rule	**Ceiling**
Visual Flight Rules (VFR)	> 3000 ft (914 m)
Marginal Visual Flight Rules (MVFR)	1000 ft (305 m) – 3000 ft (914 m)
Instrument Flight Rules (IFR)	500 ft (152 m) – 1000 ft (305 m)
Low Instrument Flight Rules (LIFR)	< 500 ft (152 m)

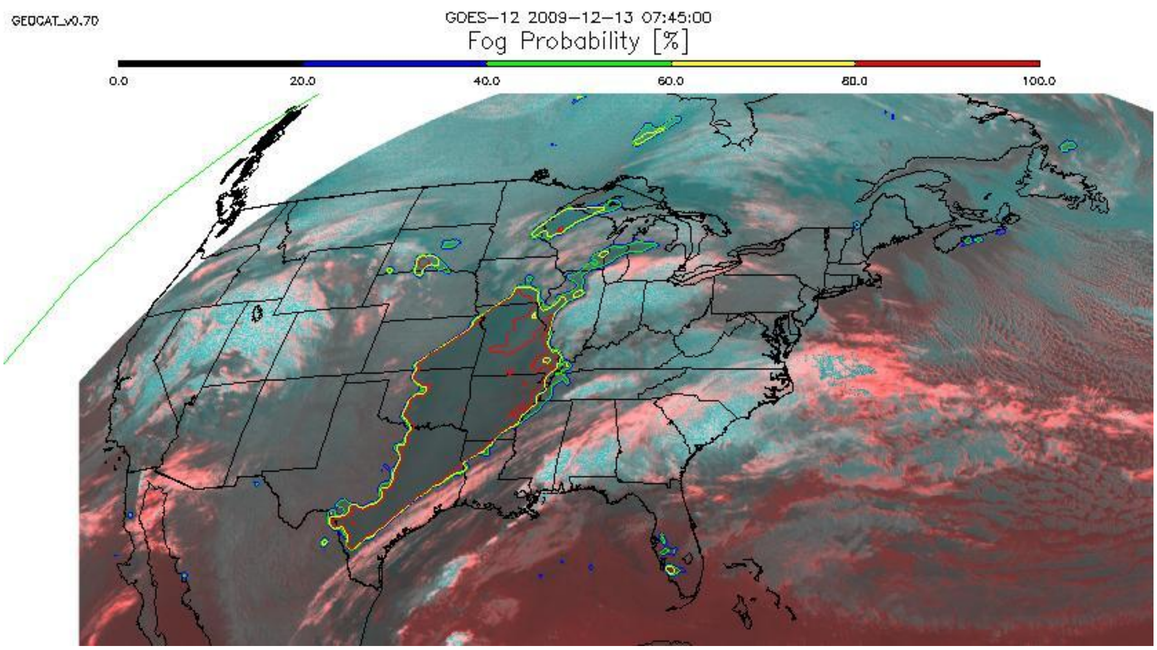

Figure 4: An example of the GOES-R fog detection product generated using GOES-12 on December 13, 2009 at 07:45 UTC. The satellite derived fog probability is denoted by the color contours overlaid on the false color image.

There are a few important caveats that users need to be aware of. Fog cannot be detected if there are higher cloud layers overlapping the fog layer. The GOES-R fog/low cloud product specifications reflect this fundamental limitation of passive remote sensing. Secondly, passive satellite measurements do not provide direct information on cloud base or ceiling, so the properties of the cloud layer actually sensed by the radiometer must be used to indirectly infer information on cloud base. Since the properties of the cloud base are not directly measured, variations in cloud base due to local boundary layer effects (e.g. local moisture sources/sinks and local turbulent mixing processes) generally will not be captured. As such, not every surface observation underneath a GOES-R detected low cloud will necessarily indicate a ceiling of 1000 ft or lower, but those surface observations that do not indicate LIFR or IFR will generally indicate Marginal Visual Flight Rules (MVFR) conditions. In other words, the GOES-R fog/low cloud algorithm will rarely identify Visual Flight Rules (VFR) conditions, which is desirable.

The GOES-R fog/low cloud detection algorithm is required to achieve a skill score (probability of detection – probability of false alarm) of 0.70. Validation efforts indicate that we are on track to meet this specification.

Finally, while the GOES-R fog product requires output from the cloud mask and cloud top phase algorithms, which will be most accurate when applied to the ABI or a comparable sensor, it can be generated using the current GOES imager, MODIS, SEVIRI, or MTSAT.

Questions concerning the GOES-R fog/low cloud product can be sent to:
Mike.Pavolonis@noaa.gov

3.5 SO_2 Detection

Identifying SO_2 clouds is important, since SO_2, when combined with water, is corrosive and harmful to breath, and, as such, is a potential aviation hazard. Further, when injected into the stratosphere, SO_2 is converted to sulfate droplets, which reflect incoming sunlight back to space, impacting climate.

The GOES-R SO_2 detection product utilizes infrared measurements (6.2, 7.3, 8.5, 11, and 12 μm) to identify pixels that contain 10 or more Dobson Units (DU) of Sulfur Dioxide (SO_2), when the SO_2 cloud is the highest cloud layer. The SO2 detection algorithm utilizes a unique blend of spectral and spatial information to detect SO_2. SO_2 loadings less than 10 DU are difficult to detect using the Advanced Baseline Imager (ABI), since the ABI cannot resolve individual SO_2 absorption lines. Validation efforts indicate that the SO_2 detection algorithm meets the GOES-R accuracy specification (70% correct detection). More specifically, the probability of detection is ~70% and the probability of false alarm is ~0%. The low false alarm rate makes this product ideal for use in an automated volcanic cloud alert system. In addition, while not required, the SO_2 loading is also estimated using a simple regression relationship. Since the SO_2 loading is not a required product, the loading information will be stored in the quality flags.

The GOES-R SO_2 algorithm can be applied to data from the Moderate Resolution Imaging Spectroradiometer (MODIS), which is in a low-earth orbit, and, as such, provides coverage of Alaska. Example GOES-R SO_2 products are shown in the figure below for an Alaskan eruption (Kasatochi).

Questions concerning the GOES-R SO_2 product can be sent to: Mike.Pavolonis@noaa.gov

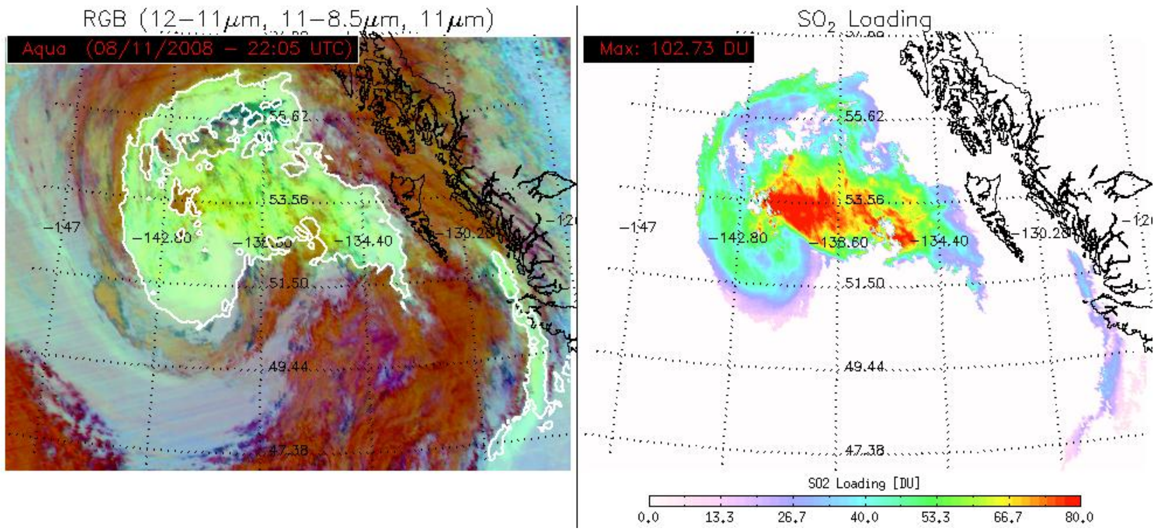

Figure 5: Example GOES-R SO_2 products generated using *Aqua* MODIS data from August 11, 2008 at 22:05 UTC. The SO_2 cloud present in this scene is from an eruption of Kasatochi, located in the Aleutian Islands of Alaska. A false color image (left panel) and the estimated SO_2 loading (right panel) are shown. The SO_2 detection results are displayed as white contours on the false color image.

4 Proving Ground Participants

The Proving Ground participants are broken into two categories, Providers and Consumers. Providers are those organizations that develop and deliver the demonstration product(s) and training materials to the consuming organization. The Consumers are those who work with the providers to integrate the product(s) for demonstration into an operational setting for forecaster interaction. For the Experiment in Alaska, there is one provider, the Cooperative Institute for Meteorological Satellite Studies (CIMSS), and there are three NWS consumers: WFO, RFC, and the AAWU. In addition, partner agencies such as the National Park Service, the Federal Aviation Administration (FAA), and the United States Geological Survey (USGS) may become end users after the initial NWS evaluation. Their participation is described in the following paragraphs.

4.1 CIMSS

CIMSS will be providing the four products demonstrated in the Spring Experiment and they are described below.

4.1.1 Volcanic Ash: Detection and Height

The volcanic ash products will be generated using MODIS data captured and processed at CIMSS. The products will be generated in netCDF and IC4D formats and pushed to UAF-Geographic Information Network of Alaska (GINA). UAF-GINA will distribute the products to the NWS for evaluation via the Local Data Manager (LDM).

4.1.2 Cloud Phase

The Cloud Type product will be generated using MODIS data captured and processed at CIMSS. Cloud Phase information can be extracted from the Cloud Type product. The product will be generated in netCDF and IC4D formats and pushed to UAF-GINA UAF-GINA will distribute the product to the NWS for evaluation.

4.1.3 Cloud/Snow Discrimination

The cloud/snow discrimination product will be generated using GOES-R cloud detection scheme implemented on AVHRR and/or MODIS data captured and processed at CIMSS. The product will be generated in netCDF and IC4D formats and pushed to UAF-GINA. UAF-GINA will distribute the product to the NWS for evaluation via the Local Data Manager (LDM).

4.1.4 Low Cloud and Fog

The fog/low cloud product will be generated using MODIS data captured and processed at CIMSS. The product will be generated in netCDF and IC4D formats and pushed to UAF-GINA. UAF-GINA will distribute the product to the NWS for evaluation

4.1.5 SO_2 Detection

The SO_2 product will be generated using MODIS data captured and processed at CIMSS. The product will be generated in netCDF and IC4D formats and pushed to UAF-GINA. UAF-GINA will distribute the product to the NWS for evaluation. The SO_2 product will be made available in an AWIPS compatible format.

4.2 UAF & GINA

UAF-GINA will receive GOES-R AWG products from CIMSS via ftp push and will distribute the data products to the NWS Alaska Region AWIPS workstations via their LDM. The Fairbanks WFO, co-located with GINA, will be the load site for the satellite products. GINA will then monitor and collect NWS forecaster feedback on the utility and value of the products.

4.3 NWS

NWS will ensure that the experimental satellite products are distributed into the AWIPS workstations and the Advanced Linux Prototype System (ALPS) for forecaster use. NWS will use the CIMSS software protocol to load the satellite products into AWIPS system.

4.4 NWS End Users

4.4.1 Forecast Offices

The three WFOs, Anchorage, Fairbanks, and Juneau, will participate in the evaluation of the GOES-R Proving Ground products. The lead at each Office for the evaluation will be the SOO. The SOO will work directly with the GINA Liaison.

4.4.2 River Forecast Center

The Alaska/Pacific River forecast Center will participate in the evaluation of the GOES-R Proving Ground products. The lead at the Office will be the Development and Operations Hydrologist (DOH) who will work directly with the GINA Liaison. The RFC is also responsible for the NWS Pacific Region and will work with their needs when the Pacific Region becomes part of the Proving Ground.

4.4.3 Alaska Aviation Weather Unit

Alaska has its own Aviation Weather Unit with responsibility for both commercial and general aviation forecasts and products. The AAWU will evaluate only those products relevant to aviation applications. The lead at the Office will be the SOO who will work directly with the GINA Liaison.

5 Responsibilities and Coordination

5.1 Project Authorization

Steve Goodman – GOES-R Chief Scientist and PG Program Manager
Gary Hufford – Regional Scientist, NWS Alaska

5.2 Project Management

Gary Hufford – Regional Scientist, NWS Alaska
Jessica Cherry – UAF

5.3 Product Evaluation

Carl Dierking – Science Operations Officer (SOO), Juneau WFO
James Nelson – SOO, Anchorage WFO
Eric Stevens – SOO, Fairbanks WFO
Scott Lindsey – DOH, Anchorage RFC
Nathan Eckstein – SOO, Anchorage AAWU

5.4 Project Training

5.4.1 General Sources

GOES-R training is developed and provided by a number of different partners across the weather enterprise. NOAA, collaboratively through NESDIS and the NWS, partners with the Cooperative Program for Operational Meteorology, Education and Training (COMET), Virtual Institute for Satellite Integration Training (VISIT), and Short-term Prediction Research and Transition Center (SPoRT) to develop and deliver training on the new features, operations, and capabilities of the GOES-R satellite. Training for the High Latitude Testbed and Alaska PG Experiment will be developed and provided through e-learning training modules, seminars, weather event simulations, and special case studies.

5.4.2 Product Training References

5.4.2.1 Volcanic Ash: Detection and Height

A product description along with examples and caveats will be made available at the beginning of the experiment (in presentation form) by Mike Pavolonis. In-person training may also be conducted at the beginning of the experiment in Anchorage.

5.4.2.2 Cloud Phase

A product description along with examples and caveats will be made available at the beginning of the experiment (in presentation form) by Mike Pavolonis. In-person training may also be conducted at the beginning of the experiment in Anchorage.

5.4.2.3 Cloud/Snow Discrimination

A product description along with examples and caveats will be made available at the beginning of the experiment (in presentation form) by Andy Heidinger. In-person training may also be conducted at the beginning of the experiment in Anchorage.

5.4.2.4 Low Cloud/Fog

A product description along with examples and caveats will be made available at the beginning of the experiment (in presentation form) by Mike Pavolonis. In-person training may also be conducted at the beginning of the experiment in Anchorage.

5.4.2.5 SO_2 Detection

A product description along with examples and caveats will be made available at the beginning of the experiment (in presentation form) by Mike Pavolonis. In-person training may also be conducted at the beginning of the experiment in Anchorage.

6 Project Schedule

There are many activities that lead up to the successful execution of the Experiment such as identifying participants, coordinating schedules, delivering and integrating algorithms, and developing training materials. These specific activities are identified in the chart below.

(1) Begin: March 2010
   a. Identify products (May, 2010)
   b. Identify AWG Leads (May, 2010)
   c. Establish an Operations Plan (roles and responsibilities and expectations (Jul 1, 2010)
   d. AK receive and integrate GOES-R algorithms (Oct 4, 2010)
   e. Produce demonstration products (Nov 2010)
   f. Distribute products (AK WFOs, RFC, and AAWU, Nov 2010)
   g. Product Evaluation (Nov 2010 – 29 Aug Mar 2011)
   h. Midterm Report Due (28 Feb 2011)
   i. Final Report Due (29 Aug 2011)

(2) End: 29 Aug 2011

7 Milestones and Deliverables

7.1 Products from Providers

Products to be demonstrated within this year's Spring Experiment should be delivered to WFOs, RFC, and AAWU in November 2010 to ensure that product dataflow and display work correctly within the forecast programs. Products delivered to the offices will be displayed within AWIPS and ALPS and will be coordinated with Jessica Cherry.

7.2 Training materials from AWG to NWS/UAF Coordinators and from Coordinators to End Users

Each product delivered to the GOES-R PG Experiment will be accompanied by related training material. Forecasters and scientists participating in the Experiment may not be familiar with the products; therefore, it is important that they receive training in order to properly evaluate product performance during real-time forecasting exercises. Training will include an in-person briefing accompanied by a short write-up explaining how the product works and its uses, including example images. It is expected that the product developer provide the training material.

7.3 Mid-term evaluation report

A mid-term evaluation report shall be provided to the project authorization team approximately midway through the experiment. This report shall detail the current status and progress of the GOES-R PG Experiment activities and suggest changes if needed.

7.4 Final report

A final report detailing the GOES-R PG Experiment activities during the entirety of the experiment shall be provided to the GOES-R Program Office at the end of April 2011. This report will discuss how each product was demonstrated within the various experiments. The report will also present feedback provided by participants within the Experiment as well as suggestions for improvements upon the GOES-R PG Experiment activities for years to come.

8 Related activities and methods for collaboration

8.1 Real Time Delivery

GOES-R Proving Ground products will be provided in near-real time to the forecasters in Alaska. The products will be used 24/7. Once per day the products will be discussed alongside other operational and experimental model-based products. The SOOs/DOHs will lead these discussions and document in surveys.

8.2 Archive for Research Application

GOES-R Proving Ground products will provide unique data sets that will be archived for case studies, research, and long-term climate data records.

8.3 Collaboration with other Regions

The High Latitude Test bed will develop collaborations with the other NWS regions, especially for products that have value in those regions. AWC is currently developing a collaborative testbed to develop and demonstrate next-generation aviation weather forecasting tools.

8.4 GOES-R Risk Reduction Products and Decision Aids

At this time there is no plan to demonstrate GOES-Risk Reduction products or Decision Aids during this Experiment.

9 Summary

This year's GOES-R PG Experiment activities at the High Latitude Test bed will support the PG effort to demonstrate the defined GOES-R baseline products within an operational framework through real time access. Collaborations with other partners such as NPS, FAA, and USGS will develop through interactions within the High Latitude Test bed. Feedback gathered from these activities will aid in successful product training for not only forecasters but for the many users of GOES-R products.

10 References

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Painter, T. H., Rosenthal, C. W., Rittger, K., McKenzie, C., Davis, R. E., and Dozier, J. (2009b), Multiple endmember spectral mixture analysis of fractional snow cover from Landsat Thematic Mapper data, *in preparation*.