



## GOES-R Algorithm Development

For the next-generation of GOES-R instruments to meet stated performance requirements, state-of-the-art algorithms will be needed to convert raw instrument data to calibrated radiances and derived geophysical parameters (atmosphere, land, ocean, and space weather). The GOES-R Program Office (GPO) assigned the NOAA/NESDIS Center for Satellite Research and Applications (STAR) the responsibility for technical leadership and management of GOES-R algorithm development and calibration/validation. STAR responded with the creation of the GOES-R Algorithm Working Group (AWG) to manage and coordinate development and calibration/validation activities for GOES-R proxy data and geophysical product algorithms. The AWG consists of 15 application teams that bring expertise in product algorithms that span atmospheric, land, oceanic, and space weather disciplines. Each AWG team will develop new scientific Level-2 algorithms for GOES-R and will also leverage science developments from other communities (other government agencies, universities and industry), and heritage approaches from current operational GOES and POES product systems. All algorithms will be demonstrated and validated in a scalable operational demonstration environment. All software developed by the AWG will adhere to new standards established within NOAA/NESDIS. The AWG Algorithm Integration Team (AIT) has the responsibility for establishing the system framework, integrating the product software from each team into this framework, enforcing the established software development standards, and preparing system deliveries. The AWG will deliver an Algorithm Theoretical Basis Document (ATBD) for each GOES-R geophysical product as well as Delivered Algorithm Packages (DAPs) to the GPO.

## **GOES-R Algorithm Development**

### **1. INTRODUCTION**

The Center for Satellite Applications and Research (STAR) is the science arm of the of NOAA's National Environmental Satellite Data and Information Service (NESDIS) and provides leadership, guidance, and direction for NESDIS research, development, and applications activities with respect to satellites and satellite data. The main objectives of the STAR are to: 1) Develop and demonstrate high quality satellite remote sensing data and information products; 2) Transition the latest state-of-the-art capabilities into operations; and 3) Work with and support the NESDIS user community to ensure the maximum utilization of these capabilities; 4) Monitor, validate, analyze, and characterize the performance of both instruments and products; and 5) Support the development of future satellite instruments and their requirements specifications.

The GOES-R Program Office (GPO) assigned NOAA/NESDIS STAR the responsibility of managing the selection and development of level-2 product algorithms for GOES-R and to participate in various capacities in a number of different calibration/validation activities. STAR responded with the creation of the GOES-R AWG. The GOES-R AWG provides an integrated program of algorithm development and calibration/ validation activities that span the entire lifecycle of the GOES-R program.

### **2. ROLE AND STRUCTURE OF THE GOES-R ALGORITHM WORKING GROUP**

The overarching objectives of the GOES-R AWG are to develop, test, demonstrate, validate, and provide Level-2 product algorithms for end-to-end GOES-R Ground Segment capabilities, provide sustained life cycle calibration/validation and product algorithm enhancements, and to ensure user readiness of GOES-R data and derived products. The AWG is responsible for delivering state-of-the-art level-2 algorithms that will convert future GOES-R instrument data to calibrated radiances and derived geophysical parameters. Table 1 provides a list of the GOES-R baseline and option2 level-2 products.

The GOES-R AWG will (1) broker and select algorithms from among government, academic and commercial sources, (2) develop GOES-R instrument proxy and simulated datasets, (3) develop and provide algorithm software, documentation, simulated and proxy test data sets, and benchmarks for the product generation functions, (4) prototype and demonstrate algorithm performance including algorithm/product meta-data generation techniques, standards, and formats, and (5) develop calibration/validation tools as part of an Integrated Calibration/Validation Enterprise System.

To achieve its objectives, the AWG is:

- Leveraging nearly 100 scientists from NOAA, NASA, DOD, EPA, and NOAA's Cooperative Institutes (University partners)
- Applying first-hand knowledge of algorithms developed for POES, GOES, DMSP, AIRS, MODIS, MetOP and Space Weather

- Leveraging STAR’s Integrated Cal/Val System Framework to provide outstanding calibration and validation capability and support to the GOES-R program
- Leveraging other programs & experience (GOES, MODIS, AIRS, IASI, NPOESS and other prototype instruments and international systems)
- Facilitating algorithm consistency across platforms – a prerequisite for the Global Earth Observing System of Systems (GEOSS) (maximize benefits and minimizes integration)

STAR management has organized and assembled a management structure for the GOES-R AWG that facilitates its success while reducing risks in meeting these objectives. The GOES-R AWG management structure and its relationship to the GOES-R Ground Segment Project are shown in Figure 1. STAR is the Office of primary responsibility for all AWG activities.

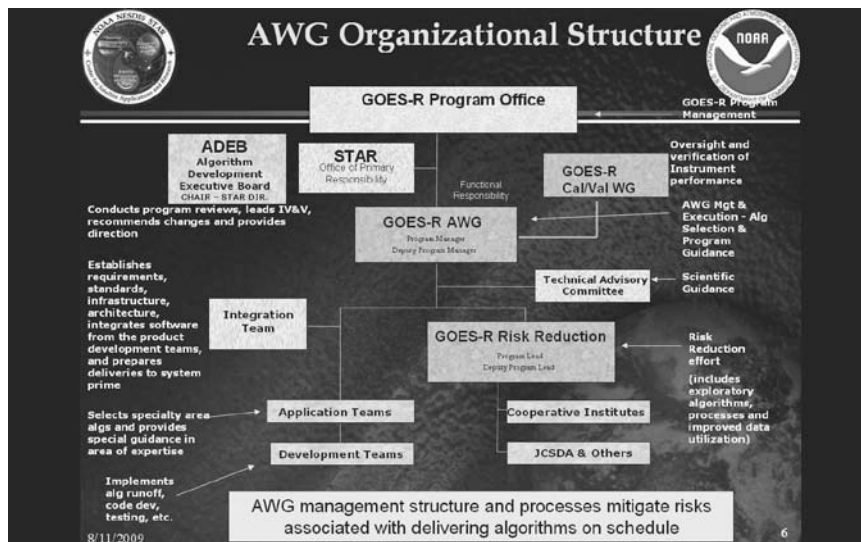


Figure 1. Organizational Structure of the GOES-R Algorithm Working Group

Two supporting elements of the GOES-R AWG program include the GOES-R Risk Reduction Program and the GOES-R Calibration/Validation Working Group (CVWG). The GOES-R Risk Reduction Program is managed and executed under the auspices of the GOES-R AWG and is one of several sources that AWG has chosen from for the level-2 product algorithms. This program, originally established in 2004, enables the NOAA science community (government research labs and universities) to explore approaches that seek to maximize the utilization of the new information from the GOES-R sensors. This has resulted in demonstrations of new capabilities (some in real time) and publication of science papers on the resulting algorithms. The GOES Risk Reduction algorithms and product demonstrations are executed on systems that have been accumulated by PIs at their respective labs, and have no conformity to government operational systems.

The GOES Risk Reduction Program connectivity to the developmental and operational steps leading to GOES-R operations is accommodated through the GOES-R AWG. The GOES-R Calibration Validation Working Group oversees the development and implementation of the calibration of the GOES-R instruments. Its goal is to ensure that each instrument’s calibration



complies with the requirements set forth in its Performance and Operations Requirements Document (PORD), is referenced to recognized international standards, and conforms to “best” calibration practices. The Working Group provides technical guidance and recommendations to the GOES-R Program Offices in NASA and NOAA, primarily through the Algorithm Working Group and scientists in NOAA and NASA. Its members are primarily working level engineers and scientists at NOAA/NESDIS (including its Cooperative Institutes and Centers), NASA/GSFC, and NIST.

<b>Baseline Products (25)</b>	<b>Option 2 Products (34)</b>
Clouds and Moisture Imagery	Cloud Layer/Heights
Clear Sky Mask	Cloud Ice Water Path
Temperature and Moisture Profiles	Cloud Liquid Water
Total Precipitable Water	Cloud Type
Atmospheric Stability Parameters (5)	Convective Initiation
Cloud Top Pressure and Height	Turbulence
Cloud Top Phase	Low Cloud and Fog
Cloud Particle Size Distribution	Visibility
Cloud Optical Depth	Surface Albedo
Rainfall Rate	Upward and Downward Longwave Radiation
Aerosols Optical Depth	Reflected and Absorbed Shortwave Radiation
Derived Motion Winds	Total Ozone
Hurricane Intensity	SO2 Detections (Volcanoes)
Volcanic Ash	Surface Emissivity
Fire/Hot Spot Characterization	Aerosol Particle Size
Land Surface Temperature	Vegetation Index
Sea Surface Temperature	Vegetation Fraction
Snow Cover	Snow Depth
Downward Surface Insolation	Flood Standing Water
	Rainfall Probability and Potential
Lightning Detection	Enhanced “V”/Overshooting Top
	Aircraft Icing Threat
	Ice Cover
	Sea & Lake Ice Concentration, Age, Extent, Motion
	Ocean Currents

Table 1. List of GOES-R baseline and Option 2 Products

The GOES-R Program requested that the AWG establish broad and cross-cutting support for the algorithms and products. The AWG responded with the formation of thirteen AWG product application teams and three specialty teams that provide cross-cutting support to each of the AWG product application and development teams. All of the GOES-R level-2 products (shown in Table 1) are mapped to each of the AWG product application teams. The specialty teams include an Algorithm Integration Team (AIT), a Proxy Data Team, and a Calibration/Validation team. Table 2 lists the AWG product application and specialty teams, the designated chair for each team, and the cross-cutting membership represented in each team.

<b><i>APPLICATION TEAM</i></b>	<b><i>CHAIR(S)</i></b>	<b><i>MEMBERSHIP REPRESENTATION</i></b>
Soundings	C. Barnett, T. Schmit	STAR, CIMSS
Winds	J. Daniels	STAR, CIMSS, CIRA, NASA
Clouds	A. Heidenger	STAR, CIMSS, NASA
Aviation	K. Pryor, W. Feltz	STAR, CIMSS, NASA, Univ. of Alabama-Huntsville
Aerosols/Air Quality/ Atmospheric Chemistry	S. Kondragunta	STAR, CIMSS, UMBC, NASA, CICS, EPA
Hydrology	B. Kuligowski	STAR, UMCP/ESSIC, Univ. of California-Irvine, NASA, NWS/CPC
Land Surface	B. Yu	STAR, CIMSS, NCDC, CICS, NCDC
SST/Ocean Dynamics	A. Ignatov	STAR, OSDPD, NASA, Hampton Univ, Univ. Miami
Cryosphere	J. Key	STAR, Univ. of Maryland, NWS/NOHRSC, CREST
Radiation Budget	I. Lazslo	STAR, OAR/ESRL, UMD/CICS, UMD/AOSC, NASA/LaRC
Lightning	S. Goodman	STAR, NASA
Space Environment	S. Hill	NOAA/SEC, NOAA/NGDC
<b><i>SPECIALTY TEAM</i></b>		
Proxy Data	F. Weng	STAR, CIMSS, CIRA, CICS, NRL, NASA/LaRC
Algorithm Integration	W. Wolf	STAR
Calibration/Validation	C. Cao	STAR

Table 2: GOES-R AWG Application Teams along with their respective Team Chair(s) and membership representation

### *AWG Application Teams*

The GOES-R AWG Applications Teams are responsible for planning and executing the activities to identify, develop, assess, select, demonstrate, and ultimately deliver the product algorithms to the Ground Segment Project. Membership in the GOES-R AWG application teams is based upon (1) the record of publications in an algorithm area including peer review journals and tech reports, (2) experience in implementing operational algorithms in this area including working with implementers, documenting software, and benchmarking algorithm output, (3) experience in science team membership in programs such as EOS, OAT, NPP, and (4) knowledge of the Global Observing System perspective including synergy of observations to achieve the algorithm product. The chair of each Application Team not only meets all of these criteria, but is a STAR civil servant, thus ensuring accountability to the program and to STAR management.

### *AWG Development Teams*

The AWG development teams are responsible for directly supporting its associated application team. The development teams are selected by the Application Team chair and are

comprised of designated civil servants in STAR, STAR contractors, or scientists and programmers from STAR's Cooperative Institutes. The development teams will work within the STAR collaborative computing environment and are responsible for:

- Implementing and executing algorithm runoffs that will allow for the assessment and inter-comparison of the performance of candidate algorithms
- Converting Algorithm Theoretical Basis Documents (ATBD), available research product software, or existing operational product software into GOES-R pre-operational software module
- Supporting the prototyping and demonstration of GOES-R algorithm performance (including algorithm/product meta-data generation techniques, standards, and format) within a scalable operational demonstration environment

#### *AWG Algorithm Integration Team (AIT)*

The AWG Algorithm Integration Team (AIT) is the primary interface between the AWG Application Teams, the AWG Development Teams, and the GOES-R Ground Segment Project. The AIT is comprised of a System Lead, Quality Assurance (QA) lead, a Configuration Management (CM) lead, and full-time programmers. The AWG AIT has a broad range of responsibilities that include:

- Working with the AWG Development Teams ensure their implementation of NESDIS standards for software development and documentation
- Providing Quality Assurance (QA) checking of GOES-R product software received from the AWG Development Teams
- Developing and implementing a GOES-R product processing system framework that will allow integration of product software received from each of the AWG development teams
- Establishing and maintaining a Configuration Management (CM) system for change management of software and documentation
- Preparing system deliveries to the GOES-R Ground Segment Project

#### *AWG Proxy Data Team*

The AWG Proxy Data Team is comprised of experts from STAR, STAR Cooperative Institutes, and NASA that together, brings a full range of capabilities and datasets needed by the AWG Application and Development Teams. The AWG Proxy Team is responsible for:

- The development of high-quality GOES-R instrument simulated and proxy data sets for GOES-R product algorithm development, testing and validation
- The development of advanced tools that include Radiative Transfer Models and simulation systems that span scales from the mesoscale to the global scale

- The development of datasets containing proxy data collocated in time and space with in-situ observations needed for Cal/Val analysis activities undertaken by the AWG product application teams

### 3. AWG MANAGEMENT PROCESSES AND STANDARDS

The AWG has established a high maturity process for algorithm and software development that each AWG application follows for each level-2 algorithm that is developed and coded up. The software development process is comparable with Capability Maturity Model Integration (CMMI) Level-3 maturity. Standards have been established for coding and documentation that each AWG application team follows explicitly. Finally, the AWG has established the necessary management processes to ensure that all AWG activities and deliverables are identified, coordinated, tracked, and completed on time and within budget. Table 3 summarizes the processes and standards followed by the AWG.

Processes	Standards
Initial Requirements Analysis	Algorithm Theoretical Basis Document
Preliminary Design Review	Metadata (FGDC guidelines)
Critical Design Review	Interface Control Document
Test Readiness Review	System Description Document
System Readiness Review	Users Manual
	Fortran 90 Programming
Earned Value Management (EVM) Reporting	C and C++ Programming
Monthly Reporting	Test Plan Document
	Algorithm Implementation Instructions
	Latency Reports

Table 3. AWG established processes and standards

### 4. AWG DELIVERABLES AND DELIVERY SCHEDULE

The main product delivered for each geophysical product by the AWG Application Teams is the Algorithm Theoretical Basis Document (ATBD). ATBDs for each algorithm will be supplied to the GOES-R Ground Segment Project, and contain the following information:

- Overview of the algorithm
- Algorithm processing outline (logic flow)
- Assumptions made on the characteristics of the sensing instrument(s)
- Algorithm inputs (primary sensor and ancillary data) and product outputs
- Theoretical/mathematical description of the physics of the process
- Description of the simulated/proxy input and output data sets, including precision and accuracy estimates with error budgets
- Practical considerations (e.g., numerical computation and programming/procedural considerations, quality assessment/diagnostics, exception handling (e.g., bad data) and algorithm validation)
- Any assumptions made during development including algorithm and sensor performance



In addition to the ATBDs, the AWG will also deliver comprehensive Delivered Algorithm Packages (DAPs) for groups of product algorithms to the Ground Segment Project that will help ensure that the product algorithms are implemented correctly. These DAPs will include:

- **Datasets**
  - Input Proxy and/or simulated datasets
  - Output product datasets
  - Ancillary datasets
- **Source Code**
  - For each product algorithm
  - Scripts and/or makefiles used in the build process
- **Tools required for compilation**
  - NetCDF and HDF libraries and compilers
- **Test Information**
  - Descriptions, plans, and/or procedures on how to test algorithms
  - Performance testing results
- **Documentation**
  - Test Plan Document
  - Software Implementation Document
  - Algorithm Implementation document

The Ground Segment Project will review and then deliver: 1) ATBDs and datasets to the Ground Segment contractor as “Government Furnished Equipment (GFE), and 2) DAPs to the Ground Segment contractor as “Government Furnished Information (GFI).

The AWG delivery schedule is as follows:

- **September 2009**
  - 80% ATBD and Algorithm Package for Baseline Products
- **September 2010**
  - 100% ATBD and Algorithm Package for Baseline Products
  - 80% ATBD and Algorithm Package for Option 2 Products
- **September 2011**
  - 100% ATBD and Algorithm Package for Option 2 Products

## 5. PROGRESS IN ALGORITHM DEVELOPMENT AND VALIDATION

The AWG has made tremendous progress in meeting its objectives:

- Numerous GOES-R ABI and GLM proxy datasets have been generated or gathered for use by the AW application and development teams
- Critical Design Reviews have been completed for 100% of the baseline products and 80% of the Option 2 products
- Test Readiness Reviews have been completed for 98% of the baseline products and 25% of the Option 2 products
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- Many of the algorithms are already meeting product specifications for accuracy and precision
- AWG is poised to deliver ATBDs (80% maturity) for each of the baseline products to the GOES-R Program on September 30, 2009 which is on schedule and within budget

## 6. SUMMARY

The GOES-R AWG is responsible for managing the selection and development of 25 baseline and 34 Option 2 level-2 product algorithms for GOES-R and to participate in various capacities in a number of different calibration/validation activities. NOAA/NESDIS/STAR management has organized and assembled a management structure for the GOES-R AWG that facilitates its success. Highly experienced product application and development teams have been formed to execute the activities necessary to develop and validate the selected algorithms. A proxy team has been established to generate and gather ABI and GLM proxy datasets needed by the product application and development teams for algorithm development and validation activities. An Algorithm Integration Team has been established to develop a common processing system framework for the developed algorithms, ensure processes and standards are adhered to, and to serve as the key interface to the GOES-R Ground Segment Project.

To date, the AWG has made tremendous progress and is poised to deliver the baseline product ATBDs (at 80% maturity), along with Delivered Algorithm Packages (DAPs), for each of the GOES-R baseline level-2 products to the GOES-R Ground Segment Project on schedule and within budget.