Translating and Evaluating GOES-R Product Requirements according to International Standards

Raghu Kacker[1], Aaron Pearlman[2], Raju Datla[3]

1 – National Institute of Standards and Technology, 2 – Integrity Applications, Inc., 3 – Riverside Technologies, Inc.

International Standards for Uncertainty

- **GUM - Guide to the Expression of Uncertainty in Measurement 1993, 1995 [1]**
  - (JCGM WG-1), De facto international standard on expression of results of measurement
- **VIM3 (International Vocabulary of Metrology, 3rd edition 2008) [2]**
  - (JCGM WG-2), Standardized terminology for all including error analysis and GUM based evaluation of uncertainty

Requirements Translation According to GUM

Requirements are written in error analysis framework where accuracy/precision are used to describe measurement results. Converting accuracy and precision requirements to uncertainty to be consistent with GUM can be done as follows [4]:

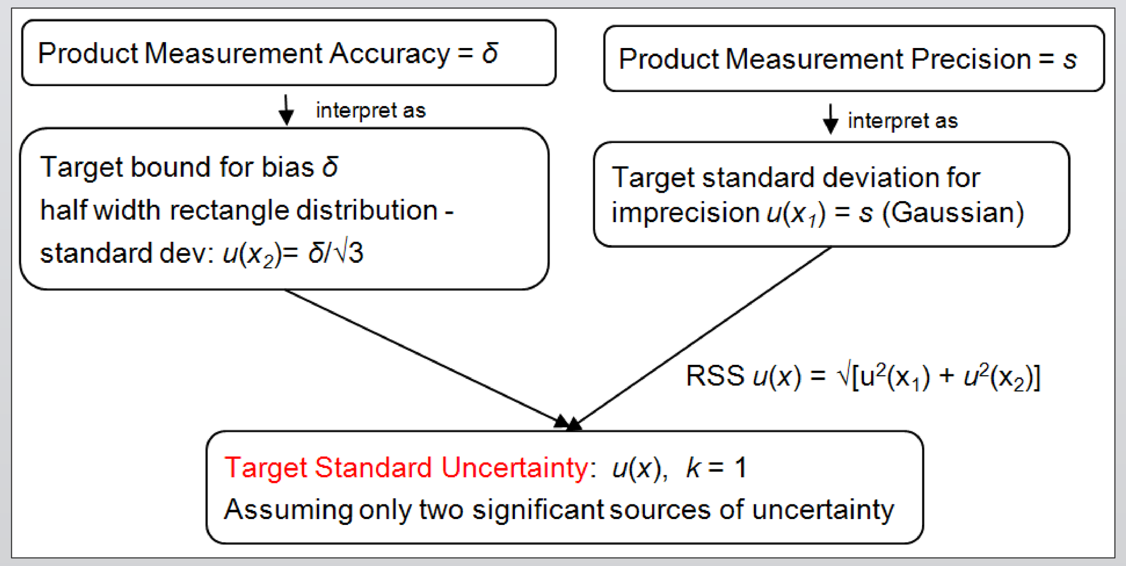

Figure 1 – Requirement translation methodology

Examples of Requirements Translation

Level 1b Products

Requirements exist for accuracy and precision for the brightness temperature detected by the emissive channels. The reflective channels have requirements for radiance accuracy, short-term repeatability (precision), and long-term drift [3]. Long term-drift is treated similarly to accuracy. The requirements are converted to uncertainty (k=1) using the procedure above:

Table 1 – Requirement translation results for L1b

	accuracy	long-term drift	precision/short-term repeatability	uncertainty
emissive channels (K)	1	NA	0.4	0.702
reflective channels (%)	5	0.2	1.5	3.020

Level 2 Product: Aerosol Optical Depth (AOD)

Requirements exist for accuracy and precision. The requirements are converted to uncertainty (k=1) :

Table 2 – Requirement translation results for L2, AOD

	Over land			Over water		
AOD	accuracy	precision	uncertainty	accuracy	precision	uncertainty
<0.04	0.06	0.13	0.135	0.02	0.15	0.150
.04-0.8	0.04	0.25	0.251	0.1	0.23	0.237
>0.8	0.12	0.35	0.357	0.1	0.23	0.237

Product 2 Evaluation- Current Practice

As an example of the way product algorithms are evaluated, we describe aerosol optical depth (AOD) as an illustrative example. In trying to remain consistent with requirements written in terms of accuracy and precision, the algorithm theoretical basis document shows an in-depth analysis of the uncertainties associated with AOD and describes validation efforts for the algorithm.

Uncertainty Estimation

The uncertainty is assessed via a sensitivity analysis, where a given AOD parameter value - like ozone, water vapor, surface pressure and wind speed- is perturbed by the estimated uncertainty and used as the input to the AOD algorithm (*test value*). This AOD result is compared to the AOD computed with the unperturbed parameter value (*reference*). The "relative AOD uncertainty" is calculated as (*test - reference*)/*test* [5]. The figure below could be clarified by plotting only uncertainty.

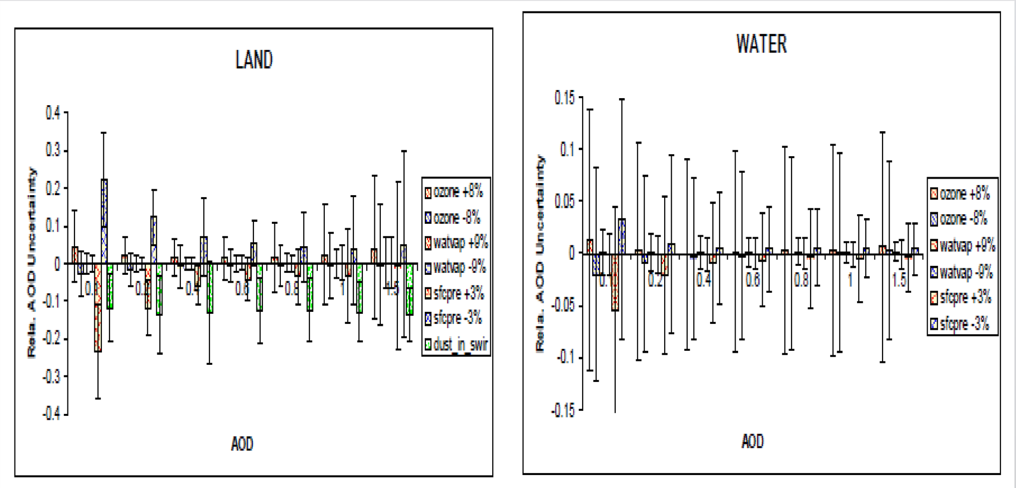

Figure 2 - AOD uncertainty evaluation results [5]

This methodology is close to the GUM one. The formula for propagation of uncertainty using numerical analysis is

$$Z_i = \frac{1}{2}\left\{f\left[x_1,\ldots,x_i+u(x_i),\ldots,x_N\right]-f\left[x_1,\ldots,x_i-u(x_i),\ldots,x_N\right]\right\}$$

$$u_c^2(y)=\sum_{i=1}^{N}\sum_{j=1}^{N} Z_i Z_j r(x_i,x_j)$$

Combined standard uncertainty

$$r(x_i,x_j)=\frac{u(x_i,x_j)}{u(x_i)u(x_j)}$$

Correlation coefficient

Background on Aerosol Optical Depth (AOD)

AOD is a measure of the extinction of solar radiation by aerosol scattering and absorption. It can be measured using satellite and ground measurements.

Beer-Lambert-Bouguer Law is used to retrieve total optical depth:

$$I(\lambda)=I_0(\lambda)e^{-\tau(\lambda)m}$$

m = air mass
$\tau(\lambda)$ = total spectral optical depth
$I(\lambda)$ = Irradiance on earth's surface
$I_0(\lambda)$ = Irradiance at the top of the atmosphere

AOD retrieved by accounting for the effects of ozone (O_3), Rayleigh scattering and absorption (R), water vapor, (wv) and other gases (g)

$$\tau_a(\lambda)=\tau(\lambda)-(\tau_R(\lambda)P/P_o+\tau_{o_3}(\lambda)+\tau_{wv}(\lambda)+\tau_g(\lambda))$$

$P(P_o)$ – Pressure at site (sea level)

Product Validation

According to the ATBD [5], simulated ABI retrievals are validated with ground-based aerosol measurements from the Aerosol Robotic Network (AERONET) [6,7]. The results of this validation exercise is shown in Figure 3. In this case, proxy reflectance values retrieved from MODIS are used as inputs to the AOD algorithm. The retrieved AOD values are compared with co-located ground measurements from AERONET. The results of the comparison are shown in an error analysis framework in terms of accuracy and precision. The accuracy (bias) is shown as a solid bar and the precision is shown using "error bars" to characterize the spread across a number of AOD retrievals. **This methodology is not consistent with GUM (see below).**

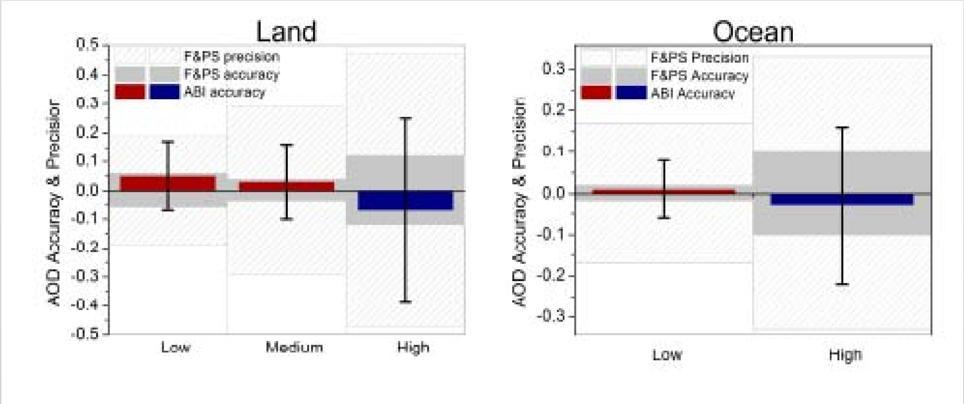

Figure 3 - AOD validation results [5]

Product 2 Validation- Recommended Practice

The validation done above considers the AOD retrievals from ground measurements as the true values. In fact, there are non-negligible uncertainties associated with these retrievals. We recommend accounting for such uncertainties using the following validation procedure:

- Find difference in retrieved AOD (τ)
- Estimate uncertainty of ground AOD retrieval and find the combined uncertainty of comparison:

$$\Delta\tau=\tau_{abi}(\lambda)-\tau_{ground}(\lambda)$$

$$u_{\Delta\tau}=\sqrt{\tau_{abi}^2(\lambda)+\tau_{ground}^2(\lambda)}$$

$$\text{If } \Delta\tau < u_{\Delta\tau} \rightarrow \text{Validation successful}$$

➢ This shows *metrological compatibility [1]*.

Instrument Requirements

Instrument vendors have a set of requirements that are generated in order to meet the higher level (MRD) requirements. They are frequently written in terms of accuracy, which can be problematic:

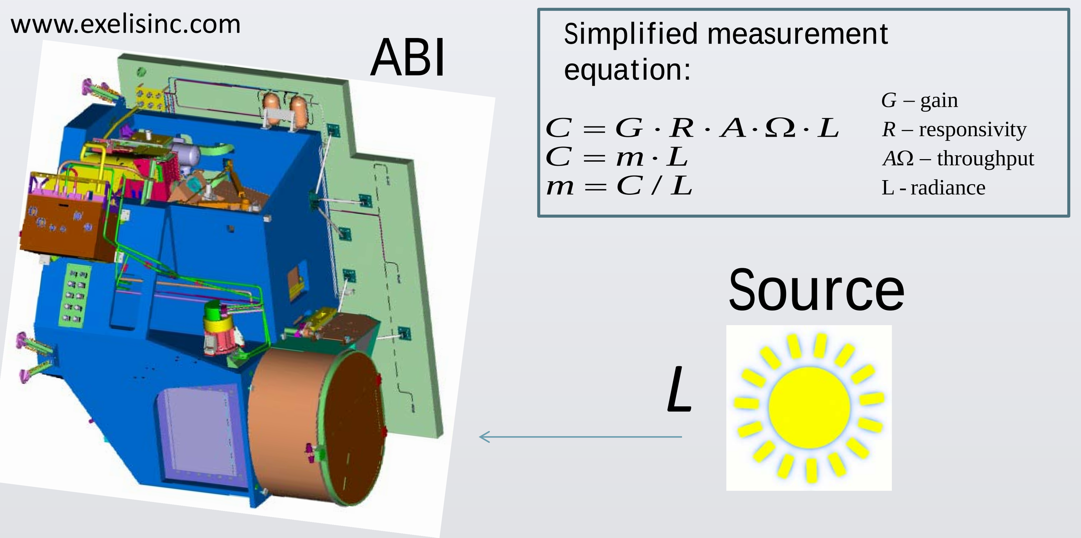

Figure 6 – Calibration test schematic for the Advanced Baseline Imager.

There is no true value of calibration coefficient (m):
- Cannot obtain accuracy
- Cannot decouple accuracy from precision.

⇨ Vendor can interpret a requirement in terms of uncertainty instead (i.e., accuracy = uncertainty).
➢ Lacks transparency

Advantages of Methodology

- Uses internationally accepted framework for requirements evaluation. Avoids confusion associated with error analysis since results are not described with reference to an unknowable truth.
- Current requirements can be straightforwardly translated to the GUM framework.
- Could lead to greater transparency in understanding requirements during instrument development; Waiver requests would be well-understood.
- On-orbit performance of instruments could be evaluated more easily and cross-comparisons can be done in common framework.

References

1. Evaluation of measurement data — Guide to the expression of uncertainty in measurement. BIPM: JCGM 100:2008. http://www.bipm.org/utils/common/documents/jcgm/JCGM_100_2008_E.pdf
2. International Vocabulary of Metrology – Basic and General Concepts and Associated Terms: JCGM 200:2012. http://www.bipm.org/utils/common/documents/jcgm/JCGM_200_2012.pdf
3. GOES-R Series Mission Requirements Document (MRD) January, 19, 2012, P417-R-MRD-0070
4. R. Kacker, K. Sommer, R. Kessel, "Evolution of modern approaches to express uncertainty in measurement," *Metrologia* 44, 513, 2007.
5. GOES-R Advanced Baseline Imager (ABI) Algorithm Theoretical Basis Document Suspended Matter/Aerosol Optical Depth and Aerosol Size Parameter NOAA/NESDIS/STAR Version 2.0 September 25, 2010
6. Holben B.N., et al., AERONET - A federated instrument network and data archive for aerosol characterization, *Rem. Sens. Environ.*, 66, 1-16, 1998.
7. Holben, B.N., et al., An emerging ground-based aerosol climatology: Aerosol Optical Depth from AERONET, *J. Geophys. Res.*, 106, 12,067-12,097, 2001