Commercial Remote Sensing Regulatory Affairs

Guidance Circular

GC No: 960.6-1
Subject: Calculation and use of the RGIQE metric for SAR Tiering
Date: March 31, 2022

Guidance Circulars (GC) are intended to provide guidance to entities subject to or potentially subject to the Land Remote Sensing Policy Act of 1992 (51 U.S.C. § 60101 *et seq.*) and the National Oceanic and Atmospheric Administration's (NOAA's) implementing regulations at 15 CFR Part 960. The contents of this document do not have the force and effect of law and are not meant to bind the public in any way. The document is only intended to provide clarity to the public regarding existing requirements under the law or agency policies.

Applicable Statute: 51 U.S.C. § 60121, 60122

Applicable Regulations: 15 C.F.R. 960.6(a); Appendix A to 15 CFR Part 960

If you have suggestions for improving this GC, we invite you to provide feedback to NOAA's Commercial Remote Sensing Regulatory Affairs office (CRSRA) at crsra@noaa.gov, noting the number of the GC you are discussing in your email.

Overview of Issue:

The Land Remote Sensing Policy Act of 1992 authorizes the Department of Commerce (delegated to NOAA) to license private entities to operate private remote sensing space systems, and prohibits the operation of remote sensing space systems without such a license. The implementing regulations require categorization of licenses based on the availability, or lack of availability, of comparable data to that which the licensed system will produce. Section 960.6(a) provides that:

the Secretary shall determine, after consultation with the Secretaries of Defense and State as appropriate, the category for the system as follows:

(1) If the application proposes a system with the capability to collect unenhanced data substantially the same as unenhanced data already available from entities or individuals not licensed under this part, such as foreign entities, the Secretary shall categorize the application as Tier 1;

(2) If the application proposes a system with the capability to collect unenhanced data substantially the same as unenhanced data already available, but only from entities or individuals licensed under this part, the Secretary shall categorize the application as Tier 2; and

(3) If the application proposes a system with the capability to collect unenhanced data not substantially the same as unenhanced data already available from any domestic or foreign entity or individual, the Secretary shall categorize the application as Tier 3.

If a system is categorized as Tier 3, there is the possibility that its license will include custom Tier-3 temporary conditions. 15 C.F.R. § 960.10. Systems categorized as Tier 1 or Tier 2 will include only the standard conditions found at 15 C.F.R. § 960.8 and 960.9, respectively.

Section 960.4 of the Rule defines ***substantially the same***:

Substantially the same means that one item is a market substitute for another, taking into account all applicable factors. When comparing data, factors include but are not limited to the data's spatial resolution, spectral bandwidth, number of imaging bands, temporal resolution, persistence of imaging, local time of imaging, geographic or other restrictions imposed by foreign governments, and all applicable technical system factors listed in the application in appendix A of this part.

This definition sets up a flexible standard that NOAA will use holistically to compare data. It is left to NOAA as the regulator to determine which factors to utilize and how to assess comparability of available data to an applicant or licensee's capabilities. Remote sensing temporal performance, also called persistence or revisit, is considered for all licenses during categorization, however each imaging modality has one or more unique additional performance metrics that are compared.

When NOAA evaluates data from standard, visible light (electro optical or "EO") cameras (typically operating in the 400-800 nanometers (nm) spectral range) without night-time imaging ability, NOAA primarily considers spatial resolution, which is the projection of a pixel onto the ground and the smallest discernible detail in the digitized image. Other types of remote sensing data can be more complex to compare, requiring looking at many primary metrics.

The subject of this GC is Synthetic Aperture Radar (SAR) data. Instead of using reflected visible light, SAR is an active remote sensing phenomenology that transmits radiofrequency energy (usually pulses) at a scene and processes the returning pulses to create a representation of the scene. SAR data is inherently three dimensional (area and elevation information) and must be mathematically processed into products before it is interpretable by humans. SAR instruments have multiple imaging modes corresponding to variation of the bandwidth of the radiofrequency pulses and differences in how the beam is moved across the ground.

While SAR data has an inherent minimum spatial resolution based on the characteristics of the instrument and the energy pulses transmitted toward the target, the spatial resolution is usually different in all three dimensions and is typically reduced at each level of processing. Further, the quality of the data varies with the strength of the radar echo received back and the length of time the instrument integrates energy from a spot on the ground. Hence higher powered SAR instruments observe details others may not.

Approach to SAR

NOAA prefers to use a single metric to compare SAR systems to avoid use of a weighting scheme. The metric should account for spatial resolution and signal strength (relative to the noise floor) so that the smallest discernible feature size can be determined. The metric used by NOAA is called the Radar General Image Quality Equation or RGIQE. RGIQE is derived from information theory and corresponds to the information density of a SAR data set or “image”, referred to as ‘C’. Larger values for ‘C’ signify higher information density and correspond to better performing systems—finer spatial resolution and higher transmitted energy level.

RGIQE represents local image fidelity within a SAR image where spatial resolution is optimized—note that it can also be calculated from instrument parameters. Because of this, RGIQE bridges the gap between hardware and data, that is, between instrument capability (the way NOAA’s regulations require it to evaluate U.S. licensees) and data quality (the way NOAA’s regulations require it to evaluate foreign data availability).

The RGIQE equation is presented below.

$$C = \text{information Density} = \text{bits/square meter} = \beta * (\log_2(1+SNR))$$

Where;

β = bandwidth = βground = (B_{range} * $B_{azimuth}$)*Cosine(*Slope*)

Bground = βarea = bandwidth per-unit-area

$B_{range} = 2 * B_{RF}/c$

c is the speed of light

B_{RF} = Radiofrequency bandwidth of the pulse

$B_{range} = 1/(Resolution_{range} * \cos(Ø))$

$B_{azimuth} = 1/(Resolution_{azimuth} * \cos(Ø))$

Ø = grazing angle for calculating resolution

SNR = signal-to-noise ratio

It can be readily seen that RGIQE has a direct dependence on spatial resolution (range and azimuth) and a Log (base 2) dependence on SNR.

Calculating RGIQE

NOAA calculates a value for RGIQE for each SAR license application, and also for each foreign SAR system appearing in the Benchmarks prior to performing tiering.

For U.S. systems, NOAA uses the values of SNR and spatial resolution provided by the applicant in the application. Applicants should follow the below guidance for calculating SNR and spatial resolution. It is noted that the SNR and bandwidth per-unit-area ($\beta_{ground}=\beta_{area}$) values should be selected at the same grazing angle for the application.

<u>Calculating SAR Signal-to-Noise Ratio (SNR)</u>

SNR=signal-to-noise ratio (*Radar Handbook*, Third Edition by Merrill Skolnik, eq 17.32):

c. SAR Signal-To-Noise Ratio (SNR):

Signal-To-Noise (SNR) – This is the standard parameter used to determine if there is enough power to collect a target at a given distance at a desired resolution. It is also used to determine the access and range of a SAR system.

$$SNR = (P_T \times (A_A)^2 \times (E_A)^2 \times \sigma \times R_R) / (8 \times \pi \times (SR)^3 \times \lambda_{CF} \times k \times T_O \times N_F \times L_S \times V_p \times \text{cosine}(T_E))$$

a) P_T = Average Transmitted Power in watts
b) A_A = Antenna Area in square meters
c) E_A = Antenna Efficiency in ratio
d) σ = Radar Cross Section in square meters. Assumption is (desired resolution in meters)^2
e) R_R = Range Resolution in meters
f) π = Pi (3.14159)
g) SR = Slant Range (Range Between Sensor and Target) in meters
h) λ_{CF} = Wavelength of the Transmitted Center Frequency in meters
i) k = Boltzmann's Constant in Joules per kelvin (1.38×10^{-23})
j) T_O = Noise Temperature in kelvin
k) N_F = Noise Figure in ratio
l) L_S = System Losses in ratio
m) V_p = Platform Velocity in meters per second
n) T_E = Target Elevation Angle in degrees

The Sigma(zero) (σ_0) scene contribution (ground RCS per unit area) term in the SNR equation should be set to 1 (or equivalently 0dB). This allows the SNR in the license application to equal SNR in the RGIQE equation (under a thermal noise-only assumption). Any losses from transmitter/receiver imperfections are also zeroed out. These assumptions have the added benefit that the resulting SNR calculation is simplified to SNR=1/NESZ, but C will be slightly inflated for some systems.

Calculating Spatial resolution

- For regulatory purposes, SAR resolution is measured as the peak-to-null width of the main lobe of the uniformly-weighted impulse response in the ground plane for single-look complex imagery and will vary with sensor geometry."

- **For Range resolution**, it is sufficient to use $Res_{range}=c/(2*B_{RF}*cos(Ø))$ where Ø is the grazing angle and B_{RF} is the pulse bandwidth/frequency content. State the range of Ø.

- **For Azimuth resolution**, use $Az_{res}= λ/(2*ρ)$ where λ=transmit frequency wavelength and ρ is the aspect angle (subtended synthetic aperture angle) with maximum planned dwell time / subtended angle or state the method used.

Useful parameters for calculations

- At 9.65 GHz, λ = .0311 m, orbital velocity~7.5 km/s
- At 500 km, orbital period=5677 seconds
- 1 degree = 0.0174533 radians

RGIQE examples

Grazing angle=55 degrees used for each system below. COS(55°)=0.573576
C=Speed of light=2.998E+8 m/sec
Azimuth resolution is held constant here at 0.25 meters though this is atypical

SAR Instrument	B_{RF} (MHz)	B_{range}	$B_{azimuth}$	B_{ground}	SNR (1/NESZ)	Log_2(1+SNR)	RGIQE
System A	300	**2*B_{RF}/C** =2	=1/(Azimuth Resolution) =1/0.25=4	4.59	**NESZ=-15** SNR=1.5dB	5.03	23
System B	600	4	4	9.18	**NESZ=-18** SNR=1.8dB	6.0	55
System C	1200	8	4	18.35	**NESZ=-22** SNR=2.2dB	7.32	134

Opportunity for Feedback: We welcome any feedback you may have about this GC. Please contact CRSRA at crsra@noaa.gov.