GVAR Data Rollover in Channel 2 of GOES-12 Imager

SUMMARY

GVAR was designed for the GOES system represented at the time by GOES-8, whose Imager channel 2 (3.8 µm) was required to be able to sense scene brightness temperatures (T_b) up to 320K. That temperature corresponds to a GVAR count of ~530. Starting with GOES-11, the specification for the maximum T_b in Imager channel 2 was increased to 335K, which corresponds to a GVAR count of ~835. These sensors are expected to degrade over time, which will cause the maximum T_b and its associated GVAR count to increase. During the up-to-nine years of life of the GOES-8, -9, and -10 Imagers, the increase in the maximum T_b in their channel 2's resulted in an increase of approximately 20 counts in the associated GVAR count level. For GOES-12, for reasons still under investigation, the maximum T_b increased much more rapidly, requiring its associated GVAR value to increase by more than 200 counts in three years. This caused the GVAR to roll over, i.e., when the required GVAR count exceeds the highest value (1023) that GVAR is capable of transmitting, it results a very low count value. Currently, rollover affects only channel 2 of the GOES-12 Imager. It may also affect channel 2 for the GOES-11, -13, -O, and -P Imagers in the future, but it is not likely to affect other channels. This report describes the occurrence, impact, history, and cause of rollover in detail, followed by analyses of several solution options. The option recommended by NOAA/NESDIS is not to modify the GVAR, but to have the GVAR recipient detect the rollover and apply a simple correction for it. Meanwhile, studies are underway, in collaboration with NASA and ITT, on the feasibility of outgassing or decontaminating the instrument to reverse the instrument degradation and reduce the GVAR count for the maximum scene temperature.

INTRODUCTION

In the winter of 2006, data in the GOES Variable (GVAR) transmission for channel 2 (3.8 µm) of the GOES-12 Imager began taking very low values (<40 digital counts), corresponding to negative brightness temperatures (in Kelvin), at some pixels in areas of fires (Fig 1). These are areas whose brightness temperatures are expected to be very high. This is an example of GVAR "rollover." Obviously, GVAR count values associated with negative brightness temperatures are incorrect. This report describes the rollover and its cause and presents the method to recover the correct sensor observations of scene radiance and brightness temperature from the rolled-over data. (Preview for the impatient reader: to correct for the rollover, add 1024 to the rolled-over value.)

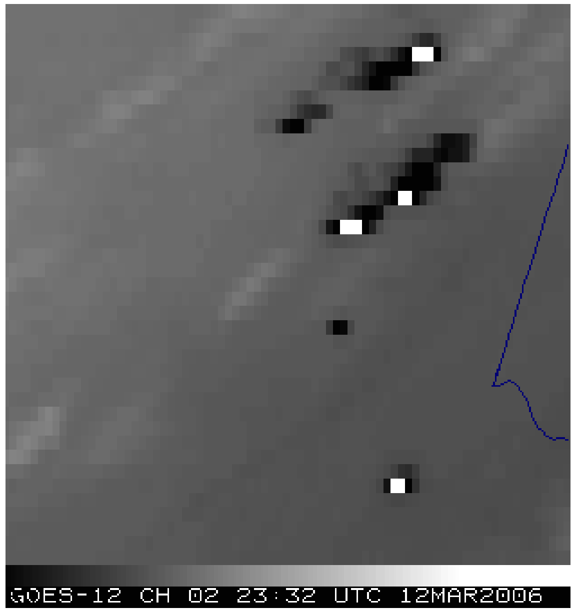

Figure 1: Example of rollover in observations by GOES-12 Imager Channel 2. The image contains an area of fires with brightness temperatures sometimes exceeding 342K. The higher the GVAR count value, the blacker the pixel. However, the observations in the hottest regions exceed the GVAR maximum and have rolled over to low values, producing the white pixels. The irregular blue line on the right is a portion of a state border superimposed on the image. (Figure courtesy of Scott Bachmeier, Space Science and Engineering Center, University of Wisconsin, Madison, WI)

DESRIPTION OF ROLLOVER

In the processing in the Modernized Sensor Processing System computer (MSPS) at the Wallops Command and Data Acquisition Station (CDAS), Imager raw output is transformed to scene radiances by application of the calibration equation. The radiances are then converted to integral GVAR count values, via an operation termed scaling, and the count values are transmitted to users in the GVAR data stream. The scaling operation in channel 2 consists of two steps--first, a linear transformation

$$X = 68.2167 + 227.3889 R, \tag{1a}$$

where R is the scene radiance, and X is the scaled value. Second, the value of X, which at this point is a real (floating point) number, is rounded

$$I_G = \text{Round}(X) \tag{1b}$$

to produce the integer I_G, the GVAR count value.

Users may invert the scaling (whose coefficients are channel dependent but are invariant in time and are the same for the Imagers on all satellites) to recover the radiances, and then they may convert the radiances to brightness temperatures via a procedure based on the Planck function. Detailed explanations can be found in Weinreb et al. (1997) and on the web at http://www.oso.noaa.gov/goes/goes-calibration/contents/page1.htm or http://www.oso.noaa.gov/goes/goes-calibration/gvar-conversion.htm.

The GVAR data stream was designed to transmit pixel values spanning the entire range of physically reasonable radiances and brightness temperatures. For channel 2 of all the GOES Imagers, the range of radiances GVAR can transmit is from 0 to 4.1989 mW/(m^2 -sr-cm^{-1}). For the GOES-12 Imager, this corresponds to scene brightness temperatures between 0 and 342.096K. The zero values of radiance and brightness temperatures occur near the GVAR count value of 68, and the highest values of radiance and brightness temperatures correspond to the maximum GVAR count value, which is 1023 in the Imagers' 10-bit GVAR data steam.[1]

Nevertheless, in certain situations, channel 2 of the GOES-12 Imager can view scenes whose radiances equal or slightly exceed 4.1989 mW/(m^2 -sr-cm^{-1}), or 342.096K. Such extreme radiances will be encountered in areas of fire, as we mentioned previously, but also in areas of specular reflection of radiation from the sun (sun glint). Sun glint usually originates at the ocean surface, although at least one example of rollover from glint has been seen in the presence of a dust cloud. What happens when the GOES-12 Imager views such scenes? The process is similar to what happens when the mileage value on your car's odometer rolls over from 999,999 to 000,000; hence the name "rollover." The scaling operation in the MSPS computer would produce a GVAR count value of 1024 or more, whose binary representation requires 11 bits. If the GVAR count value needed to be precisely1024, the most significant bit (the 11th bit) would set to unity, and the ten less significant bits would be set to zero. As the GVAR count value increases from 1024, the11th bit would be unity, and the first few of the less significant bits would begin to turn on. But the GVAR transmits only the least significant ten bits/pixel. The 11th (most significant) bit is missing. Thus the transmitted value will be too low by 1024, the value represented by that missing bit. As an example, suppose the radiance value corresponded to a GVAR count value of 1040. Then 1040 minus 1024, or 16, is the rolled-over value transmitted in the GVAR. This explains the occurrence of the white pixels in Fig. 1. Their radiances exceeded 4.1989 mW/(m^2 -sr-cm^{-1}); i.e., their brightness temperatures exceeded 342.096K. Thus, their GVAR count levels rolled over to low values.

WHY ONLY THE GOES-12 IMAGER

In the initial days of the GOES I-M program, NOAA specified that the Imagers on the GOES-8, -9, and -10 satellites should be capable of measuring scene temperatures up to 320K in channel 2 (3.8 µm). The instrument manufacturer, ITT, provided some

[1] Why is the GVAR count value for zero radiance chosen to be 68, not zero? Choosing a value higher than zero allows us to transmit data from the lower half of the distribution of outputs when the Imager views cold space. If the count value of space were chosen to be zero, the data in the lower half of the noise distribution would be missing. This is not a desirable state of affairs. For example, GVAR recipients would not be able to compute correct values of the mean and standard deviation of the observations of space.

margin for error ("headroom"), designing Imagers whose highest observable temperature (HOT) in this channel fell somewhere between 320K and 324K. As an Imager ages in orbit, its HOT typically increases by a one or two tenths of a degree (K) per year. The reason for this is that the instrument's responsivity (change in output counts per unit change in scene radiance) gradually decreases, possibly because of contamination of optical elements. As the responsivity decreases, the radiance for any given value of net output counts increases[2]. In particular, the radiance for the instrument's highest possible net output increases, i.e., the HOT increases. Near the end of an Imager's five-year lifetime, then, its HOT could reach 325K.

As we mentioned previously, the maximum scene radiance that GVAR can transmit in channel 2 is 4.1989 mW/(m^2 -sr-cm^{-1}). The scene temperature corresponding to this radiance varies slightly from Imager to Imager, because the transformation from radiance to temperature depends on the instrument's spectral response. Although the channel 2's of all GOES Imagers nominally have the same spectral response, we're talking about real pieces of hardware, so the actual spectral responses differ slightly from one to the other. For all GOES Imagers, the highest scene temperatures transmitted in GVAR in channel 2 lie between 341.1 and 342.1K, as listed in the following table:

Table 1: Maximum brightness temperatures (T_B, in degrees Kelvin) for data transmitted in GVAR for Imager channel 2.

GOES	8	9	10	11	12	13
Max T_B	341.7	341.3	341.1	341.8	342.1	341.6

These temperatures exceed the GOES 8-10 end-of-life HOTs of 325K, so GVAR will be capable of transmitting temperatures of all scenes viewed in channel 2 of the GOES-8, -9, and -10 Imagers.

For channel 2 of the Imagers on GOES-11 and beyond, NOAA changed its specification of the HOT. Instead of 320K, it became 335K. This was done primarily to benefit researchers characterizing fires, which, as we've seen, generate scenes with very high brightness temperatures. Now, considering that ITT built these more recent Imagers with headroom of up to 4K in the channel-2 HOT, and that the HOT slowly increases with time in orbit, you can imagine that the HOT may approach and possibly exceed the maximum GVAR temperature. This has happened with GOES-12 (and GOES-11 in one instance, as we will see below) and may occur in operations with GOES-11 and GOES-13 and beyond. As the specification for the HOT was not changed in any of the other infrared channels, their HOTs remain significantly below the maximum scene temperature GVAR can transmit. Thus, channel 2 enjoys the distinction of being the only channel with rollover.

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[2] By "net output counts" we mean the true output of the instrument, which is the absolute value of the difference between the output counts from the scene and the output counts from space—a target whose radiance is essentially zero. The absolute value is required, as the Imagers are designed such that the colder the scene, the higher the output value in counts.

Figure 2 shows the history of the HOTs for channel 2 of the GOES 8-12 Imagers. For the first three satellites, GOES 8-10, these HOTs have stayed well below the GVAR

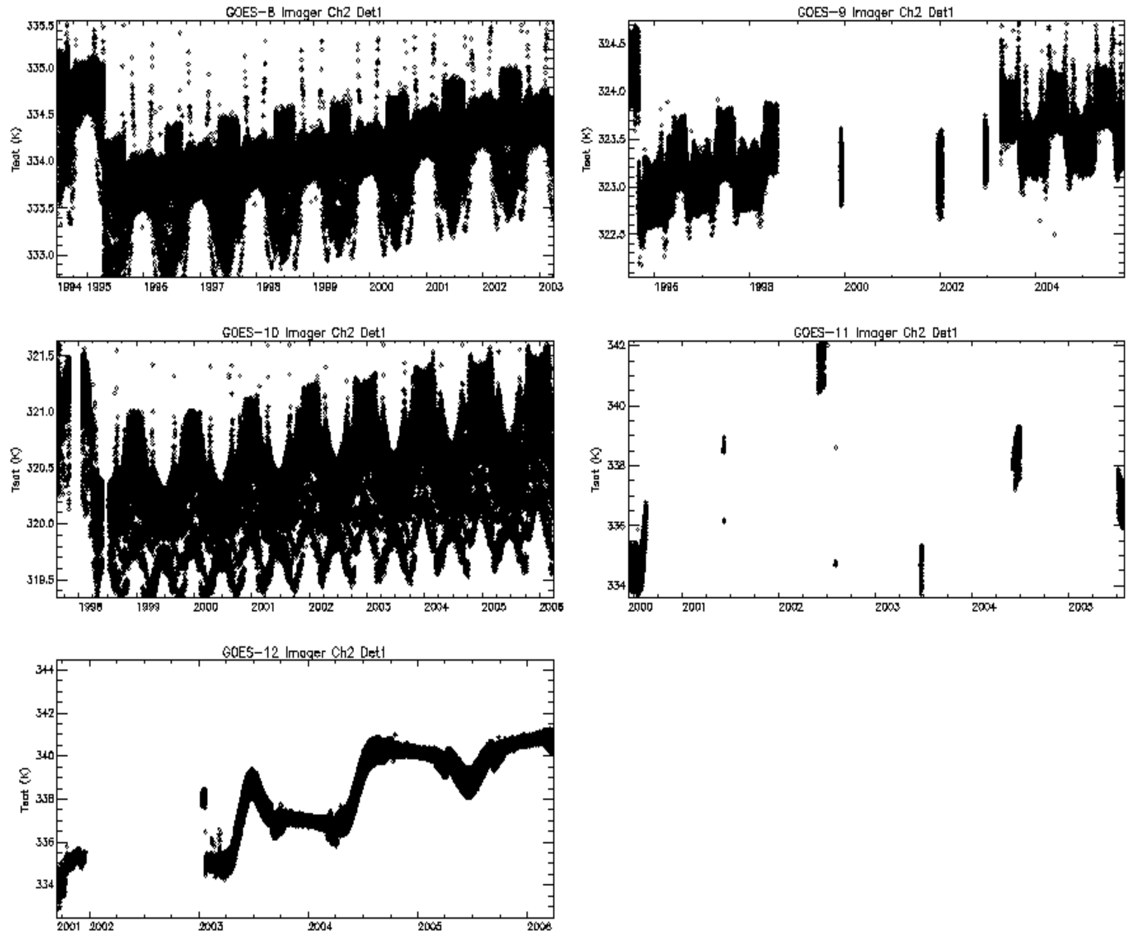

Figure 2: History of highest observable temperature (HOT) in channel 2 of GOES 8-12 Imagers. The figure shows data for only one of the two detectors in this channel. The values are similar for the other detector. Gaps in data for GOES-9, -11 and -12 correspond to periods of storage in orbit. GOES-12 became operational in April 2003; earlier data were collected in checkout periods. All data from GOES-11 were taken during checkout periods. According to this figure, only for the GOES-11 and -12 Imagers did the HOT in channel 2 reach and exceed the GVAR maximum of approximately 341K. Figure courtesy of Dejiang Han (ASRC).

maxima of approximately 341K, as expected. But for GOES-12 (and GOES-11) it's a different story. Although there was little headroom when the GOES-12 Imager was built, it appears that its HOT has been increasing at an average annual rate of over 2K, a rate that far exceeds those seen with the earlier Imagers. If the GOES-12 HOT continues increasing at that rate, the rolled-over GVAR counts may soon invade the domain of the truly coldest scenes, making it more difficult to recover the information in the rolled-over data (see next section).

The GOES-11 Imager, which was in storage in space from 2000 until 2006, also exhibited rollover in 2002, during one of the occasional periods when it was taken out of storage for a performance check. But since June 21, 2006, when GOES-11 was made operational, we have not seen rollover in the data from channel 2 of the GOES-11 Imager.

METHOD TO RECOVER TRUE SENSOR OBSERVATION FROM ROLLED-OVER VALUE

When users recognize a rolled-over pixel, they can recover the radiance by first adding 1024 to the rolled over value. This produces a valid value for I_G in Eq. (1), which can then be inverted to produce R, the radiance.

The trick is to recognize when a pixel is rolled over. Rollover results in low count values, but so do observations of the coldest scenes, such as space or high clouds. For channel 2 of the Imager on GOES-12, we believe it is safe to assume that any GVAR count value under 55 is a rolled-over value (or a negative electronic spike, which we leave to the reader to decide how to handle). On the other hand, count levels at 55 and above could conceivably originate from observations of space or cold clouds. The mean value of such observations will be approximately 68, and lower values will occur in the distribution of noise about the mean. The standard deviation of the noise in channel 2 of the GOES-12 Imager is approximately one GVAR count, and as a full Earth image contains roughly 15 million pixels in that channel, the noise distribution may reach 7 or 8 sigma below the mean (to approximately 60 counts) before the frequency of occurrence becomes negligible. However, users have reported seeing at least one pixel with a count level of 56, so to be safe, we picked 55 as the lowest possible value for space or high cloud.

Thus, GVAR count levels between zero and 55 can safely be treated as rolled-over values. At the time of this writing, we have not seen any rolled-over values above 40. However, the values have been increasing rapidly as the HOT increased at a rate of approximately 2K/yr (see previous section). If the rolled-over values ever begin exceeding 55, users may need to apply additional information, such as the radiance (or GVAR count level) in channel 4 (10.7µm), to distinguish the rolled-over values in channel 2 from the true low values from views of space or high clouds. Channel 4 does not experience rollover, so it will report a high value on the (hot) scenes where the data in channel 2 rolls over but a low value on the coldest scenes[3].

ALTERNATIVE APPROACHES

When the specification on the value of the HOT in channel 2 was increased to 335K for GOES-11 and beyond, we didn't give much thought to the possibility that the HOT might exceed the capacity of GVAR. After all, the HOT was still approximately

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[3] This screening method was suggested by Chris Schmidt of the Space Science and Engineering Center at the University of Wisconsin.

7K below the GVAR maximum, and we had not encountered an Imager whose HOT could increase by more than a few tenths of a degree/yr. But when recently GOES-12 countered our expectations and the rollover began, we considered several approaches for dealing with it, which we will describe here. We are interested in user reaction to those approaches, so if the reader has any opinions on them (especially if you prefer we had selected another approach), we would appreciate hearing from you. Please contact Dr. Xiangqian Wu at Xiangqian.Wu@noaa.gov.

1. Do nothing. This is the alternative we selected. We leave it to GVAR recipients to recover the information in the rolled-over counts, as we described in the previous section. The advantage of this approach is that it makes the information in the rolled-over counts available to all GVAR recipients, effectively increasing the dynamic range of the observations at the upper end. The disadvantage is that we have thrown the responsibility for dealing with the rollover onto the users. It may become more difficult if the rolled-over count levels begin to invade the domain of the truly coldest scenes.

2. Cap the GVAR at 1023; i.e., transmit the value 1023 in place of all GVAR values that would have rolled over. This may make life easier for GVAR recipients who would find it difficult to deal with rolled over values. However, the information in the rolled-over values would be lost for all GVAR recipients. Capping reduces information in the GOES data stream, and as a general principal we believe that reductions in information should be done as far downstream as possible, e.g., by the end user, so that the maximum amount of information is available to those users who want it.

3. Cap the GVAR at 1023, but make the information in the rolled over values available to GVAR recipients by flagging the occurrences of rolled-over values, and sending the flags and the minimum amount of information required to correct for the rollover—perhaps the correct value itself--in a new type of block 11 in the GVAR. This alternative turned out to be both impractical for NOAA to do and difficult for users to take advantage of.

4. Modify the scaling coefficients (in Eq. 1) so that the GVAR can transmit higher radiances. NOAA has a philosophical objection to this approach. The scaling coefficients for each channel have been advertised to remain fixed for the life of the GOES I-Q program. If we changed them in mid-steam, then, to select the proper scaling coefficients, users would need to know which satellite produced their data, and, in the case of current satellites, knowledge of the date the data were taken. We believe such a change will lead to unacceptable confusion.

5. Correct the problem at the instrument. Reverse the decrease in the Imager's responsivity by driving contaminants off the affected optical components. The Imager is designed with procedures to do just that. It can execute an outgassing (heating of the entire instrument) or a window decontamination (heating of only a particular window) by command from the ground. The advantage of this approach is that it corrects the problem at its source. However, it has its disadvantages. It assumes optics contamination is truly the culprit and would be ineffective if it were not. It requires a

major expenditure of time and resources in the Satellite Operations Control Center at NOAA/NESDIS. Furthermore, an outgassing will require the Imager to be turned off for at least two days. Finally, if the outgassing or decontamination succeeded in reducing the instrument's HOT, users will be deprived of data at the highest scene temperatures—temperatures in the interval between the old and the new values of the HOT. Therefore, as long as we can successfully deal with the rollover in the processing, we do not recommend an outgassing or a decontamination.

REFERENCE

Weinreb, M.P., M. Jamison, N. Fulton, Y. Chen, J.X. Johnson, J. Bremer, C. Smith, and J. Baucom, 1997: Operational calibration of Geostationary Operational Environmental Satellite-8 and -9 imagers and sounders. *Applied Optics****, 36,*** pp 6895-6904.