# P2.18 ROBUST TECHNIQUES FOR THE AVHRR THERMAL CALIBRATION

Alexander P. Trishchenko[*]
Canada Centre for Remote Sensing, Ottawa, ON, Canada

## 1. INTRODUCTION

Standard methods currently employed in operational practice for the AVHRR data processing frequently fail to remove some of the unwanted fluctuations in calibration data that may lead to biases in brightness temperature exceeding 1 K. We propose an advanced complex method for removing these fluctuations specifically designed for the thermal channels of AVHRR radiometers. The procedure is based on combining robust statistical procedures and Fourier transform filtering techniques. Procedure is recommended for application to various components of calibration data: temperature sensors, blackbody and space count as well as gain and offsets in all thermal channels. High Resolution Picture Transmission (HRPT) data and Global Area Coverage (GAC) data are analysed. The method may be useful for the development of calibration techniques for similar radiometers and the future NPOESS system.

## 2. SOURCES OF UNWANTED FLUCTUATIONS IN CALIBRATION DATA

Despite measures to detect and remove contaminated calibration data, the situation when outliers in calibration data are present is quite usual (Trishchenko, 2002). The problem of outliers is especially important in the beginning and the end of data transmission session when antenna elevation angles are small, distance to satellite is large and ratio signal/noise may be small. These are data transmission errors. However, calibration data may be corrupted also due to some internal processes happening onboard: data transformation, digitisation etc. The third source of errors is a radiative contamination by sun or other sources of external or internal nature (Trishchenko and Li, 2001). Contamination causes spatial and temporal variations of temperature field inside radiometer and internal calibration target (ICT), which in case of AVHRR radiometer is a passive blackbody. An example of contaminated calibration is given in Figure 1 that shows fluctuations of the gain for AVHRR/NOAA-14 (top) and data transmission errors (bottom).

## 3. IMPACT OF ERRORS IN CALIBRATION DATA

There are three basic calibration parameters employed in AVHRR calibration: space counts (SP), ICT counts and Platinum Resistance Thermometer (PRT) data used to determine the ICT temperature. Impact of errors in the calibration data depends on calibration parameter affected. To evaluate this impact we have to consider its consequences for calibration gain and offset. Gain G is computed according to

$$G^{(i)} = \frac{R^{(i)}_{ICT}(T_{ICT}) - R^{(i)}_{SP}}{C^{(i)}_{ICT} - C^{(i)}_{SP}}, \qquad (1)$$

where $R^{(i)}_{ICT,SP}$ is either radiance of blackbody at temperature $T_{ICT}$ in spectral channel (i) or “effective” non-zero radiance assigned to space, while $C^{(i)}_{ICT,SP}$ is a corresponding count (Kidwell, 1998). The radiance of a pixel in linear approximation is computed as

$$R^{(i)} = G^{(i)} \cdot C^{(i)}_{pix} + I^{(i)}, \qquad (2)$$

where $C^{(i)}_{pix}$ is the pixel count, and $I^{(i)}$ is the offset in channel (i) defined as

$$I^{(i)} = R^{(i)}_{SP} - G^{(i)} \cdot C^{(i)}_{SP}. \qquad (3)$$

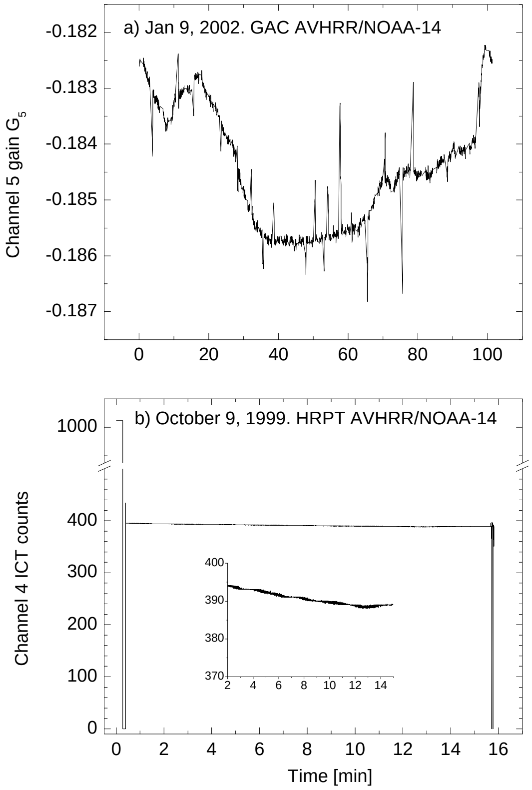

Fig. 1. An example of noisy fluctuations in a) AVHRR GAC data and b) HRPT data.

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[*] *Corresponding author address:* A. P. Trishchenko, Canada Centre for Remote Sensing (CCRS), 588 Booth Str, Ottawa, ONT, K1A 0Y7 Canada, e-mail: trichtch@ccrs.nrcan.gc.ca

For channels 4 and 5 one needs to apply a non-linear correction to obtain corrected radiance (Kidwell, 1998; Sullivan, 1999).

The effect of data corruption on pixel brightness temperature depends on which variable is affected. The error ΔT in temperature of internal calibration target $T_{ICT}$ translates directly in the determination of pixel brightness temperature. It is equal to ΔT for scene temperatures close to $T_{ICT}$, which is approximately in the range of 285 K-300 K. It decreases to zero for very small radiance values approaching signal level close to the one observed during the deep space observation. The errors in SP and ICT counts have a different impact on the brightness temperature error. The error, as function of brightness temperature, may be determined from the following expressions

$$\Delta R(T_P)\big|_{SP} = \frac{R(T_P)-R_{ICT}}{C_{ICT}-C_{SP}}\Delta C_{SP}, \qquad (4a)$$

$$\Delta R(T_P)\big|_{ICT} = -\frac{R(T_P)-R_{SP}}{C_{ICT}-C_{SP}}\Delta C_{ICT}, \qquad (4b)$$

$$\Delta R(T_P)\big|_{T} = \frac{C(T_P)-C_{SP}}{C_{ICT}-C_{SP}}R'(T_{ICT})\Delta T_{ICT}, \qquad (4c)$$

where

$$R'(T)=\frac{d}{dT}R(T)=\frac{d}{dT}\left(\frac{c_1 n^3}{\exp(\frac{c_2 n}{T^*})-1}\right). \qquad (4d)$$

The above expressions were obtained assuming a linear approximation (2), which provides quite accurate results for the estimation purpose. Symbol $\Delta R(T_P)\big|_{SP,ICT,T}$ denotes the error in pixel radiance due to error in SP counts, ICT counts or error in determination of calibration target temperature $T_{ICT}$. Error in terms of pixel brightness temperature depends on the magnitude of pixel brightness temperature $T_P$ itself and may be derived by inverting Planck's function

$$\Delta T(T_P)=\frac{\Delta R(T_P)\big|_{SP,ICT,T}}{R'(T_P)}. \qquad (5)$$

The structure of temperature errors due to various factors computed using Eqs (4a-c) is presented in Figure 2. It was estimated for typical calibration parameters of AVHRR NOAA-14 at $T_{ICT}$ = 289K.

## 4. ROBUST APPROACH FOR PROCESSING OF CALIBRATION DATA

We propose a combination of three methods to ensure robustness of calibration data processing: median filtering, global threshold control, Fourier transform filtering.

### 4.1 Median Filtering Of Outliers

Approach we suggest is based on the idea of a statistical median filtering, i.e. selection of the central data point in the sorted array. We slightly modify this approach to introduce more continuity in the calibration data. To get robust estimate of SP and ICT values we suggest analysing **m** consecutive samples, i.e. **m** x 10 elements of data, since each sample contains 10 calibration observations of SP and ICT signal. Selection of a suitable number **m** for the HRPT and GAC data and various calibration parameters is discussed later. We sort the **m** x 10 elements in increasing order. Then, we keep 10 central elements only and produce the weighted average of these 10 elements as a replacement for the simple average of the original data. A weighting function is chosen to provide a larger weight to the elements located closer to the median value. Thus, the weighted average is computed as

$$y=\left[\sum_i w_i y_i\right]/\left[\sum_i w_i\right]. \qquad (6)$$

For example, one can choose the weighting function values $w_i$={1, 2, 3, 4, 5, 5, 4, 3, 2, 1} for i ranging from 1 to 10.

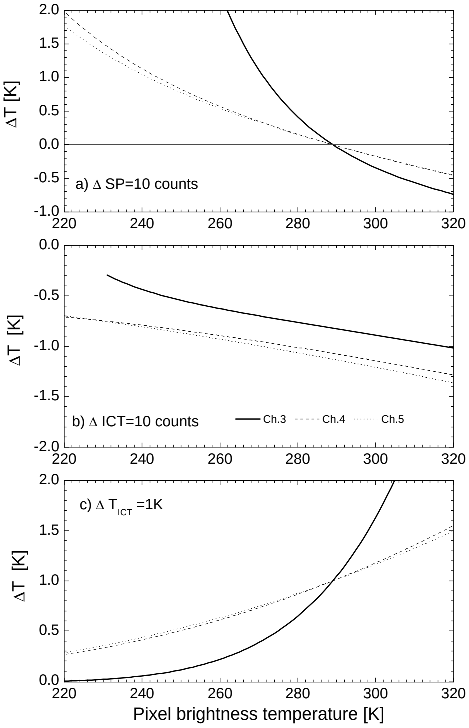

Fig.2 Absolute errors in pixel brightness temperature due to errors in SP counts (a), ICT counts (b) and determination of ICT temperature (c).

We suggest a similar scheme for PRT data: analysing several (**n**) consecutive data samples for each PRT sensor. There are 3 PRT counts in each scan line calibration sample. We analyse a group of **n** x 3 elements, sort them in increasing order, keep 3 central elements and produce a weighted average (Eq. 6) with weights $w_i$={1, 2, 1} for i ranging from 1 to 3. Data for an individual PRT sensor are not available for every AVHRR scan line, therefore the numbers **n** for PRT data and **m** for ICT and SP data may be different. These numbers differ also between GAC and HRPT data. The sample data for each individual PRT sensor are included in every 5-th line, therefore n consecutive samples correspond to the time interval 5/6***n** sec for HRPT data, and 0.5*5***n** sec for GAC data, given that the AVHRR sampling rate is 6 scan lines per second, and only every third scan line is recorded for GAC data. The corresponding intervals for ICT and SP calibration data are **m**/6 sec for HRPT and 0.5***m** sec for GAC data. To apply this approach on an equal basis for HRPT and GAC data and for various calibration parameters, we select an elementary time interval of data sampling for robust estimation equal to 12.5 sec. This interval is deemed to be short enough to satisfy our requirements for stationary, unimodal and symmetric data distribution. With this choice, our numbers of data samples are **n**=5 for PRT data in GAC format, **n**=15 for PRT data in HRPT format, **m**=25 for ICT and SP data GAC format, **m**=75 for ICT and SP data in HRPT format.

An example of results using the proposed robust approach is shown in Figure 3 for PRT data (top), SP (center) and ICT (bottom) counts for NOAA-9. To emphasize the improvement achieved by robust estimation, we plotted results obtained by simple averaging and the robust technique using shifted y-axes. Much improvement is observed when applying the robust technique.

The proposed approach cannot remove significant errors that last over 12.5 seconds. This may happen in the case of very severe interference during the data reception. To cover this rare case with outliers of large magnitude, we apply a threshold technique, which detects data beyond the potential limits of variability.

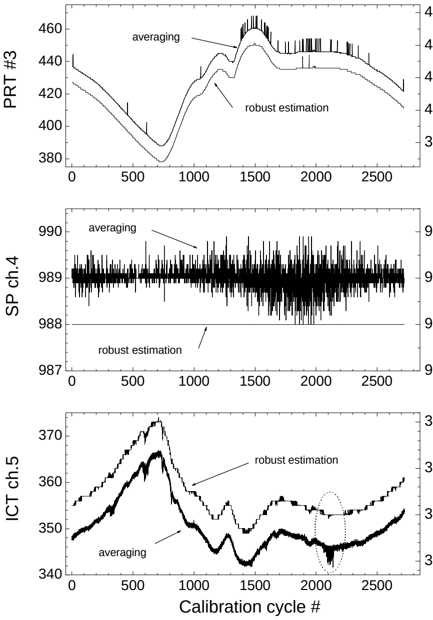

Fig.3 Scan-line average calibration data for averaging method and robust median estimation

### 4.2. Determination Of Potential Limits

Determination of potential limits for various calibration components depends on the nature of the component. The application also depends whether it is GAC or HRPT data. In the latter case, the potential range of variability is smaller.

1) *Space counts*. The SP data provide the simplest case. The SP data sequence closely resembles a stationary process with quite a narrow range of variability. First, we suggest computing the grand average for an entire sample (HRPT scene or GAC orbit) processed as described above. Since it is still possible that large errors are present, to compute a grand average, we apply a variant of the robust procedure, which is resistant to large outliers. A grand average is computed for the trimmed data set where the largest and smallest 5% of the data points are removed. Altogether, we remove 10% of the data with the reasonable assumption that there are less than 10% large outliers in the data. Then, we apply limits of ±3 counts for channels 4 and 5 and of ±10 counts for channel 3 around the corresponding grand averages to flag values that are below and above these limits as suspicious. Suspicious values are then replaced by linear interpolation between the two adjacent good data points. The bounding limits for outlier removal are the same for the HRPT and GAC SP data.

*2) PRT counts*. The assessment of potential limits for PRT counts also employs the robust computation of grand averages for each PRT sensor, based on a trimmed data set. The limits of potential variability are deduced from a long-term analysis of the ICT temperature for several AVHRR radiometers onboard NOAA-9 to NOAA-16. A maximum range of ~ 7 K is observed for NOAA-12. For all other AVHRR radiometers, the range is typically smaller that 5 K. For the new AVHRR/3 radiometers onboard NOAA-15 and –16, the temperature variability within one orbit is less that 3 K. Thus, for the GAC data one can safely impose a limit ±4 K for AVHRR/NOAA-12 and ±2.5 K for all other AVHRR's. The corresponding limits we suggest for the HRPT data are ±4 K for AVHRR NOAA-12 and ±1.5 K for all other radiometers. These limits are applied for every individual PRT sensor. Values that fall outside of the imposed limits are flagged as suspicious and replaced by linear interpolation of adjacent good values.

*3) ICT counts*. The measurements of blackbody depend on the instrument gain and offset as well as on the ICT temperature. We propose the determination of the potential range for ICT counts based on Eqs (1-3) and robust estimation of average gain. The robust grand average of ICT signal is again determined by trimming the largest and lowest 5% of ICT data and producing an average for the remaining data points. The average value of gain is then computed according to Eq. (1) with the average ICT temperature determined from available PRT data. We then determine the potential range for ICT counts by applying minimum and maximum values of gain for minimum and maximum ICT temperatures to compute the range of variability for the difference (ICT-SP) in Eq (1). Minimum and maximum gains are determined from analysis of multi-year data (Trishchenko, 2002; Trishchenko et al., 2002). The relative variations of gain and offset within one orbit are typically less than ±5%, i.e. 10% total. For the HRPT scene we assume limits of ±3%. Since SP count is already defined earlier, we can determine the range of variability for ICT data as well. Thus established thresholds are applied to mark outliers in the ICT and (ICT-SP) datasets, which fall outside of predetermined limits. Suspicious data are then replaced by linear interpolation between two good neighbouring points.

### 4.3 Fourier Tansform Fltering

The above robust procedures remove very efficiently many short-time noise fluctuations, especially single transmission errors. Nevertheless, the errors occurring over long time intervals may still persist. To further reduce the effect of outliers that may exist within the potential range of variability, as well as to provide some smoothing and reduce noise in the data, we apply a Fourier transform filter. This filtering removes the harmonics with a period of less than one minute, equivalent to 360 scan lines of HRPT data and 120 scan lines of GAC data. For PRT data, a one minute period covers 72 cycles for HRPT data and 24 cycles for GAC data respectively. The selection of a one minute interval is based on power spectrum analysis. Analysis shows that the power spectra are reduced by a factor of $\sim 10^3$ for a 10-minute component, and by a factor of $\sim 10^5$ for a one minute component. A few harmonics with long periods (>20 minutes) account for most changes in the signal, while all remaining components have amplitudes below 1%.

## 5. REMOVING UNWANTED FLUCTUATIONS IN CALIBRATION GAIN AND OFFSET DATA

The accuracy of thermal calibration required for climate monitoring and weather forecasting is estimated to be around ±0.1 K (Kidwell, 1998). This demands high accuracy in the determination of instrument calibration coefficients. Procedures described in previous sections can remove high-frequency noise contamination and large outliers in the calibration measurements. Nevertheless, they are powerless in correcting fluctuations of gain and offset due to solar radiative contamination, which is quite ubiquitous phenomenon for AVHRR. It occurs on every orbit for all AVHRR instruments onboard NOAA satellites, including AVHRR NOAA-16. Removing this type of contamination is difficult due to its “signal-like” behaviour.

Solar radiative contamination rapidly changes the thermal state of the ICT radiating surface (Trishchenko and Li, 2001). The thermal inertia of PRT sensors implanted into the ICT does not allow tracking of these changes instantly. The PRT-determined ICT temperature is underestimated during heating periods and may be overestimated when the ICT surface cools down. This leads to a mismatch between computed and measured radiation in Eq. (1), which introduces a bias in the computed gain and offset.

An effective way to eliminate these variations is the Fourier transform filtering technique similar to the one we introduced for the calibration measurements, but with longer cut-off periods (Trishchenko and Li, 2001). The length of the cut-off period depends on the duration of the solar contamination period. We estimate that a 10 to 15-minute cut-off limit is adequate for filtering of solar contamination effects in the gain time series. The duration varies with time due to the satellite orbit precession and depends on the angle between the sun and satellite orbital plane. Filtering must be applied for all thermal channels.

## 6. CONCLUSIONS

Thermal measurements available from AVHRR onboard of the NOAA polar orbiting satellite are an important component of a global weather and climate-observing system. Despite a long history of the AVHRR observations, the accuracy of these measurements remains undetermined. This study attempted to shed more light on this subject.

Detailed analysis of the nature and consequences of various fluctuations in the AVHRR thermal calibration data has been conducted. Outliers in the data may arise during transmission and decoding of radio signal, as well due to noise generated as a result of various internal processes in the AVHRR radiometer. Special attention must be paid to the effects caused by solar radiative contamination.

Novel methods of quality control and robust calibration are proposed. They are superior in removing unwanted fluctuation in the calibration data relative to commonly used techniques based on an averaging approach. The proposed method combines 3 steps: 1) robust estimation of ICT, SP calibration measurements and PRT counts based on a modified median filter, 2) limiting large-amplitude outliers within prescribed bounds based on the robust criteria and physical principles, 3) Fourier transform filtering.

Methods proposed in the paper may be useful for the development of calibration techniques for similar radiometers and future NPOESS sensors.

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## 7. REFERENCES

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