Investigating the Australian Bureau of Meteorology GMS satellite archive for use in tropical cyclone reanalysis

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The Bureau of Meteorology (the Bureau) has an extensive archive of geostationary satellite imagery, which is derived from a number of data sources. Most of this data now exists in a single data format, namely Man computer Interactive Data Access System (McIDAS) AREA. The McIDAS system was commissioned in the Bureau in 1985 and used to digitise locally received analogue GMS-3 data as its geostationary data source. This was the first McIDAS system to handle real time GMS data. McIDAS is the principal display and analysis tool utilised by the Bureau and is currently used to analyse tropical cyclone (TC) data received from satellites.

This study is concentrated on data calibration from Geostationary Meteorological Satellite (GMS) 1 to 3 for the years 1981 to 1989 as these data had recently been obtained from the Japan Meteorological Agency (JMA) in VISSR format. It is hoped that the new data can be utilised within the McIDAS system to perform reanalysis of TCs to give a consistent 30 year record.

This study revealed many possible sources of uncertainty with the initial calibration of the GMS data and highlighted issues with the methods of utilisation within McIDAS. It was discovered that there is the possibility, during the solar equinox periods, that error in temperature estimates from GMS data for temperatures of 160 K and above could exceed ±6 K due to the calibration procedure. Smaller errors due to the implementation of the calibration procedure are expected at other times during the year.

A comparison of the JMA GMS data calibration with the International Satellite Cloud Climatology Project (ISCCP) and HURicane SAtellite (HURSAT) calibrations found a definite trend toward colder temperatures being produced when using the ISCCP calibration but no noticeable temperature trend when using the HURSAT calibration.

HURSAT data were then selected to investigate how data calibration affected Dvorak analysis and the determination of TC intensity. Dvorak analysis for 11 cyclones using the JMA calibration and the HURSAT calibration was undertaken. This found that there was no detectable difference unless an eye or embedded centre pattern was noticed in the scene. Only 39 such scenes were identified from
the 703 scenes examined. Of these 39 scenes three showed a difference in analysis of 1.0 T number, eight showed ±0.5 T number difference and 28 were ranked as exactly the same. This indicates that Dvorak analysis will not be affected by small errors in calibration.

Presently, the Bureau has more than 30 years of data of Geostationary Satellite IR radiance and temperature data in McIDAS AREA format. It is now possible to use a single system (McIDAS) and a single method (EIR Dvorak) to reanalyse all available geostationary data for the Australian TC region.

Introduction

The Bureau possesses an archive of geostationary satellite data extending from 22 December 1977 until the present day. This archive consists of imagery from five Geostationary Meteorological Satellite (GMS) missions of almost identical design, one Geostationary Operational Environmental Satellite (GOES) and the Multi-function Transport Satellite (MTSAT–1R and MTSAT–2). These data were received, stored, processed, navigated and calibrated in many different formats using a variety of processes. These data were produced by several different instruments and even those of very similar design, such as those aboard the GMS satellites had variations in the bands, filter responses, and spatial and temporal resolution.

This long-term data set can potentially be used for climatological studies of tropical cyclone (TC) characteristics in the Australian region. Currently, the technique for estimating TC intensity from satellite images is the Dvorak analogue procedure based on patterns of infrared (IR) brightness temperature (Dvorak 1984, Velden et al. 2006). The original version of the technique, applied to visible satellite imagery, was published in 1975, with its present form, based on digital infra-red imagery, published in 1984.

Long-term environmental records can have data inhomogeneity where perceived changes are the result of better instruments, improved calibration and navigation techniques. Other researchers (Knapp and Kossin 2007) have expended considerable effort to produce geostationary satellite datasets that remove these induced trends for the purpose of long-term analysis.

The motivation for the work presented here was a desire to produce a geostationary satellite archive at the Bureau in digital format that could be used initially for TC reanalysis. The early plan to achieve these data involved taking scanned High Resolution Facsimile (HR–FAX) data, and producing navigated and calibrated data in McIDAS AREA format. The navigation of the digital images would be derived from the latitude and longitude lines embedded in the images and the calibration would be derived from a 32 block colour bar that represented temperature values from a fixed calibration table. During the course of this work it was shown that the navigation and calibration extracted from the scanned imagery would produce poorly calibrated and navigated digital data.

It was discovered that the Japan Meteorological Agency (JMA) had found a majority of the original GMS IR data already archived in a digital format on tape. This is fortunate as tape data were never planned to be archived for more than two years (JMA, 1980). JMA initially opting to store HR–FAX negatives and microfilm only as the long-term archive. All but 14 months of the IR data in digital format from the GMS series of satellites are available.

GMS satellites and data sources

The Bureau has geostationary satellite data from a number of satellites over a period of almost 30 years (see Table 1 in Appendix 1). The data from these satellites were received at the Bureau in a number of different formats. The Bureau received GMS data in three different formats, which will be referred to herein as HR–FAX, Visible Infrared Spin Scan Radiometer (VISSR) and Stretched VISSR (S–VISSR). Explanations about these formats are given in Appendix 3.

As all geostationary satellite data at the Bureau are archived as McIDAS AREA format, this paper will concentrate on VISSR IR data and data derived from the VISSR IR data, and the data accessibility from McIDAS.

The GMS satellites

The GMS satellites contained the VISSR instrument, which provided infrared (IR) and visible data of the observable earth. Each satellite in the series had a nominal orbital height of 35 900 km and a sub-satellite point of 140° east longitude directly over the equator.

The satellites themselves consisted of a de-spun antenna section and the satellite body that was spun to not only allow scanning but also to provide stabilisation. An illustration of the GMS design and the scanning mechanism are shown in Fig. 1. Each satellite had a nominal rotational frequency of 100 revolutions per minute. As the satellite spun it imaged the earth from west to east. At each revolution a scanning mirror tilted down so that lines were scanned from north to south. A complete scan of the earth took approximately 30 minutes.

Data from all GMS satellites were first transmitted to the Command and Data Acquisition Station (CDAS) in VISSR format. These data were processed to either High Resolution Facsimile (HR–FAX), Low Resolution Facsimile (LR–FAX) or S–VISSR data and retransmitted to the satellite where it
The VISSR instrument and IR calibration

The design of the VISSR instrument is essentially the same across the series with GMS–5 having major differences in the detection systems.

The visible detection system for GMS–1 to GMS–4 consisted of four Photomultiplier tubes (PMT) for detecting reflected radiation and a single HgCdTe infrared detector provided thermal emission data. The visible band detected radiation in the range 0.55–0.75 μm, and the IR band ranged from 10.5–12.5 μm, with slight variations to the bandwidths between satellites. GMS–5 used four Silicon photodiodes for visible detection and three HgCdTe infrared detectors. GMS–5 had a single visible channel (0.55–0.9 μm) and three IR channels (10.5–11.5 μm, 11.5–12.5 μm and 6.5–7.0 μm, called respectively IR1, IR2 and IR3).

On-board calibration of the detection systems is provided by sun pointing for the visible detector and by a black body cavity and free space for the IR system. The IR calibration system is described below.

The optical system consists of a scan mirror coupled to a Ritchey-Chretien telescope, which focuses the incoming radiation through lenses and a filter onto the HgCdTe detector(s). The calibration blackbody is located behind the telescope system and thermal energy is directed to the detector apparatus by flipping in a shutter mirror (JMA, 1997). This design requires that the radiative contribution of the fore optics (anything located before the blackbody shutter in the optical chain) needs to be included in the calibration procedure (Weinreb et. al. 1997).

The following calibration procedure is described in the GMS Users’ Guide, Issue 1 (JMA 1980) using the same symbols and terminology. This procedure is also described (in less detail) in JMA (1989) and JMA (1997). The calibration is applied to the data by the CDAS after reception, after which the data are retransmitted to the MDUS. The various procedures on how and when the calibration procedure is conducted and applied to the data are described in subsequent sections.

Initially a relationship is determined between instrument produced voltage \( V \) and brightness \( C \) using six brightness levels to yield a linear relationship by a least-squares fit such that:

\[
C = \beta_0 + \beta V
\]

where \( \beta_0 \) and \( \beta \) are the coefficients of the linear fit. Brightness refers to digital levels between 0 and 255. There is no mention in the calibration procedure on how these levels are quantised, just that they have been quantised to 256 brightness levels. Herein this quantity will be referred to as counts. We direct the reader to Appendix 2 for a detailed description of the calibration procedure.

In practice a lookup table was created for temperature between 170 K and 330 K with increments of 0.25 K for GMS–1 and GMS–2 (JMA 1980) and between 125 K and 330 K with increments of 0.4 K for GMS–3 (JMA, 1989). The determined temperature value was then linearly interpolated between the closest two values in the lookup table. Two tests were applied to the new calibration. The new count to voltage relationship (Eqn. 1) is compared to the previous calibration. If these do not agree to within 95 per cent then the previous calibration is used. A similar test is applied using Eqn. 4 (see Appendix 2 for detail) for current values of \( G \) and \( V_0 \) and averaged values from the previous eight images. If the results do not agree to within 95 per cent then the previous calibration is used.
Fig. 2. Count to radiance conversion table showing a plot of 28 day averages of the 256th greyscale level.

Fig. 3. Count to temperature conversion table showing plots of 28 day averages of every 4th level.
Investigation of GMS–1 to –3 IR calibration

The header section of each VISSR file contains at the very least a count to radiance and a count to temperature conversion table. These tables are dynamic and are produced from the process outlined in section The VISSR instrument and IR calibration. Before February 1987 these calibration tables were determined once a day and used for the next 8 images (from 0600 UTC to 0300 UTC) (Sasaki, 1988). If the verification tests for the calibration failed then it is possible that the same calibration is used for two or more days.

When the recently acquired JMA VISSR data were converted to McIDAS AREA format the calibration tables for each file were copied into the AREA file header.

The calibration tables for each VISSR file contain 256 values for radiance or temperature which correspond to a count value of 0–255 within the data section of the file. The AREA file format follows this same convention. Figs. 2 and 3 show 28-day averages with Fig. 2 showing the 256th greyscale or maximum level of radiance and Fig. 3 every fourth count value of the respective temperature. Each of the coloured horizontal lines shows a single count level from 0 to 255 and the temperature or radiance that that level represents over time. These plots show gaps between the satellites (even though the observations are continuous) as only full 28-day averages from the same satellite were plotted. Figure 2 and 3 shows a significant amount of variability in the range of the radiance and temperature scales with Fig. 2 showing only a single radiance level to emphasise this variability. These plots show, at the top, the approximate position on the time scale of the March equinox and September equinox where the sun is directly over the equator.

At these times of year, geostationary satellites will be totally eclipsed for some part of each day. Around the solstice periods the satellite will have direct sunlight incident upon it all the time. As time passes between equinox and solstice the satellite will experience varying amounts of daily insolation. The orientation of the satellite with respect to the sun will also change throughout the year, with the top of the satellite leaning towards the sun in the northern summer, and the bottom leaning towards the sun in the southern summer. Figure 4 shows the average temperature of the fore optics (primary, secondary and scan mirror), which is TA from Eqn. 2, the average scanner temperature (two sensors within the blackbody apparatus), which is TS from Eqn. 2, and the determined effective temperature TE. Each point on the plot for each of the three temperatures is for a single VISSR file. These points are for the latter half of the GMS–3 mission as before this time these calibration parameters were not included in the file header even though the capacity was there. The southern hemisphere summer periods can be recognised as the larger double bumped peaks.

As expected the radiance and temperature calibration tables vary with the scanner (blackbody) temperature. Figure 4 shows that the average scanner temperature changes over the course of the year with peaks during the solstice periods and troughs during the equinoxes. The

Fig. 4. Measured onboard temperatures for GMS-3.
smaller sections of the disk could be scanned. Partial scenes taken with GMS–1 to GMS–3 are most likely not calibrated as this was the standard procedure for GMS–5 as indicated by Tokuno et. al. (2000). A single fixed calibration table was used with these files. A fixed calibration will manifest as horizontal lines in the graph in Fig. 4. The horizontal lines in the plot in Fig. 4 are all for the 1200 UTC scene. This indicates that the 1200 UTC scenes in this period were not calibrated at all, giving large discrepancies in effective temperature for these scenes. As this anomaly occurs during the northern hemisphere summer period it will not affect re-analysis of southern hemisphere tropical cyclones.

An examination of the data during the equinox periods shows that there are some full disc scenes for consecutive hours. These scenes have the same calibration information indicating that one of the consecutive scenes has not been calibrated and the calibration information is simply copied from one to the other. Tokuno et. al. (2000) indicates that for GMS–5 the calibration table for the previous day at the same hour was used with each scene as there was insufficient computing power to calculate the table for the current S–VISSR scene which was broadcast to users in near real-time. It is possible that there was no time to calculate a set of calibration information for subsequent full scans with GMS–3 and the previous hour’s calibration information was then used. During the equinox periods the effective temperature can change rapidly over the course of a day due to the changing day-length and the changing solar angle during the equinox period.

The blackbody is used to provide a known radiance for a known temperature. When the blackbody and fore optics change temperature, the calibration table changes to follow suit. This variation could have been largely avoided if the blackbody was able to be viewed by the entire optical path of the telescope. This way the reference blackbody/space readings and the earth readings include the contribution from the optics which simply and effectively removes this from the resultant retrieved earth radiance and temperature. The blackbody and space views allow the responsivity of the detector/s to be measured over time and the calibration tables will reflect this. If the blackbody is included after the fore optics then any change in the emissivity of the fore optics is not captured by the calibration procedure.

Figure 4 shows three distinct horizontal lines of points for the three temperatures for scenes taken in the northern hemisphere summer of 1998. This behaviour was associated with partial scenes. Partial scenes differ from full scenes (or full disk) because a limited part of the earth disk is scanned. This is generally the northern or southern hemisphere but in cases of severe weather events such as cyclones even smaller sections of the disk could be scanned. Partial scenes taken with GMS–1 to GMS–3 are most likely not calibrated as this was the standard procedure for GMS–5 as indicated by Tokuno et. al. (2000). A single fixed calibration table was used with these files. A fixed calibration will manifest as horizontal lines in the graph in Fig. 4. The horizontal lines in the plot in Fig. 4 are all for the 1200 UTC scene. This indicates that the 1200 UTC scenes in this period were not calibrated at all, giving large discrepancies in effective temperature for these scenes. As this anomaly occurs during the northern hemisphere summer period it will not affect re-analysis of southern hemisphere tropical cyclones.

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of the day and the overall trend (average temperature) will change less rapidly over the course of a few days. Changes of approximately two to six degrees between effective temperatures for scene at three hour intervals are apparent from Fig. 5. It is possible that scenarios separated by one hour, where the proceeding hour’s calibration is used, could result in an estimated error in effective temperature of between 0.7 and 2 degrees. This error would propagate through the calibration calculations giving errors for both radiance and temperature tables leading to incorrect retrievals. Previous to February 1987 when there was only a single daily calibration table, the temperature at the 160th brightness level could drop by up to 6 K between the 1200 UTC and 1600 UTC scenes (Sasaki 1988). This would lead to even larger errors at higher temperatures.

These calibration parameters as mentioned are only included for the second half of the GMS–3 mission and considering this information is not included in the rest of the VISSR data obtained from JMA it is unlikely that this information has ever been permanently stored, although Sasaki (1988) states that values for \( \beta \) and \( \gamma \) (Eqn. 1) and \( G \) and \( V_0 \) (Eqn. 4) have been stored as a compact dataset since September 1982. If the calibration information in the compact dataset has been stored then it is possible to produce a far more accurate calibration table for each scene since September 1982.

It is also possible, with all of the calibration parameters, to recalculate the calibration temperature tables more accurately rather than relying on interpolation. This would only provide a minimal improvement and is unlikely to have significant impact on Dvorak enhanced imagery and subsequent analysis of cyclone intensity.

The Bureau of Meteorology GMS McIDAS archive

The GMS archive at the Bureau currently consists of data from five GMS satellites. It contains data from 1 March 1981 to 21 May 2003. These data are derived from two different but similar formats, namely VISSR and S–VISSR. The VISSR data as described previously were provided by JMA on optical storage media. These data were converted to AREA file format based on the format used for GMS–5. The S–VISSR data were broadcast from the Command and Data Acquisition Station (CDAS) to GMS–3, GMS–4 and GMS–5 where they were received by the Medium Data User Systems (MDUS). The Bureau operated an MDUS where GMS–3, GMS–4 and GMS–5 S–VISSR data were ingested and converted to McIDAS AREA file format.

McIDAS image data are stored in AREA file format. This format has differences between data from different platforms and some minor differences between the GMS satellites. The version of McIDAS used at the Bureau in 2009 had in-built capacity to view data from GMS–4 and GMS–5 only. All of the GMS–3 data that were ingested at the Bureau have subsequently been reprojected and reformatted to the GMS–4 format.

The one major difference between the GMS–4 and GMS–5 formats is GMS–4 does not contain calibration tables within the McIDAS header. These tables are built into McIDAS and remain static. GMS–5 contains calibration tables within the data header and so has the capacity to provide variable calibration information. When McIDAS displays and reports calibration information for pixels, it refers to the calibration tables in the header to retrieve values. In practice, however, the GMS–5 calibration tables do not change as the S–VISSR data are altered by JMA before transmission to match static calibration values. This procedure is described in Tokuno et. al. (2000).

When the calibration table is produced using the calculations and procedures described above in section The VISSR instrument and IR calibration it is compared to the fixed calibration table. The closest temperature match between the fixed table and the newly produced table is found for temperatures above the 220th count level. If the corresponding level for the matching temperature is different then the levels of the raw image are incremented or decremented by this amount. The maximum value will still be 255 and the minimum value 0. There may now be two or more levels at the extremities of the table set to the same brightness value. The temperature scale does not change. This process will only cause some difficulty when the maximum or minimum brightness levels are recorded in the raw image. This will clip temperatures resulting in a lack of accuracy. In practice these extremes of temperature are rarely reached. It is reported in JMA (1993) that using the fixed calibration table for GMS–5 can result in an error of up to 2 K (at the 300 K level) for a few days around the equinox periods. The annual variation at this temperature level is 0.5 K.

S–VISSR data from GMS–3 and GMS–4 were also altered to match a fixed calibration table. It is expected that the procedure employed is the same as described in Tokuno et al. (2000). McIDAS–X does not have an AREA file format specifically for GMS–3.

Figure 6 shows a comparison of the differences between maximum, minimum and average scene temperatures for VISSR and S–VISSR when subtracted from ISCCP data. These values were produced for subsetted and remapped GMS–3 imagery of 1500 × 1500 km centred on cyclone Harry. The VISSR data is calibrated using the calibration table in the data header, the S–VISSR data uses the BRIT static table within McIDAS, and the ISCCP data uses a calibration derived by means described in the following section. The point to note here is if the VISSR and S–VISSR data were representing the same temperature values then the blue lines (minimum values), red lines (average values) and green lines (maximum values) would show no discrepancies from each other. This figure shows that the S–VISSR derived McIDAS AREA files vary from the VISSR derived AREA files especially for the minimum values. This figure also shows that there are also omissions in the S–VISSR derived dataset.

The GMS–3 data that were ingested as S–VISSR and converted to McIDAS AREA had the AREA file header
changed to use the BRIT calibration method, as this was the only way to display the data in McIDAS at the time. The GMS–3 data were altered to fit a fixed calibration table at JMA before being transmitted as S–VISSR. Real time GMS functionality was added to McIDAS in 1985 (Le Marshall et al. 1987) and this included installation of a fixed calibration table. This fixed table is exactly the same as the GMS–4 fixed table which is included with the McIDAS–X system. Any analysis conducted before this time would have been using a calibration table within McIDAS which was most likely designed for use with GOES VISSR data.

Tokuno et al. (2000) points out that the fixed calibration tables for GMS–5 were not correct for the data in the files due to the incorrect emissivity value being used when determining the radiance for the effective temperature (Eqr. 3). This affected data from 0600 UTC 13 June 1995 to 2300 UTC 29 November 1996. This resulted in a maximum error up to 0.81 K for the IR1 channel and 1.02 K for the IR2 channel. Tokuno et al. (2000) publish within the paper a correction table for values for the IR1, IR2 and water vapour channels. There is no evidence that any such correction has been applied at the Bureau.

**Comparisons between Bureau GMS archive and the HURSAT–B1 data set**

The HURSAT–B1 dataset is derived from the ISCCP B1 dataset (Knapp 2008a). The HURSAT–B1 data are subsets of the ISCCP B1 data and are remapped and recalibrated to the rotational centre of tropical cyclone/hurricanes (Knapp and Kossin 2007). This dataset contains information from a multitude of geostationary satellites (GMS, GOES, Meteosat, and MTSAT series of satellites) and is calibrated to remove temperature biases from and between the satellites. The geostationary satellites were located at sub-satellite points dispersed around the globe. It utilises data as far back as 1983 and full longitudinal coverage was achieved in 1999.

The content of the dataset is remapped so that the spatial resolution and projection of all data are the same. The temporal resolution is also standardised to 3 hours to match the earliest instruments so a majority of available data from newer instruments is not included.

A temperature bias was introduced to the ISCCP B1 data by the cross-calibration method utilised with the AVHRR instrument. This was due partly to ‘clear-sky’ only pixel match-ups being used for the inter-comparisons, thus using a small and relatively warm part of the available spectrum (Knapp 2008b) and in 2001 poorly documented changes in the AVHRR calibration parameters (Knapp and Kossin 2007). Cross-calibration of the ISCCP B1 data with the High-resolution Infrared Radiation Sounder (HIRS) instrument and a far broader range of match up pixels resulted in a monthly averaged temperature correction determined for each satellite that removed the temperature bias.

This approach is designed to produce a dataset where improvements in instrument design, retrieval methods and nominal sub-satellite position do not introduce temporal or spatial trends. The entire dataset is essentially normalised to a single calibration. The great advantage of this approach is it should remove disparity and inter-instrument trends allowing real physical trends to be perceived. The big disadvantage of this approach is that it does not represent departures of individual scenes from the monthly HIRS-based correction, and so will not necessarily yield the most accurate scene by scene estimates of physical parameters.

An investigation between VISSR derived McIDAS AREA data and HURSAT–B1 data was conducted. This involved a number of steps to ensure that the data being compared were as spatially similar as possible.

The HURSAT data are interpolated to a Lagrangian grid centred at the circulation centre of the TC and comprises a box of 21° latitude by 21° longitude with elements of 0.07°. This produced an image of 301 × 301 pixels with spatial resolution of 7.8 km latitudinally by 3.9 to 7.8 km longitudinally. The HURSAT data are stored as netCDF files and contain not only the image but many other attributes of the data such as calibration, view zenith angles, centre latitude and longitude, wind speed and central pressure (when available).

A process was developed to convert AREA file data to netCDF maintaining as near as possible the same spatial resolution, grid size and central position as the HURSAT data. McIDAS has the ability to produce subsets and to remap to several projections. Using the functionality of McIDAS a rectilinear projection of 301 × 301 pixels with a latitudinal resolution of 7.8 km could easily be produced from a full disk GMS file. Ensuring that this subset was produced for the correct place in the full disk image was far from trivial due to differences in the navigation of the two datasets.

The easiest way is to ignore the navigation and concentrate on maximising the spatial correlation of the HURSAT image and that produced from McIDAS. To achieve this, a dynamic process was developed to:

1. Given an estimated central position, produce a remapped and subsetted netCDF file from the appropriate AREA file.
2. Compare the central 30 × 30 pixels from the HURSAT image to a 30 × 30 set of pixels from the McIDAS derived image.

![Fig. 6. Comparisons of temperatures from subsets of GMS-3 data centred on cyclone Harry (1988)](image-url)
Fig. 7. Comparison of the temperature histograms for GMS-3 data from the Bureau and HURSAT, where the Bureau data uses raw calibration and the HURSAT data uses the ISCCP B1 calibration.

Temperature Histograms 10/02/1989 (00:00 UTC)

<table>
<thead>
<tr>
<th></th>
<th>GMS-3 RAW</th>
<th>ISCCP-B1</th>
<th>Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>256.358</td>
<td>255.067</td>
<td>1.27126</td>
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<tr>
<td>Max</td>
<td>296.392</td>
<td>296.941</td>
<td>0.549286</td>
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<tr>
<td>Min</td>
<td>179.231</td>
<td>172.821</td>
<td>6.40987</td>
</tr>
<tr>
<td>Correlation Coefficient</td>
<td>0.989737</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 8. Comparison of the temperature histograms for GMS-3 data from the Bureau and HURSAT, where the Bureau data uses raw calibration and the HURSAT data uses the HURSAT calibration.

Temperature Histograms 10/02/1989 (00:00 UTC)

<table>
<thead>
<tr>
<th></th>
<th>GMS-3 RAW</th>
<th>HURSAT-B1</th>
<th>Diff</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>256.358</td>
<td>256.592</td>
<td>-0.23467</td>
</tr>
<tr>
<td>Max</td>
<td>296.392</td>
<td>296.120</td>
<td>0.271851</td>
</tr>
<tr>
<td>Min</td>
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<td>178.900</td>
<td>0.330673</td>
</tr>
<tr>
<td>Correlation Coefficient</td>
<td>0.989737</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Given that the two datasets were not exactly spatially correlated, it is not possible to do a pixel by pixel comparison. Instead the comparisons have been done by examining the temperature histograms, maximum, minimum and average values of comparable images.

Fig. 7 shows comparisons of the temperature histograms for an AREA file derived image with raw calibration (GMS–3 RAW) and the same image of HURSAT–1B data with the ISCCP–B1 calibration. Figure 8 shows the same AREA file histogram compared with the histogram for the HURSAT–B1 with HURSAT–B1 calibration. These histograms were produced for cyclone Harry from the 10 February, 1989. The mean, maximum and minimum for the ISCCP and VISSR raw calibrations for this scene are also displayed as the first point in the plots in Fig. 6.

The bin size for histograms in Figs. 7 and 8 is 0.51 K with 256 bins from 170–300 K. The non-linear nature of the temperature scale can be seen as the distance between the columns increases at the colder end of the scale. What these

Table 1. Differences in Kelvin between averaged temperature values for a number of cyclones using VISSR raw and ISCCP-B1 calibrated data.

<table>
<thead>
<tr>
<th>Start date</th>
<th>Maximum Difference</th>
<th>Minimum Difference</th>
<th>Average Difference</th>
<th>Average Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEIL</td>
<td>01/03/1981</td>
<td>0.127</td>
<td>-0.262</td>
<td>0.027</td>
</tr>
<tr>
<td>ABIGAIL</td>
<td>25/01/1982</td>
<td>-0.008</td>
<td>-0.453</td>
<td>0.001</td>
</tr>
<tr>
<td>ELINOR</td>
<td>11/02/1983</td>
<td>-0.857</td>
<td>1.971</td>
<td>-0.077</td>
</tr>
<tr>
<td>BOBBY</td>
<td>16/02/1984</td>
<td>-2.323</td>
<td>2.209</td>
<td>-0.681</td>
</tr>
<tr>
<td>MONICA</td>
<td>26/12/1984</td>
<td>-2.440</td>
<td>2.177</td>
<td>-0.688</td>
</tr>
<tr>
<td>JACOB</td>
<td>16/02/1986</td>
<td>-1.341</td>
<td>6.147</td>
<td>1.545</td>
</tr>
<tr>
<td>TIFFANY</td>
<td>27/02/1986</td>
<td>-1.100</td>
<td>6.581</td>
<td>0.399</td>
</tr>
<tr>
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<td>23/04/1986</td>
<td>-2.798</td>
<td>5.071</td>
<td>-0.731</td>
</tr>
<tr>
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<td>12/12/1986</td>
<td>-0.949</td>
<td>5.642</td>
<td>1.364</td>
</tr>
<tr>
<td>KAY</td>
<td>06/04/1986</td>
<td>-2.482</td>
<td>5.701</td>
<td>-0.413</td>
</tr>
<tr>
<td>CHARLIE</td>
<td>20/02/1988</td>
<td>-0.038</td>
<td>5.686</td>
<td>1.672</td>
</tr>
<tr>
<td>KIRIRILY</td>
<td>05/02/1989</td>
<td>-0.362</td>
<td>5.133</td>
<td>0.873</td>
</tr>
<tr>
<td>HARRY</td>
<td>10/02/1989</td>
<td>-0.799</td>
<td>5.696</td>
<td>0.964</td>
</tr>
</tbody>
</table>

3. Find the set of pixels that gives the highest spatial correlation and note the offset from the centre of the AREA derived image.

4. Repeat step 1 with the new centre position calculated by the determined offset and record the spatial correlation.

Use the determined central position as an estimate for the next image in the series.

In practice the spatial correlation varies from 0.90 to 0.99. The reason for lower correlation is different remapping and different data sources—in this study, we use 4 km data while HURSAT was limited to 8 km ISCCP B1 data. It is also due to the two sets of remapped images not exactly matching spatially. This could be because the map projections are slightly different or because the AREA files used are derived from VISSR data and the HURSAT data may be derived from S–VISSR data. S–VISSR data has already been remapped from the raw VISSR image by merging the pixels along the scan lines. This has not been investigated so the possible effect on the correlation between the images is conjecture.

Given that the two datasets were not exactly spatially correlated, it is not possible to do a pixel by pixel comparison. Instead the comparisons have been done by examining the temperature histograms, maximum, minimum and average values of comparable images.

Figure 7 shows comparisons of the temperature histograms for an AREA file derived image with raw calibration (GMS–3 RAW) and the same image of HURSAT–1B data with the ISCCP–B1 calibration. Figure 8 shows the same AREA file histogram compared with the histogram for the HURSAT–B1 with HURSAT–B1 calibration. These histograms were produced for cyclone Harry from the 10 February, 1989. The mean, maximum and minimum for the ISCCP and VISSR raw calibrations for this scene are also displayed as the first point in the plots in Fig. 6.

The bin size for histograms in Figs. 7 and 8 is 0.51 K with 256 bins from 170–300 K. The non-linear nature of the temperature scale can be seen as the distance between the columns increases at the colder end of the scale. What these
plots most ably demonstrate is the scale stretch of the ISCCP calibrated data toward the colder end of the scale. This indicates that far more pixels would now fall into the 190–240 K region where most of the Dvorak temperature breakpoints used for image analysis are located. This is likely to cause noticeable differences in Dvorak enhancement imagery. This is most likely to change Dvorak analysis in images that have a distinct eye where intensity can be inferred from the temperature difference between eye and surrounding cloud bands. The HURSAT–B1 histogram differs very little from that of the raw calibration. There are peaks in the HURSAT histogram at the warmer end of the scale that are higher in magnitude indicating more pixels in the image at higher temperatures. These peaks occur in the 280–300 K region where the Dvorak enhancement does not rescale the pixels so this has no net result on the Dvorak enhancement.

Figure 9 shows three images and their associated Dvorak enhancements. The normal images were derived from temperature values but as these are scaled to 8-bit (0–255) values to be displayed as greyscale images there is no discernable difference between them. McIDAS and many other display applications scale images so it is generally not possible to see the differences in the imagery. The GMS–3 RAW image was produced from a VISSR derived AREA file using the process described above. The HURSAT and ISCCP images use the same base image but use different temperature calibration. The Dvorak enhancement is based on the pixel temperatures so it is possible to see the structure of the image when different methods of calibration are used. As the histograms suggest, there is no significant difference between the GMS–3 RAW and HURSAT–B1 Dvorak enhanced images. The GMS–3 RAW image is sharper but this more likely a result of the differences in the remapping. The ISCCP–B1 Dvorak enhancement is noticeably different due to the fact that structure within the cyclone has been lost. This would suggest that the ISCCP–B1 calibration is in error. Figures 10 and 11 and Tables 1 and 2 show averaged values of differences over an entire cyclone.

---

Table 2. Differences in Kelvin between averaged temperature values for a number of cyclones using VISSR raw and HURSAT-B1 calibrated data.

<table>
<thead>
<tr>
<th>Cyclone</th>
<th>Start date</th>
<th>Maximum Difference</th>
<th>Minimum Difference</th>
<th>Average Difference</th>
<th>Average Correlation</th>
</tr>
</thead>
<tbody>
<tr>
<td>NEIL</td>
<td>01/03/1981</td>
<td>-0.568</td>
<td>-0.036</td>
<td>-0.499</td>
<td>0.978</td>
</tr>
<tr>
<td>ABIGAIL</td>
<td>25/01/1982</td>
<td>2.167</td>
<td>-0.150</td>
<td>1.599</td>
<td>0.984</td>
</tr>
<tr>
<td>ELINOR</td>
<td>11/02/1983</td>
<td>3.084</td>
<td>1.220</td>
<td>2.616</td>
<td>0.985</td>
</tr>
<tr>
<td>BOBBY</td>
<td>16/02/1984</td>
<td>-0.556</td>
<td>0.346</td>
<td>-0.061</td>
<td>0.978</td>
</tr>
<tr>
<td>MONICA</td>
<td>26/12/1984</td>
<td>-0.001</td>
<td>-0.785</td>
<td>-0.110</td>
<td>0.976</td>
</tr>
<tr>
<td>JACOB</td>
<td>16/02/1986</td>
<td>0.927</td>
<td>1.406</td>
<td>1.226</td>
<td>0.980</td>
</tr>
<tr>
<td>TIFFANY</td>
<td>27/02/1986</td>
<td>1.021</td>
<td>0.753</td>
<td>0.876</td>
<td>0.979</td>
</tr>
<tr>
<td>MANU</td>
<td>23/04/1986</td>
<td>-0.471</td>
<td>-2.024</td>
<td>-0.542</td>
<td>0.989</td>
</tr>
<tr>
<td>PATSY</td>
<td>12/12/1986</td>
<td>0.612</td>
<td>0.075</td>
<td>0.432</td>
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</tr>
<tr>
<td>KAY</td>
<td>06/04/1986</td>
<td>-0.596</td>
<td>-0.794</td>
<td>-0.591</td>
<td>0.984</td>
</tr>
<tr>
<td>CHARLIE</td>
<td>20/02/1988</td>
<td>1.823</td>
<td>1.080</td>
<td>1.637</td>
<td>0.990</td>
</tr>
<tr>
<td>KIRRILY</td>
<td>05/02/1989</td>
<td>0.623</td>
<td>-0.203</td>
<td>0.416</td>
<td>0.983</td>
</tr>
<tr>
<td>HARRY</td>
<td>10/02/1989</td>
<td>0.137</td>
<td>0.042</td>
<td>0.129</td>
<td>0.978</td>
</tr>
</tbody>
</table>
These values are calculated by taking the maximum difference, minimum difference and mean difference over each scene and then averaging these figures for all the scenes over an entire cyclone. The difference values for a single scene are calculated by subtracting the maximum, minimum and average value for the ISCCP and HURSAT calibrated images from the maximum, minimum and average values derived from the VISSR RAW calibrated image. The satellite that produced the data for each cyclone is also shown in the plots in Figs. 10 and 11.

What is most obvious with these graphs and tables is the very large separation of the maximum, minimum and average difference values between the VISSR RAW calibration and the ISCCP–B1 calibration (Fig. 10 and Table 1). If this data were to be believed, it would indicate that there were serious problems with the original calibration of the VISSR data. Figure 11 and Table 2 show, in general, that the maximum, minimum and average values do vary between GMS–RAW and HURSAT calibrated data but they follow each other from point to point. There is a major discrepancy between the three values for Abigail and Elinor, which occurred during the GMS–2 mission. This may indicate some difficulties with GMS–2 but more samples during this period would need to be analysed to see if this is systematic. The comparison between the VISSR RAW and HURSAT–B1 calibrations show variation but no noticeable trends.

**Dvorak cyclone intensity comparison of the Bureau GMS archive and the HURSAT–B1 dataset**

In order to determine what differences in Dvorak analysis would be observed between the Bureau GMS archive with the VISSR RAW calibration and HURSAT–B1 data with the HURSAT calibration, the HURSAT–B1 data was converted to McIDAS AREA format. The HURSAT–B1 data were written to an AREA file with rectilinear navigation (which requires parameters such as coordinate of the top left pixel and pixel size) and a calibration table determined from the data. The HURSAT–B1 data have been converted to a linear calibration so this calibration table development process is relatively simple. The VISSR derived AREA files were subsetted, remapped and converted so that these also used the same rectilinear file format. The original calibration tables were retained in the new files. The Severe Weather Section of the Western Australian Regional Office used these data to perform Enhanced Infrared (EIR) Dvorak analysis. This analysis was conducted using the same Dvorak techniques that are employed operationally for current MTSAT–1R satellite imagery of tropical cyclones and have been used for many years at the Bureau as outlined by Dvorak (1984).

The Dvorak EIR technique utilises temperature information to analyse tropical cyclone intensity. The satellite imagery is scaled to 8-bit greyscale values depending on the temperature range. Figure 12 shows the temperature to greyscale value of the enhanced imagery and the results of this enhancement on satellite imagery can be seen in Fig. 9.

There are rules in place to determine the intensity of the cyclone based on what structure is revealed by the Dvorak enhancement. The description of the process is covered in great detail elsewhere (Dvorak 1984).

Images from 11 cyclones were reanalysed to determine any discrepancies and biases between the two calibrations. In a majority of the images (663) there were no differences because the technique is largely independent of calibration when a ‘Shear’ or ‘Curved Band’ scene type is used for the analysis. Discrepancies are only likely when an ‘Eye’ or ‘Embedded Centre’ scene type is examined. From the 11 cyclones analysed only 39 scenes had this distinctive appearance.

These 39 scenes were assigned ‘Data T number’ (DT) intensity estimates and the ‘Current Intensity’ (CI) number was assumed to be equivalent to the DT. Discrepancies between the two datasets were recorded. A difference of 0.5 in T numbers relates to a difference of between 4.2 and 6.9 m/s in the 10 minute mean wind (the relationship is non-linear). Figure 13 shows the histogram of CI differences between the analysis done for VISSR and HURSAT. Of the 39 scenes, 28 showed no difference in T number, four saw the HURSAT evaluation exceed the VISSR evaluation by 0.5, four saw the VISSR evaluation exceed the HURSAT evaluation by 0.5 and three saw VISSR exceed HURSAT by 1.0.

Overall it’s questionable whether the differences are significant. There was no noticeable auto-correlation in bias (meaning that observing a difference between two images at time=0 did not prove a good predictor that the images three or six hours later would have a similar bias). The overall differences in Dvorak analysis between these two methods of calibration would typically be less than those that are observed between two analysts for the same satellite image. There was also some questionability about differences in elongation of the eye between the two datasets (a factor that can affect the intensity estimate). This may have been caused by the slight differences in the navigation and original map projections of the datasets.
Summary

At the end of February 2011 the Bureau now has a 30 year dataset of geostationary satellite IR radiance and temperature data in McIDAS AREA format. These data can be used to give a consistent 30 year re-analysis of tropical cyclones. Prior to the advent of S-VISSR broadcasts in 1989 all TC analysis for satellite data was done using HR–FAX data. It is now possible to use a single system (McIDAS) and a single method (EIR Dvorak) to re-analyse all known available geostationary data for the Australian TC region.

The Bureau dataset consists of data from GMS–1 to GMS–5, GOES–9, MTSAT–1R and MTSAT–2 located at approximately 140° East as well as Chinese Fengyun–2 satellites which were primarily located over the Indian Ocean. These systems have different instrument responses, some have differences in calibration method, and there are several different data formats. To use all of these sources of data to do any sort of consistent analysis, it is important to understand the calibration and limitations of each of the data sources.

The satellites of the GMS series were all spin-scan radiometers with one thermal infrared band until the advent of GMS–5, which had two thermal infrared bands. Each of these satellites employed on-board calibration for the IR bands using the method described in Section VISSR instrument and IR calibration with free space used as a cold target and a blackbody radiator used as the warm target. Diurnal and inter-annual solar heating of the satellites affected the temperature of the warm target and the optical path. Without proper calibration on a timescale appropriate for the timescale of environmental heating of the satellite, measurement errors will be induced in the data.

GMS–1 to GMS–3 (pre September 1989 for GMS–3) were at most only calibrated once per 24-hour period and this may have extended to periods of two days or more if the current calibration parameters were not within 95 per cent of the previous calibration parameters. GMS–5, due to limitations in computer power did not use the current hourly calibration, as this was not complete before the transmission of the data as S–VISSR. Instead the calibration provided for the GMS data at the Bureau was used.

All S–VISSR data ingested at the Bureau utilised a fixed calibration table. This table was the same for GMS–3 and GMS–4, and GMS–5 used fixed tables for all of the available bands. The fixed tables for the three IR bands were found to be incorrect for the 18 months of the mission due to a mistake in the emissivity of the optical path. The S–VISSR data is shifted in value to match the fixed tables. This is accomplished by finding the closest temperature match for levels above the 220th count level. The count levels of the table are shifted up or down by the amount of count level difference.

Both VISSR and S–VISSR data has been converted to AREA file format for use with the McIDAS application. All VISSR derived data (1 March 1981–13 February 1989) use a dynamic calibration table and the RAW calibration method. S–VISSR data (24 January 1989–27 June 1995) used fixed tables but the table for GMS–5 was included in the data header and the RAW calibration method was used. GMS–3 and GMS–4 used the BRIT method of calibration and thus used the table included with the McIDAS system. The GMS fixed table was not included in the earliest versions of McIDAS used at the Bureau so it is likely that the GOES calibration table would have been utilised instead.

Work has been done by both the ISCCP and HURSAT projects to cross-calibrate and normalise geostationary satellite data. Observation match-ups between AVHRR and geostationary satellites (by ISCCP) and HIRS and geostationary satellites (by Knapp 2008) are used to remove temperature biases both within and between different geostationary satellites. Comparisons between average, maximum and minimum temperatures for GMS, ISCCP and HURSAT data calibrations have shown a huge temperature bias between GMS and ISCCP for a number of TCs. The comparison between GMS and HURSAT shows variation no noticeable trend or bias.

Both VISSR and S–VISSR data has been converted to AREA file format for use with the McIDAS application. All VISSR derived data (1 March 1981–13 February 1989) use a dynamic calibration table and the RAW calibration method. S–VISSR data (24 January 1989–27 June 1995) used fixed tables but the table for GMS–5 was included in the data header and the RAW calibration method was used. GMS–3 and GMS–4 used the BRIT method of calibration and thus used the table included with the McIDAS system. The GMS fixed table was not included in the earliest versions of McIDAS used at the Bureau so it is likely that the GOES calibration table would have been utilised instead.

A small sample reanalysis of TCs was undertaken to examine the intensity differences between GMS and HURSAT datasets utilising McIDAS to implement the EIR Dvorak method. The modest differences in the calibration between the two datasets had no effect on banding and shear patterns so only scenes with distinct eye or embedded centres were examined for differences. This is not currently the calibration provided for the GMS data at the Bureau of Meteorology. Of the 39 scenes that fit the examination criteria, only three showed any differences of significance given that a difference of 0.5 for the CI number might be expected between different analysts for the same scene.

Conclusions

The GMS archive on the whole is poorly calibrated. GMS–1 to GMS–3 has only been at most calibrated once a day, at the same time each day so diurnal errors of greater than 6 K for warmer pixels may result. The use of fixed tables and the data shift procedure may introduce greater than 1 K differences and the fixed table problems at the start of the GMS–5 mission could lead to up to 2 K error at warmer temperatures.

Obtaining the entire GMS VISSR archive from JMA and converting these to McIDAS AREA will allow further standardisation of the Bureau GMS archive. All GMS data post September 1989 also has calibration parameters contained within the data header. It is not know if the calibration parameters for each scene have had the correct calibration applied when the VISSR data was archived. If the entire VISSR data archive is obtained then investigation may reveal if calibration for the correct day has been applied.
If not then the correct calibration table can be applied from the following day.

This investigation has also revealed that JMA was storing as ‘compact data’ calibration parameters for GMS–1 to GMS–3. If this data could be sourced from JMA (assuming that this data still exists) then calibration tables for GMS–1 to GMS–3 could be recalculated for each scene.

The HURSAT–1B dataset contains GMS data standardised to a single global calibration as a result of match-up between geostationary satellites, AVHRR and HIRS. This standardisation procedure is designed to remove, on a monthly basis, instrument, calibration and satellite position effects that may induce spurious intensity trends for TCs. A dataset with better radiometric accuracy and the full available spatial and temporal resolution could be achieved using the raw GMS data with the most accurate scene-by-scene calibration that can be provided. This, unfortunately, is not likely to be the calibration provided for any of the GMS data at the Bureau. The calibration could be improved using a cross-calibration approach as described by Knapp (2008b) and Le Marshall et al. (1999) or use of a physically based model such as that described by Mittaz et al. (2009).

The Dvorak analysis undertaken for this report showed that the Dvorak method seems to be indifferent to small changes in calibration. Even though EIR Dvorak analysis is based on shape and structure of cloud patterns derived from temperature information, small changes in calibration do not seem to greatly affect the derived shape.

The HURSAT–B1 dataset could be used to re-analyse the Bureau’s TC archive. This dataset is designed to examine long-term trends but is reduced in spatial and temporal resolution in comparison to the Bureau GMS archive. If re-analysis is undertaken using the current Bureau GMS archive the short-comings of the calibration of the archive needs to be understood.

The authors would suggest performing re-analysis concurrently on both datasets. If the intensity determination for a scene were markedly different then only those scenes would need to be investigated to find which dataset provides the best intensity estimation. This would allow the spatial resolution to be maintained. Analysis can also be done for scenes that are not present in the HURSAT–B1 dataset, but care would need to be taken with the calibration.

Acknowledgments

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Appendix 1. The Bureau’s geostationary satellite data

Presently, the Bureau of Meteorology holds the following data in McIDAS AREA format. The table gives the format of the original direct readout stream, except for the VISSR format data, which were received on optical media.

<table>
<thead>
<tr>
<th>Data format</th>
<th>Satellites</th>
<th>Observation period</th>
</tr>
</thead>
<tbody>
<tr>
<td>VISSR</td>
<td>GMS-1/2/3</td>
<td>28 Feb 1981 – 13 Feb 1989</td>
</tr>
<tr>
<td>GVAR</td>
<td>GOES-9</td>
<td>15 May 2003 – 17 Nov 2005</td>
</tr>
<tr>
<td>HRIT</td>
<td>MTSAT-1R/2</td>
<td>16 May 2006 –</td>
</tr>
</tbody>
</table>

Appendix 2. IR calibration.

Applying Eqn 1, initially a relationship is determined between instrument produced voltage (V) and brightness (C) using six brightness levels to yield a linear relationship. The effective shutter temperature \( T_{sh} \) is then determined. This comprises terms for the temperature of the blackbody, the fore optics and energy that may be leaked around the fore optics and is expressed as:

\[
T_{sh} = T_e + K_1(T_s - T_e) + K_2(T_s - T_e) \quad \text{(2)}
\]

where \( T_e \) is the mean temperature of the two sensors on the blackbody, \( T_s \) is the mean temperature of the sensors on the primary, secondary and scan mirrors, \( T_1 \) is the temperature of the secondary mirror, \( K_1 \) is a coefficient for the emissivity of the primary, secondary and scan mirrors and the ‘hiding rate’ of the secondary mirror (\( K_2 = 0.325 \)) and \( K_2 \) is a coefficient to account for energy leaked from around the secondary mirror (\( K_2 = 0.175 \)). This approach accounts for the IR energy contribution of the fore optics.

The radiation energy \( [R(T_e)] \) corresponding to the effective shutter temperature is evaluated as:

\[
R(T_e) = \varepsilon \int_{\lambda_1}^{\lambda_2} \varphi(\lambda) B(\lambda, T_e) d\lambda \quad \text{(3)}
\]

where \( \varepsilon \) is the emissivity of the shutter (\( \varepsilon = 0.995 \)), \( \lambda \) is the wavelength (\( \lambda_1 = 10.5 \mu m, \lambda_2 = 12.5 \mu m \)), \( B(\lambda, T_e) \) is the spectral energy density derived from the Planck function at temperature \( T_e \) and \( \varphi(\lambda) \) is the normalised spectral response function of the IR detector. The effective temperature is a combination of the fore optics temperature and the calibration blackbody.

The shutter voltage \( (V_{sh}) \) and voltage of space \( (V_{sp}) \) for the given count values \( (C_{sh}) \) and \( (C_{sp}) \) can be calculated using Eqn. 1. These voltage values can then be used to provide a voltage to radiance \( (R) \) relationship of the form:

\[
V = \frac{V_{sh} - V_{sp}}{R(T_e)} + V_{sp} \quad \text{(4)}
\]

OR

\[
V = G \times R + V_0 \quad \text{(5)}
\]

given that the radiance of space is very small and regarded as effectively 0. Substituting \( V \) from Eqn. 1 into Eqn. 4 gives the relationship between the blackbody radiance \( (R) \) and counts as:

\[
R = \left( \frac{C - B_0}{B_1} - V_0 \right) / G \quad \text{(5)}
\]

The blackbody radiance will correspond to a temperature value. In order to determine what this temperature is the radiance must be matched to the correct Planck function which has been band averaged with the spectral response function of the detector such that:

\[
R = \frac{\int \varphi(\lambda) B(\lambda, T) d\lambda}{\int \varphi(\lambda) d\lambda} \quad \text{(6)}
\]

where \( \varphi(\lambda) \) is the normalised spectral response function of the detector and \( B(\lambda, T) \) is the Planck function for temperature \( T \). Solving Eqn. 6 for \( T \) is not trivial as the Planck function is unique for each temperature. It is more efficient to evaluate the radiances for a set of temperatures in advance and then look up the temperature corresponding to the observed radiance.

Appendix 3. Explanations for technical terms

VISSR format

The format of the data collected from the VISSR instrument and transmitted by the GMS satellites to the Command and Data Acquisition Station (CDAS). The data values in VISSR format are the digital numbers (counts) reported by the VISSR instrument onboard the satellite.

S-VISSR format

The Stretched-VISSR (S-VISSR) format is used for retransmission of data collected from the VISSR instrument, by the CDAS via the GMS satellite to Medium scale Data Utilisation Stations (MDUS) such as operated by the Bureau. The data values have been adjusted from the sensor values by the CDAS to account for variations in calibration and geolocation. The S-VISSR data contain calibration and mapping information. The name ‘stretched’ arises from the duration of transmission of one scan line of S-VISSR data being effectively stretched to occupy most of one satellite spin period, compared to the small fraction of a spin period required to for the instrument to acquire the data and also to transmit it in VISSR format.
HR-FAX
High Resolution Facsimile image data, which is an analog format produced from VISSR data. Coastlines and geographic grid lines are overlayed on the image during HR-FAX production.

RAW calibration method
When applying calibration type RAW, McIDAS reports the values that are stored in the AREA files.

BRIT calibration method
When applying calibration type BRIT, McIDAS reports the result of a conversion table that has been applied to the values stored in the AREA file. This facility was intended for conversion of the data to greyscale levels suitable for visual display.