The Influence of Star Camera and Calibrated Satellite Magnetic Field Sources on the Ambient Field as Measured by the GAMES Magnetometers

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1. Summary

In practice, the accuracy of the Earth's magnetic field determination from satellite measurements depends critically on how well the satellite magnetic field effects are known. Satellite magnetic sources are usually detected and their magnitudes are estimated during the ground calibration procedures. Magnetic data as measured by the on board satellite magnetometers are then corrected for these effects. In this study, we examine the impact of uncertainties of various calibrated satellite magnetic field sources and small but uncalibrated effect of star cameras on the recovery of the satellite ambient field as measured by the Gravity and Magnetic Earth Surveyor (GAMES) mission magnetometers. We considered various satellite source magnitudes, alternative boom lengths, different magnetometer locations and ambient field magnitudes. Uncertainties introduced by the instrument precision, mission configuration, uncertainties of the calibrated satellite magnetic field sources, and total error estimates that also include unadjusted star camera magnetic field effects, were quantified for different scenarios.

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2. Introduction

The determination of the ambient magnetic field by instruments on board the GAMES spacecraft will be complicated by magnetic fields produced by the spacecraft itself such as; magnetic fields produced by the satellite batteries, power systems, gyros, motors, relays, magnetotorquers and other magnetic material. The variable effects of switching satellite subsystems on and off, of thruster firings and of other operations that introduce magnetic disturbances are usually modeled, so these effects can be subtracted from measurements of the ambient magnetic fields in space. In any case, information about the location, magnitude and direction of all these effects is a necessity. In practice however, not only the imperfect knowledge about the satellite generated magnetic effects but also unknown stray fields and unaccounted moments induced by soft magnetic materials introduce additional uncertainties in the recovery of the ambient magnetic field.

All these effects are reduced if the magnetic field instruments are located at the end of a boom, as far from the spacecraft as possible. Yet, the length of the boom is limited and the boom deflection may introduce additional uncertainties, mainly on the vector magnetometer measurements. This problem has been examined in an earlier report (Iz and Langel, 1992).

On the other hand, however carefully calibrated on the ground, there will always be some satellite borne magnetic fields that become apparent after the satellite launch. Also, The number of satellite magnetic sources may be quite large but their effects can be disregarded if their effect on the recovery of the ambient field is found to be small. If the satellite magnetic sources are well defined during the ground calibration procedures then it is sufficient to apply their effects as data corrections during preprocessing. The uncertainties of the calibrated values can also be propagated to the ambient field measurements (Iz and Langel, 1993).

A particular magnetic field that will influence the vector and scalar magnetometer measurements will be due to the star cameras which will be located in between the magnetometers along the boom (NASA and CNS Study Report, 1993). Although the magnitude of star camera induced magnetic effects will be small, it will influence the measurements because of its proximity to the magnetometers and it will create a systematic effect close or above the instrument noise level depending how well the cameras are isolated and how far apart from the magnetometers.

For all these cases, it is necessary to quantify the influence of accounted (calibrated) as well as unaccounted (unmodeled) satellite magnetic sources on the ambient field measurements. We focus on the following questions:

- What is the trade-off between proximity of the magnetometers to the unadjusted low magnetic star camera sources for various star camera magnetic field magnitudes?

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- How accurately must the satellite magnetic sources be known?
- What is the trade-off between boom length and satellite magnetic sources?

We will consider an a priori breakdown for the total error of the magnetometer instrument budget (Langel, 1991) given in Table 1 which quantifies the upper limits for the effect of these uncertainties on the ambient field determination.

Table 1. Magnetometer Error Budget (Langel, 1991).
Units are in nT.

Type	Scalar	Vector
Instrument	1.0	2.0
Spacecraft Field	1.0	1.0
Star Camera	0.5*	0.5*
Position and Time	1.3	1.3
RSS	2.0	2.6

*At 1 meter

In this analysis, spacecraft magnetic sources are represented as dipoles. We will assume that major satellite magnetic sources are known *a priori* within a prescribed accuracy as a result of ground calibration procedures. The observed magnetic fields at the magnetometers due to these sources will be formulated and their uncertainties will be propagated, together with the effect of unadjusted star camera magnetic field effect, into the uncertainty of the ambient field recovery at a given epoch.

In the following sections, first the adopted satellite and instrument configuration are given. Physical and statistical modeling of the total magnetic field measurements are discussed in the subsequent sections. The error analysis results are reported under the 'Numerical Results and Conclusion' section.

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3. Spacecraft and instrument configuration

GAMES science requirements demand accurate ambient magnetic field measurements. In this study, it is assumed that the magnetic field instrument package for GAMES consists of one vector magnetometer and one scalar magnetometer, both located at the end of a boom (Figure 1). The ambient vector magnetic field is required to be measured to an accuracy of 2 nT, and the corresponding magnitude to an accuracy of 1 nT.

The vector magnetometer , a multiple ring-core fluxgate design, measuring three orthogonal components of the vector magnetic field is complemented by a second magnetometer (scalar magnetometer), which measures the magnitude of the ambient field. This instrument is to provide a continuous in-flight calibration standard for the vector magnetometer. Since the absolute accuracy of the scalar magnetometer is determined by fundamental atomic constants, the corresponding measurements by acting as constraints on the vector magnetometer results, will allow accurate determination of the ambient magnetic field.

These instruments should operate in a magnetically clean environment which can be achieved by locating the instruments at a large distance from the spacecraft, near or at the end of an extensible (6 m) astromast-type (NASA and CNS Study Report, 1993). In this configuration a set of low magnetic star sensors located in the middle of the magnetometers provides information about the attitude of the instrument package. It is assumed that the magnetic field created by the star camera will be low but nevertheless it will influence the scalar and vector magnetometer measurements.

In this study, the spacecraft coordinate system origin is assumed to be located at the far end of the spacecraft, opposite the boom. The vector and scalar magnetometers are on the x-axis of the spacecraft coordinate system which is assumed to be tangent to the orbit at the satellite coordinate system origin. The x-axis coordinate system is also assumed to coincide with the boom. The z-axis of the satellite coordinate system is directed toward the geocenter and contained in the orbit plane. Normal to the x-z plane at the satellite coordinate system origin defines the y-axis to form a right-handed cartesian coordinate system. The vector magnetometer coordinate system is centered on the far end of the boom and is assumed to be parallel to the spacecraft system. Consequently, translation of the magnetometer coordinate system in the x direction results in the spacecraft coordinate system.

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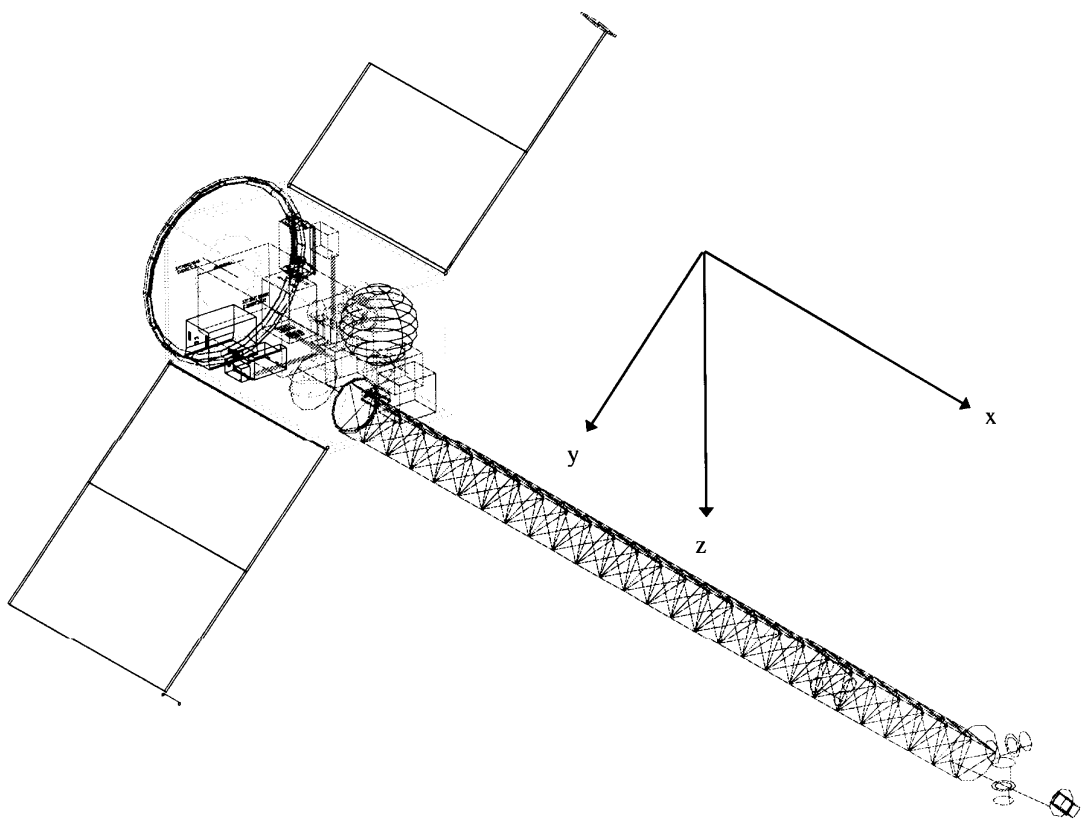

Figure 1. Adopted GAMES Satellite Coordinate System.

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4. Spacecraft magnetic field model

Spacecraft magnetic fields are modeled as dipoles. The potential at a point $\mathbf{r}' = (x\ y\ z)'$ due to a magnetic dipole at $\mathbf{r}_d$ can be expressed as

$$V_d = \mu_0 \frac{\mathbf{m} \cdot \mathbf{u}_d}{4\pi\ u_d^3} = \frac{\mu_0}{4\pi\ u_d^3}\left[m_x(x - x_d) + m_y(y - y_d) + m_z(z - z_d)\right] \tag{1}$$

where $\mathbf{u}_d = \mathbf{r} - \mathbf{r}_d$ is the vector from the dipole to the point $\mathbf{r}$, $\mathbf{m}' = (m_x\ m_y\ m_z)'$ is the dipole moment vector (prime denotes transpose of a vector or a matrix and bold letters are for matrices or vectors). Making use of (1), the magnetic field generated at $\mathbf{r}$ by this dipole moment is given, after some algebraic manipulations, by

$$\mathbf{B}_d = -\nabla V_d = -\frac{\mu_0}{4\pi\ u_d^3}\left[\mathbf{m} - 3\frac{\mathbf{m} \cdot \mathbf{u}_d}{u_d^2}\mathbf{u}_d\right] \tag{2}$$

where μ_0 is the permeability of free space. This model can be rearranged and expressed as

$$\mathbf{B}_{d_i} = \mathbf{A}_{d_i}\mathbf{m}_i \tag{3}$$

where the subscript i denotes the i*th* dipole and

$$\mathbf{A}_{d_i} := -\frac{\mu_0}{4\pi\ u_{d_i}^3}\left[\mathbf{I} - 3\frac{\mathbf{u}_{\mathbf{d}_i}}{u_{d_i}^2}\mathbf{u}'_{\mathbf{d}_i}\right] \tag{4}$$

The total magnetic field $\mathbf{B}_T^v$, as measured by a magnetometer at an arbitrary position on the boom, is the sum of the individual effects. The superscript 'v' is used to indicate that the corresponding quantity is related to a vector magnetometer whereas superscript '*s*' shows a scalar magnetometer related quantity. The total .magnetic field, $\mathbf{B}_T^v$, is obtained by considering (3) and (4)

$$\mathbf{B}_T^v = \mathbf{B}_A + \sum_i \mathbf{B}_{d_i} \tag{5}$$

where $\mathbf{B}_A$ and $\mathbf{B}_{d_i}$, are the 3x1 vectors of ambient magnetic field and the satellite magnetic field (dipoles), respectively. They are evaluated at their corresponding locations $\mathbf{r}$ and $\mathbf{r}_{d_i}$.

The above expression is not only valid for relating the ambient field and the satellite magnetic field to the vector magnetometer components but also can be used to represent

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the scalar magnetometer measurements through the corresponding magnitude expression, i.e.,

$$B_T^S = \left| \mathbf{B}_A + \sum_i \mathbf{B}_{d_i} \right| \tag{6}$$

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5. Statistical model

Making use of (3), (4), (5) and (6), the following set of equations relates the total magnetic field as observed by the scalar and vector magnetometers to the ambient field

$$\mathbf{B}_T^{v^{obs}} = \mathbf{B}_A + \sum_{i=1}^{n} \mathbf{A}_{d_i}\mathbf{m}_i + \mathbf{v} \qquad (7)$$

$$B_T^{s^{obs}} = \left| \mathbf{B}_A + \sum_{i=1}^{n} \mathbf{A}_{d_i}\mathbf{m}_i \right| + s \qquad (8)$$

$$\begin{matrix} \mathbf{m}_{d_1}^p & = \mathbf{m}_{d_1} & + \mathbf{d}_1 \\ \vdots & \vdots & \vdots \\ \mathbf{m}_{d_n}^p & = \mathbf{m}_{d_n} & + \mathbf{d}_n \end{matrix} \qquad (9)$$

where $\mathbf{B}_T^{v^{obs}}$ is the 3x1 vector of vector magnetometer measurement at a given epoch, $\mathbf{B}_A$ is the 3x1 vector of ambient field components at the same epoch, $\mathbf{v}$ is the 3x1 array of vector magnetometer measurement disturbances with the following assumed statistical properties

$$E(\mathbf{v}) = \mathbf{0}, \qquad E(\mathbf{v}\mathbf{v}') = \sigma_v^2.\mathbf{I} \qquad (10)$$

where $\mathbf{0}$ is a 3x1 zero vector. σ_v^2 is the a priori variance of unit weight of the vector magnetometer component measurements. In the case of scalar magnetometer instrument, the observations denoted by exponent indices "s," are scalar quantities with the following assumed statistical properties for their errors,

$$E(s) = 0, \qquad E(s^2) = \sigma_s^2 \qquad (11)$$

Stochastic noise vector $\mathbf{v}$ and scalar noise s are further assumed to be uncorrelated, i.e.,

$$E(\mathbf{v}s) = \mathbf{0} \qquad (12)$$

$\mathbf{m}_{d_i}^p$ is the 3x1 vector of spacecraft field dipole moments magnitudes and is available from laboratory calibration procedures. The corresponding 3x1 dipole error vector $\mathbf{d}_i$ has the following assumed distributional properties

$$E(\mathbf{d}_i) = \mathbf{0}, \qquad E(\mathbf{d}_i\mathbf{d}_i') = \sigma_{d_i}^2.\mathbf{I} \qquad (13)$$

This random error is also assumed to be independent of the vector and scalar magnetometer measurements v and s. For n dipoles, (13) introduces 3n x1 vector of

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dipole moment components with 3n x 3n error covariance matrix. Note that (7) and (9) are linear in terms of the dipole moments and ambient field components whereas (8) is not. Expressing (8) in Taylor series and retaining only the linear terms,(7), (8) and (9), can be collected into a single matrix expression as follows

$$\Delta\mathbf{y} = \mathbf{A}\Delta\mathbf{x} + \mathbf{u} \tag{14}$$

where

$$\mathbf{A} := \begin{bmatrix} \mathbf{A}_d \\ \mathbf{x}'\mathbf{A}_d'\mathbf{A}_d\left(\mathbf{x}'\mathbf{A}_d'\mathbf{A}_d\mathbf{x}\right)^{-1} \\ \mathbf{I} \quad \mathbf{0} \end{bmatrix}_{\mathbf{x}=\mathbf{x}_0} \tag{15}$$

$$\mathbf{u}' := \begin{bmatrix} \mathbf{v} & s & \mathbf{d} \end{bmatrix}' \tag{16}$$

$$\Sigma_{\mathbf{u}} := \begin{bmatrix} \sigma_v^2.I & 0 & 0 \\ 0 & \sigma_s^2 & 0 \\ 0 & 0 & \sigma_{\mathbf{d}}^2.I \end{bmatrix} \tag{17}$$

$$\Delta\mathbf{y} := \mathbf{y}_{obs} - \mathbf{y}_0' \tag{18}$$

$$\mathbf{y}_{obs}' := \begin{bmatrix} \mathbf{B}_T^{v\ obs} & B_T^{s\ obs} & \mathbf{m}^p \end{bmatrix}' \tag{19}$$

$$\mathbf{y}_0' := \begin{bmatrix} \mathbf{B}_T^v & B_T^s & \mathbf{m}^p \end{bmatrix}'_{\mathbf{x}=\mathbf{x}_0} \tag{20}$$

$$\Delta\mathbf{x} := \mathbf{x} - \mathbf{x}_0 \tag{21}$$

$$\mathbf{A}_d := \begin{bmatrix} \mathbf{A}_{\mathbf{d}_1} & \dots & \mathbf{A}_{\mathbf{d}_n} & \mathbf{I} \end{bmatrix} \tag{22}$$

$$\mathbf{x}' := \begin{bmatrix} \mathbf{m}_1' & \dots & \mathbf{m}_n' & \mathbf{B}_A' \end{bmatrix} \tag{23}$$

$$\mathbf{x}_0' := \begin{bmatrix} \mathbf{m}_1' & \dots & \mathbf{m}_n' & \mathbf{B}_A' \end{bmatrix}_0 \tag{24}$$

Note that, $\mathbf{A}_{\mathbf{d}_i}$'$s$ in equation (22), the sub-coefficient matrices of dipole moments (satellite magnetic sources) are evaluated at their corresponding locations. The zero subscript indicates that the corresponding quantity is computed using the adopted nominal values of the parameters. $\mathbf{x}$ is the (3n + 3) x 1 vector of parameters (true values) consists of 3n dipole components that are known from the calibration procedures and 3 ambient field components, If the above model is a realistic representation of the satellite magnetic sources that affect the magnetometer measurements, it can be solved using the

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well known least-squares procedures and the effect of the error sources on the ambient field can be computed accordingly using the following relationships,

$$\hat{\mathbf{x}}_1 = \mathbf{x}_1^0 + (\mathbf{A}_1'\Sigma_u^{-1}\mathbf{A}_1)^{-1}\mathbf{A}_1'\Sigma_u^{-1}\Delta\mathbf{y} \tag{25}$$

$$\Sigma_{\hat{\mathbf{x}}_1} = (\mathbf{A}'\Sigma_u^{-1}\mathbf{A})^{-1} \tag{26}$$

where circumflex denotes the corresponding parameter is an estimate.

Alternatively, some of the model parameters, such as satellite magnetic sources, can be left out (i.e., not adjusted) if their influence on the magnetometer measurements are found to be negligible. To asses the influence of various satellite sources, consider the following representation in which now the model parameters are represented in two groups. The first group of parameters, which will be adjusted, includes ambient field components and 3n dipole components. The second group of parameters consists of 3m dipole moment components where m is the number of satellite sources. This second group of parameters will not be adjusted in the solution, but the magnetometer measurements may be corrected for some a priori values of these parameters,

$$\Delta\mathbf{y} := \mathbf{A}_1\Delta\mathbf{x}_1 + \mathbf{A}_2\Delta\mathbf{x}_2 + \mathbf{u} \tag{27}$$

where $\mathbf{A}_1\Delta\mathbf{x}_1$ is defined by the corresponding expressions in (15)-(24), $\mathbf{A}_2\Delta\mathbf{x}_2$ represents the unadjusted satellite field effects, including star camera induced magnetic field, on the magnetic field measurements. $\Delta\mathbf{x}_2$ is the 3m x 1 vector of unadjusted m satellite dipoles where

$$\mathbf{A}_2 := \begin{bmatrix} \mathbf{A}_d^2 \\ \left(\mathbf{x}_2'\mathbf{A}_d'^2\mathbf{A}_d^2\mathbf{x}_2'\right)^{-1}\mathbf{A}_d'^2\mathbf{A}_d^2\mathbf{x}_2 \end{bmatrix} \tag{28}$$

$$\mathbf{A}_d^2 := \begin{bmatrix} \mathbf{A}_{d_{n+1}} & \cdots & \mathbf{A}_{d_{n+m}} \end{bmatrix} \tag{29}$$

In obtaining a least squares solution to (27) with respect to ambient field components, we will omit the some of the satellite effects represented by the second term in (27) and make use of the following form,

$$\Delta\mathbf{y} = \mathbf{A}_1\Delta\mathbf{x}_1 + \mathbf{u} \tag{30}$$

Taking into consideration (27), the error committed of using an incomplete model given (30) can be assessed using the well-known definition of the Mean Square Error matrix

$$\mathbf{MSE}(\hat{\mathbf{x}}_1) := \mathbf{E}(\mathbf{x}_1 - \hat{\mathbf{x}}_1)(\mathbf{x}_1 - \hat{\mathbf{x}}_1)' \tag{31}$$

which reduces after some lengthy matrix manipulations, considering (27) as the true

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model, to

$$\mathbf{MSE}(\hat{\mathbf{x}}_1) = \mathbf{N}_1^{-1} + \mathbf{N}_1^{-1}\mathbf{A}_1'\Sigma_u^{-1}\mathbf{A}_2\Sigma_{x_2}\mathbf{A}_2'\Sigma_u^{-1}\mathbf{A}_1\mathbf{N}_1^{-1} \tag{32}$$

where

$$\mathbf{N}_1 := (\mathbf{A}_1'\Sigma_u^{-1}\mathbf{A}_1)^{-1} \qquad \Sigma_{x_2} := E(\Delta\mathbf{x}\Delta\mathbf{x}^T) = \sigma_{x_2}^2.\mathbf{I} \tag{33}$$

In the above expression,$\sigma_{x_2}^2$ is the uncertainty attributed to the unadjusted dipoles. Note that if the uncertainty of the unadjusted dipole is zero than the second term in (32) drops and the remaining expression is nothing but the covariance matrix of the model described by (14) - (26). Therefore the second term in (32) is the increase in the total error (MSE) due to nominally corrected but unadjusted satellite dipole sources. As expected, if these sources are well known —they possess smaller uncertainties—then they need not to be adjusted but introduced as a correction to the data. Larger uncertainties imply that they are lesser known and more influential if the corresponding signals are large. A signal to noise ratio of one for instance can be used to evaluate the full impact of these sources if they are completely omitted from the solution, i.e., data is neither preprocessed or included in the model adjustment.

The error expression given by (32) can now be systematically evaluated for various design parameters such as dipole strengths and orientations, dipole locations, boom lengths, magnetometer precision, and ambient field components.

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6. Numerical results and conclusion

In this section, the magnitudes of various satellite and magnetic sources at the vector and scalar magnetometer locations are evaluated. The impact of the uncertainty of previously calibrated satellite magnetic sources together with the effect of instrument noise (scalar and vector magnetometer noise) on the ambient field are also computed for various design parameters. The resulting error is called *noise only* case. The unmodeled effect of the star camera magnetic fields on the ambient magnetic field components as measured by a scalar and vector magnetometer and the effect of the noise only case are together reported as the *total error.*

Satellite magnetotorquers are expected to be the major source of satellite magnetic fields (Vittone and Maggi, 1992). Under scenario 1 the influence of the calibrated torquer uncertainties were examined. The postulated magnetic data characteristics; such as their locations, magnitudes, uncertainties as will be determined by the calibration procedures, are given in Table 2. It is assumed that major torquer magnetic fields intensities are aligned along the torquer rods and they can be calibrated with an uncertainty of 2 A m^2 on all components (10 percent of the maximum torquer magnetic field of 20 A m^2). Alternatively, 1 and 0.2 A m^2 calibration uncertainties (5 and 1 percent of the maximum component of 20 A m^2) are considered. Star cameras are located in between the scalar and vector magnetometers at 1 meter distance from the instruments. Their soft magnetic effect, on the order of 0.005 A m^2, however, is neither calibrated nor modeled and consequently treated as an error as described in Section 4. Results displayed in Figure 2 indicate that at this distance the error introduced by not modeling the star camera magnetic field, overall, is negligibly small. However, it is compounded by the magnitude of the calibration uncertainties of the torquers mainly for the x-component of the ambient field.

On the other hand, the remnant torquer effects, mainly the one which is aligned is the x-direction is very influential. Overall, 10 percent (of the maximum component) calibration uncertainty may not be sufficient to reduce the influence of the calibrated torquer effects in the x-direction of the ambient field measurements.

Scenario 2 is about quantifying the unmodeled magnetic effect of star cameras on the ambient field components. Three different star cameras magnetic field considered: 0.005, 0.01 and 0.01 A m^2 alternatively. Table 3 gives all the design parameters of this scenario. Figure 3 shows that star camera magnetic field effects are very large at 0.02 A m^2 level. Their influence drop quickly with decreasing magnitude on all components of the ambient field as measured by the scalar and vector magnetometers. And again dominant on the x-component of the ambient field as expected.

Under scenario 3, vector magnetometer location, and the relative position of the vector magnetometer and the scalar magnetometer remained the same. Star cameras are still located on the boom in between the scalar magnetometer and the vector magnetometer.

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But alternative locations for the star cameras are considered. As a result of different camera locations, scalar magnetometer gets closer to the satellite magnetic sources (Table 4). Figure 4 shows that under these circumstances the star camera magnetic effect overwhelmingly dominates the scalar and vector magnetometer measurements and hence the accuracy of the ambient field recovery (mainly on the x-component) rather than the closeness of the scalar magnetometer to the satellite magnetic field sources (i.e. magnetotorquers).

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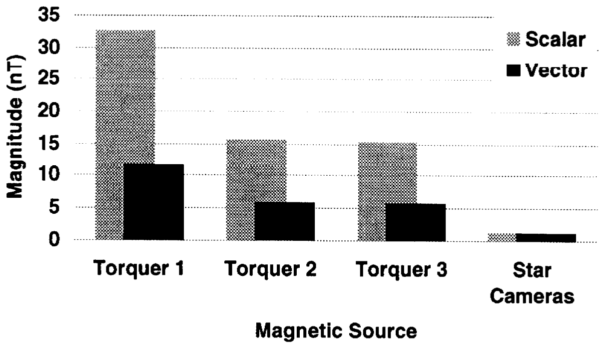

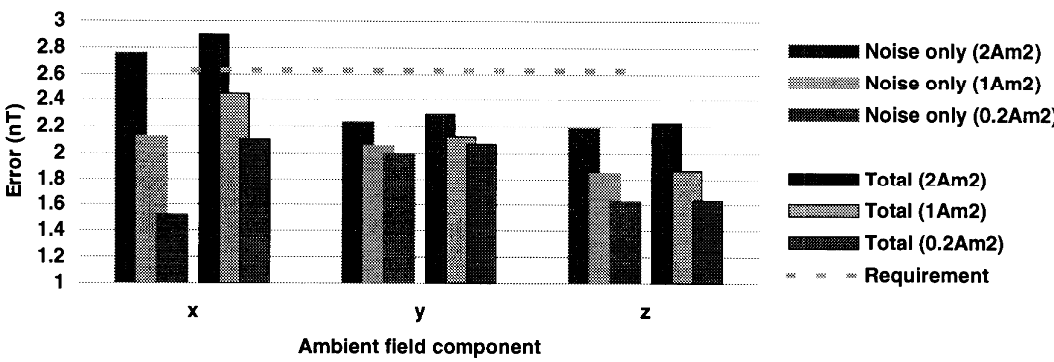

Figure 2 The impact of various calibrated satellite magnetic field error magnitudes and unmodeled low magnetic star camera effect to the computed ambient field components. Total error icludes the effect of unmodeled star camera magnetic effect in addition to the noise only case error. Table 2 contains additional information about the paramcters.

Table 2. Design parameters for scenario 1.

Parameter	Range of values
Boom lengths (m)	5
Calibrated torquer values/uncertainties (Am^2)	(20, 1, 1) $\sigma = 2^*$, 1, 0.2
	(1, 20, 1) $\sigma = 2$, 1, 0.2
	(1, 1, 20) $\sigma = 2$, 1, 0.2
Magnetotorquer locations (m)	(0.40, -0.31, 0.00)
	(0.30, -0.52, 0.00)
	(0.31, -0.47, 0.20)
Star camera magnetic field (Am^2)	(0.005, 0.005, 0.005)
Star camera locations (m)	(6.36, 0.00, 0.00)
Vector and scalar magnetometer precision (nT)	2.00, 1.00
Vector magnetometer location (m)	(7.36, 0.00, 0.00)
Scalar magnetometer location (m)	(5.36, 0.00, 0.00)
Nominal ambient fields (nT)	(25600, -1600, 22500)

*Note that 2 A m^2 uncertainty applies to all three components. Subsequent values are alternatively investigated uncertainties.

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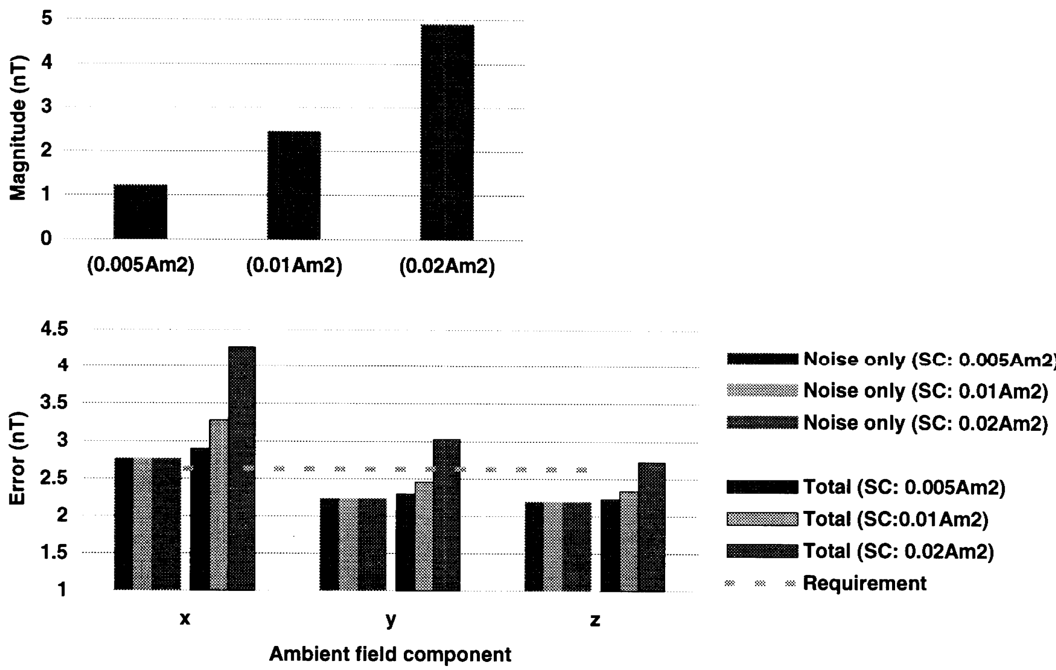

Figure 3 The impact of various unmodeled star camera induced magnetic field magnitudes to the computed ambient field components. Table 2 contains additional information about the parameters.

Table 3. Design parameters for scenario 2.

Parameter	Range of values
Boom lengths (m)	5
Calibrated torquer values/uncertainties (Am^2)	(20, 1, 1) $\sigma = 2^*$
	(1, 20, 1) $\sigma = 2$
	(1, 1, 20) $\sigma = 2$
Magnetotorquer locations (m)	(0.40, -0.31, 0.00)
	(0.30, -0.52, 0.00)
	(0.31, -0.47, 0.20)
Star camera magnetic field (Am^2)	(0.005, 0.005, 0.005)
	(0.01, 0.01, 0.01)
	(0.02, 0.02, 0.02)
Star camera locations (m)	(6.36, 0.00, 0.00)
Vector and scalar magnetometer precision (nT)	2.00, 1.00
Vector magnetometer location (m)	(7.36, 0.00, 0.00)
Scalar magnetometer location (m)	(5.36, 0.00, 0.00)
Nominal ambient fields (nT)	(25600, -1600, 22500)

*Note that 2 A m^2 uncertainty applies to all three components.

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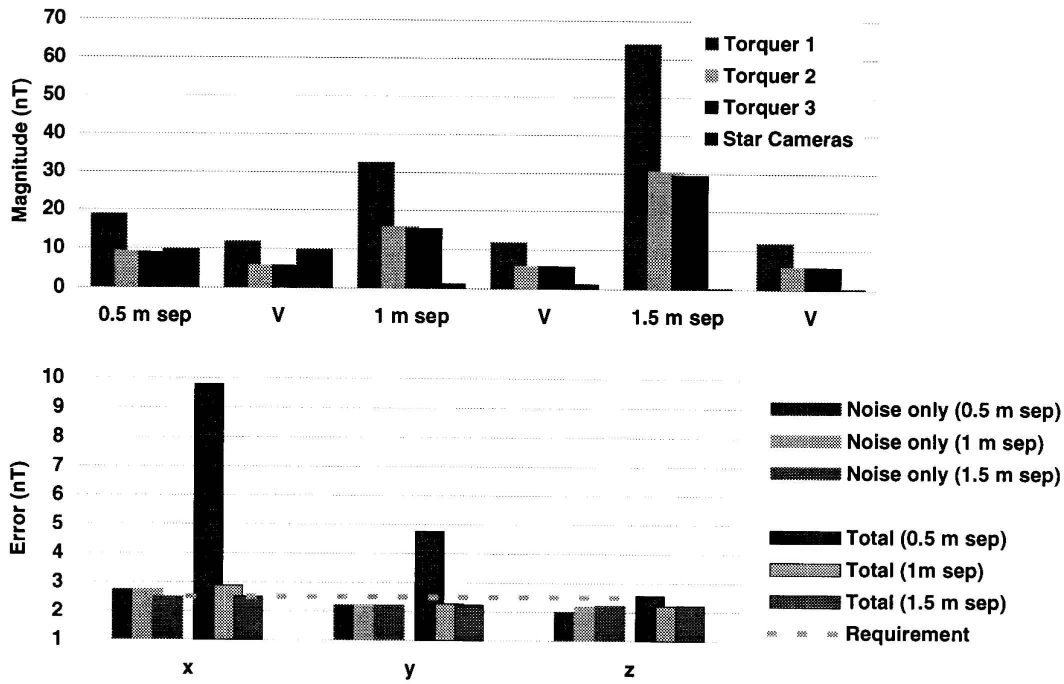

Figure 4. The impact of various calibrated satellite magnetic field error magnitudes and unmodeled low magnetic star camera effect to the computed ambient field components. Table 2 contains additional information about the parameters.

Table 4. Design parameters for scenario 3.

Parameter	Range of values
Boom lengths (m)	5
Calibrated torquer values/uncertainties (Am^2)	(20, 1, 1) $\sigma = 2^*$
	(1, 20, 1) $\sigma = 2$
	(1, 1, 20) $\sigma = 2$
Magnetotorquer locations (m)	(0.40, -0.31, 0.00)
	(0.30, -0.52, 0.00)
	(0.31, -0.47, 0.20)
Star camera magnetic field (Am^2)	(0.005, 0.005, 0.005)
Star camera locations (m)	(6.36, 0.00, 0.00)
Vector and scalar magnetometer precision (nT)	2.00, 1.00
Vector magnetometer location (m)	(7.36, 0.00, 0.00)
Scalar magnetometer location (m)	(6.86, 0.00, 0.00)
	(6.36, 0.00, 0.00)
	(5.86, 0.00, 0.00)
Nominal ambient fields (nT)	(25600, -1600, 22500)

*Note that 2 A m^2 uncertainty applies to all three components.

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