Orbit determination for the KOMPSAT-1 Spacecraft during the period of the solar maximum

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Abstract

The KOMPSAT-1 satellite, launched into a circular sun synchronous orbit on Dec. 21, 1999, entered its 6th year of successful operation this year. The purposes of the mission are to collect earth images (6.6 m resolution), multi-spectral images of the ocean, and to collect information on the particle environment of the low earth orbit. For normal operation, KOMPSAT-1 orbits are determined using GPS navigation solutions. However, at the start of the life of KOMPSAT-1, the 11-year solar activity cycle was at a maximum. Solar flux was maintained at this level until 2002, and thereafter reduced to a moderate level by 2004. Thus, the OD (Orbit Determination) accuracy has varied according to the solar activity. This paper presents the degree to which the OD accuracy could be degraded during a high solar activity period compared with that of a (relatively) low solar activity period. We investigated the effect of the use of solve-for parameters such as a drag coefficient (C_D), solar radiation coefficient (C_R), and the general accelerations (G_A) on OD accuracy with solar activity. For the evaluation of orbit determination accuracy, orbit overlap comparison is used since no independent orbits of comparable accuracy are available for comparison. The effect of the use of a box-wing model instead of a constant cross-sectional area is also investigated.

Key Word : KOMPSAT-1, Orbit determination

Introduction

On 21 December 1999 the Korea Multi-Purpose SATellite-1 (KOMPSAT-1) was launched into a circular, sun-synchronous orbit at an altitude of 686 km. The primary mission goals are to collect earth images and multi -spectral images of the ocean, and to collect information about the particle environment of the low earth orbit. The orbit characteristics for KOMPSAT-1 are shown in Table 1.

The KOMPSAT-1 satellite carries a Viceroy™ global positioning system (GPS) receiver [1] that generates point position and velocity solutions on board. These navigation solutions are nominally recorded at 32-s intervals and telemetered to the ground. The dumped GPS navigation solutions data is used for orbit determination at KGS (Kompsat Ground Station). The KGS at KARI (Korea Aerospace Research Institute) employs MicroCosm orbit determination software as a part of the Flight Dynamics System. In this study, MicroCosm was used to assess the KOMPSAT-1 orbit determination accuracy [2].

However, at the start of the life of KOMPSAT-1, the 11-year solar activity cycle was at a maximum. Solar flux was maintained at this level until 2002, and thereafter reduced to a moderate

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Table 1. KOMPSAT-1 Characteristic and Mean Orbital Elements (as of January 2003)

Parameter	Type / Value
Orbit Type	Sun-Synchronous
Period	98.25 min
Mean Altitude	669.38 km
Inclination	98.095^0
Eccentricity	0.00165
Spacecraft Mass	437.97 kg
Average Cross-sectional Area	5.871 m^2

level by 2004 as shown in Figure 1. Thus, KOMPSAT-1 has experienced both high ($F_{10.7}$ = 260) and relatively low ($F_{10.7}$ = 100) solar activity levels during its operation to date. As is well known, atmospheric forces represent the largest non-gravitational perturbations acting on low altitude satellites such as KOMPSAT-1 and are directly related to solar activity. In particular, atmospheric density is the dominant error source at high solar activity and radiation pressure forces play an equally important role at low solar activity. Consequently, the OD accuracy for the KOMPSAT-1 varies according to the solar activity.

This paper presents the degree to which the OD accuracy could be degraded during a high solar activity period compared with that of a (relatively) low activity period. We investigated the effect of the use of solve-for parameters such as a drag coefficient (C_D), solar radiation coefficient (C_R), and the general accelerations (G_A) on OD accuracy with solar activity. The solar panels of KOMPSAT-1 rotate to track the sun and are not allowed to rotate when KOMPSAT-1 is imaging. Thus, the effect of the use of a box-wing model instead of a constant (average) cross-sectional area is also investigated.

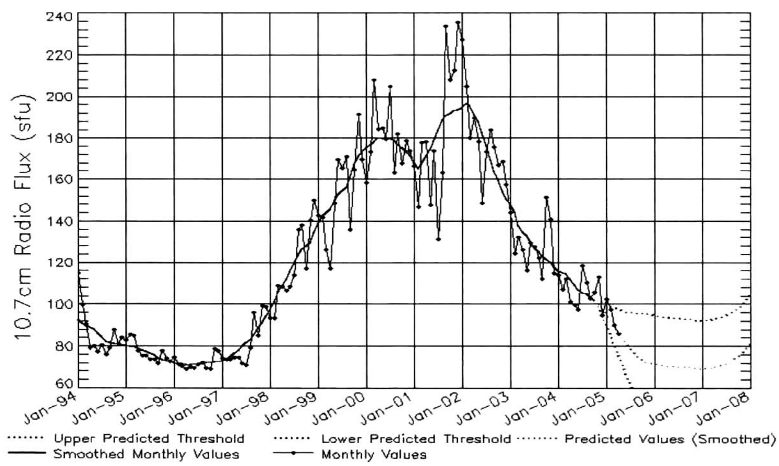

Fig. 1. Solar Cycle F10.7cm Radio Flux Progression (from http://www.sec.noaa.gov/SolarCycle)

In this paper, the KOMPSAT-1 orbit solutions were determined using MicroCosm software (version 2003). This high-precision orbit determination software has been used for numerous missions, including Quickbird, Quikscat, AMSAT, GPS/MET spacecraft, etc. This software package is derivative of and based upon a full implementation of the GEODYN II version 8609 precision orbit and geodetic parameter determination software system developed for NASA's Goddard Space Flight Center [3]. Bayesian least squares estimation is used by this software for parameter determination and the batch mode of estimation is used.

Regarding measurement, we use only GPS position data recorded every 32 seconds since velocity data from a GPS receiver tend to contain significant systematic errors in addition to measurement noise. Additionally, the GPS receiver onboard KOMPSAT-1 does not transmit raw pseudo-range and carrier phase data to the ground. The dynamic models used in this study are presented in Table 2, and the estimated orbit-dependent parameters are given in Table 3. The drag coefficient, solar radiation coefficient, and the general accelerations are options as solve-for parameters according to each case, which are described in section 3.

Table 2. Dynamical Model employed in the KOMPSAT-1 OD

Earth gravity	JGM-3 (70x70)
Third bodies (Moon, Sun)	JPL DE405 ephemerides
Atmospheric drag	Jacchia 71
Solar radiation	Spherical Solar radiation model (using average values for the cross-sectional area and the reflectivity coefficient)
Spacecraft Box-wing model	Option for case study

Table 3. Solve-for parameters for the case study

State vector at epoch	Default (position, velocity)
Drag coefficient (C_D)	Option (constant value 2.2) once per arc
Solar radiation coefficient (C_R)	Option (constant value 1.5) once per arc
General accelerations (G_A)	Option Type; Constant and time-dependent once per arc Direction; Radial, Cross, and Along

One of the most challenging issues in studies related to OD for spacecraft is that it is not possible to determine the true orbit of the spacecraft. However, we use the orbit overlap method, which remains the best method for assessing orbit accuracy, since we have no independent orbits of comparable accuracy for KOMPSAT-1. To assess orbit accuracy in this paper, 30-hour solutions are generated centered on noon of a given day [4]. This results in a 6-hour overlap of consecutive orbit determination solutions. The orbits in the center 4-hours of the overlap period are differenced. To avoid end effects commonly encountered with reduced dynamic orbit determination, one-hour segments from each end of the two solutions are omitted. This leaves a 4-hour overlap between two consecutive days for assessment of orbit determination accuracy. The difference between the orbits is a measure of orbit precision and is a rough indication of accuracy.

Results

As noted in section 1, we focused on the effect of solar activity on OD accuracy according to the type of solve-for parameters and the use of a box-wing model instead of a constant area model. Because inaccuracies in the modeling of non-gravitational forces such as air drag, radiation drag, and general accelerations, form a major error source [5]. Therefore, we can categorize cases regarding the type of solve-for parameters and the use of a box-wing model as shown in Table 4.

Table 4. Case according to type of solve-for parameters and use of box-wing model

CASE	Adjust Parameters		Box-wing Model
	C_D , C_R	G_A	
1	No	No	No
2	Yes	No	No
3	Yes	Yes	No
4	Yes	No	Yes
5	Yes	Yes	Yes

Table 5. Period and level of solar activity

Period	Solar activity	Average $F_{10.7}$	Date
1	Low (relatively)	103.7	2004/2/3 - 2004/2/8
2	Medium	148.9	2002/6/19 - 2002/6/24
3	Maximum	253.9	2001/12/25 - 2001/12/30

Table 6. RCA RMS Difference during (relatively) low solar activity (Period 1 in Table 5)

CASE	Radial (m)	Cross-track (m)	Along-track (m)	3-D (m)
1	1.384	0.615	4.603	4.873
2	1.250	0.602	3.183	3.500
3	0.443	0.636	1.612	1.844
4	0.347	0.831	1.284	1.639
5	0.347	0.837	1.286	1.644

Table 7. RCA RMS Difference during medium solar activity (Period 2 in Table 5)

CASE	Radial (m)	Cross-track (m)	Along-track (m)	3-D (m)
1	1.479	1.007	5.155	5.540
2	1.359	1.018	3.518	3.934
3	0.626	1.004	2.408	2.689
4	0.635	1.009	2.309	2.609
5	0.635	1.003	2.286	2.606

Table 8. RCA RMS Difference during high solar activity (Period 3 in Table 5)

CASE	Radial (m)	Cross-track (m)	Along-track (m)	3-D (m)
1	3.539	1.528	18.860	19.333
2	3.601	0.822	9.114	9.845
3	0.856	0.867	5.614	5.825
4	1.484	1.073	6.210	6.541
5	1.484	1.073	6.209	6.540

The level of solar activity was divided into 3 cases, high, medium, and low. Table 5 shows periods of high (average $F_{10.7}$ = 253.9 over selected period), medium (average $F_{10.7}$ = 148.9), and low (average $F_{10.7}$ = 103.7) solar activity, as selected in this study. An average $F_{10.7}$ of 103.7 was chosen for this study because it is representative of the lowest range of $F_{10.7}$ values during the period spanning Dec. 21, 1999 (Launch date) through Feb. 28, 2004. Six OD with a 30 hour fit span were performed for epochs for each case of each period in order to assess the OD accuracy using the overlap method. Consequently, 5 orbit overlaps were generated and compared for each case of each period. The RMS differences presented in Tables 6, 7, and 8 are average values of 5 orbit overlap differences.

As anticipated, it is very clear that the orbit differences decrease with solar activity and significantly increase during a high solar activity period (period 3) compared with low (relatively) solar activity periods (period 1 and even period 2). The 3-D RMS difference for period 3 is up to four times greater than for period 1 for all cases, while the 3-D RMS difference between period 1 and period 2 is about 1 meter for all cases.

Table 6 indicates that it is possible to obtain an overall accuracy on the order of 1.6 meters based on the overlap comparison at low solar activity when C_D , C_R , and/or G_A are employed (CASE 4 and 5) as solve-for parameters in OD process. However, the 3-D RMS difference was slightly increased to 1.8 meters when the box-wing model was not employed, even though C_D , C_R , and/or G_A were employed as solve-for parameters (CASE 3). As shown in Tables 6, 7, and 8, significant improvement is observed for solve-for parameters of C_D and C_R as solar activity grows. The 3-D RMS difference of CASE 1 can be reduced to about half time compared to that of CASE 2 in Table 8. Meanwhile, the 3-D RMS differences of CASE 1 and CASE 2 in Tables 6 and 7 are less than 2 meters. While this result is not surprising, the use of solve-for parameters of C_D and C_R without further adjustment parameters such as general accelerations is sufficient to obtain an orbit of better than 10 meters at high solar activity.

The improvement made by the use of a solve-for parameter of G_A in addition to the adjustment of C_D and C_R is 48% at low solar activity, 32% at medium solar activity, and 41% at high solar activity. Thus, it is clear that a significant degree of non-conservative force model errors can be absorbed and the overlap differences can be significantly reduced by increasing the number of solve-for parameters in the OD process.

On the other hand, we found that the box-wing model does not significantly improve the orbit consistency as the solar activity increases, as shown in Tables 7 and 8. Moreover, Table 8 shows that the use of the box-wing model instead of a constant area decreases the orbit consistency at high solar activity, even though C_D , C_R , and/or G_A were employed as solve-for parameters (CASE 4 vs. CASE 5).

Consequently, CASE 4 and CASE 5 result in the best average fits at low solar activity and at medium solar activity, respectively. However, the difference between CASE 4 and CASE 5 is less than 0.005 meters. On the contrary, CASE 3 yields the best average fits at high solar activity, although it is clear that the use of the box-wing model without the estimation of general accelerations improves the orbit consistency even when the solar activity is high (CASE 2 vs. CASE 4 in Table 8). This result is attributed to deficiencies of the box-wing model, which either did not accurately reflect or overestimated unexpected accelerations to the spacecraft surfaces at high solar activity.

Conclusion

A comprehensive comparison study was performed in order to evaluate the effect of solve-for parameters and use of the box-wing model instead of constant cross-sectional area on OD accuracy for the KOMPSAT-1 spacecraft during the period of the solar maximum. Not surprisingly, the orbit accuracy significantly grows with solar activity. However, it is clearly shown that the 3-D RMS difference at high solar activity is up to four times greater than that of the period of the solar minimum (that is, the relative minimum during the period of interest in this paper) for all cases, which contain the use of solve-for parameters such as a drag coefficient (C_D), solar radiation coefficient (C_R), and the general accelerations (G_A) including the box-wing model.

As a result, we could obtain an overall accuracy on the order of 1.6 meters at low solar activity when C_D , C_R , and/or G_A were employed as solve-for parameters in OD process. On the other hand, the OD accuracy was improved from 19.3 meters to 5.8 meters by adjusting the drag coefficient, solar radiation coefficient, and general accelerations with a constant (average) drag area instead of the box-wing model during the period of the solar maximum.

However, the optimal selection of the general accelerations and the estimation period in order to improve the OD accuracy is remained as further study.

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