Defence Research and Development Canada
Recherche et développement pour la défense Canada

DEFENCE DÉFENSE

Modelling of the TerraSAR-X sensor modes in CSIAPS

Karim E. Mattar

Defence R&D Canada – Ottawa
Technical Memorandum
DRDC Ottawa TM 2008-284
March 2009

Canada

Modelling of the TerraSAR-X sensor modes in CSIAPS

Karim E. Mattar
DRDC Ottawa

Defence R&D Canada – Ottawa

Technical Memorandum
DRDC Ottawa TM 2008-284
March 2009

Principal Author

Original signed by Karim E. Mattar

Karim E. Mattar

Defence Scientist

Approved by

Original signed by Paris W. Vachon

Paris W. Vachon

Defence Scientist

Approved for release by

Original signed by Pierre Lavoie

Pierre Lavoie

Chair, Document Review Panel

Abstract

The Commercial Satellite Imagery Acquisition Planning System (CSIAPS) was designed by Defence R&D Canada – Ottawa to help collection managers plan satellite image acquisition. Its strength is in its capability to integrate models of Synthetic Aperture Radar (SAR) and Electro-Optical (EO) satellite sensors into a single system. This enables the collection manager to plan image acquisition from several different sensors at the same time, providing a comparison of coverage and image acquisition times.

CSIAPS relies on the Satellite ToolKit (STK) for orbital models of the various satellites. So far CSIAPS has been configured to handle several SAR and EO satellites including RADARSAT-1, RADARSAT-2 and the ENVISAT-ASAR (SAR), as well as IKONOS-2, OrbView-3, and QuickBird-2 (EO).

This report details integration of TerraSAR-X into CSIAPS. TerraSAR-X provides higher resolution single polarization acquisition (up to 1 metre x 1 metre) and higher resolution dual-polarization acquisition (up to 2 metres x 2 metres) than any of the above SAR sensors. This report will briefly describe TerraSAR-X, outlining the more then 600 modes this sensor provides. It will describe integration of the TerraSAR-X sensor model into CSIAPS, and provide validation of the results using TerraSAR-X's own acquisition planning tool available at its website as well as using recently acquired data.

Résumé

Le système de planification d'acquisition d'images de satellites commerciaux (SPAISC) a été mis au point par R & D pour la défense Canada (RDDC) – Ottawa comme outil d'aide à l'intention des gestionnaires de collections pour la planification de l'acquisition d'images de satellite. Son point fort est sa capacité à intégrer, dans un seul système, des modèles de capteurs de radar à synthèse d'ouverture (SAR) et de satellites électro-optique (EO), ce qui permet aux gestionnaires de collections de planifier l'acquisition d'images à partir de plusieurs capteurs en même temps, ce qui assure une comparaison des délais d'acquisition d'images et de couverture.

Le SPAISC dépend de la trousse d'outils satellites (STK) pour obtenir des modèles orbitaux de divers satellites. Jusqu'à maintenant, il a été configuré pour prendre en charge plusieurs SAR et satellites EO, dont RADARSAT-1, RADARSAT-2 et ENVISAT-ASAR (SAR), ainsi que IKONOS-2, OrbView-3 et QuickBird-2 (EO).

Le présent rapport décrit en détail l'intégration de TerraSAR-X au SPAISC. TerraSAR-X offre une acquisition à polarisation simple à résolution (jusqu'à 1 m x 1 m) et une acquisition à polarisation double à résolution (jusqu'à 2 m x 2 m), toutes deux supérieures à n'importe quel des capteurs SAR susmentionnés. Le présent rapport décrit brièvement TerraSAR-X en donnant un aperçu des modes offerts par ce capteur (plus de 600). Il décrit l'intégration du modèle de capteur de TerraSAR-X au SPAISC et assure la validation des résultats au moyen du propre outil de

planification de l'acquisition de TerraSAR-X, disponible sur son site Web, ainsi que l'utilisation de données récemment acquises.

Executive summary

Modelling of the TerraSAR-X sensor modes in CSIAPS

Karim E. Mattar; DRDC Ottawa TM 2008-284; Defence R&D Canada – Ottawa Ottawa; March 2009.

Introduction: The Commercial Satellite Imagery Acquisition Planning System (CSIAPS) is a software system for planning and archiving of remote sensing data. It supports multi-sensor acquisition planning. Developed at DRDC Ottawa, CSIAPS includes tools to assist the intelligence staff and collection managers in the Canadian Forces (CF), Department of National Defence (DND), such as planning for coherent and non-coherent change detection analyses, and guidance that uses pre-defined rules and an expert system to recommend satellites to address specific Request For Information (RFI). CSIAPS includes models of several Synthetic Aperture Radar (SAR) and Electro-Optic (EO) satellites into a single system. So far CSIAPS has been configured to handle several SAR and EO satellites including RADARSAT-1, RADARSAT-2 and the ENVISAT-ASAR (SAR), and IKONOS-2, OrbView-3, as well as QuickBird-2 (EO). CSIAPS can be expanded to include sensor models for other satellites.

Results: CSIAPS has now been expanded to include the new German SAR sensor TerraSAR-X. TerraSAR-X is an X-band SAR with high resolution single polarization acquisition (up to 1 metre x 1 metre) and a lower resolution dual-polarization acquisition (up to 2 metres x 2 metres). This report briefly describes TerraSAR-X, outlining the more then 600 modes this sensor provides. It details integration of the TerraSAR-X orbital model into CSIAPS.

The models are validates using TerraSAR-X's Earth Observation on the WEB (EOWEB) future acquisition planning tool, EOWEB's archived database, and a few recently acquired scenes. For TerraSAR-X's *StripMap* and *ScanSAR* modes the swath width and acquisition timing predicted by CSIAPS are in good agreement with EOWEB and with data received. The overall comparison of the *SpotLight* mode is less favourable. The accuracy of the published values of minimum and maximum incidence angles are suspect due to differences between the documented values and those obtained from EOWEB's archived database. Since these are key to building good models for CSIAPS, the predicted coverage and swath width are not as accurate as with the other two modes. This is exacerbated by the polarization and bandwidth options that come with the *SpotLight* mode. Nevertheless the offsets are relatively minor. With the addition of TerraSAR-X, CSIAPS is now a more valuable tool for easy comparison of the timing and coverage of readily available satellite sensors.

Sommaire

Modelling of the TerraSAR-X sensor modes in CSIAPS

Karim E. Mattar; DRDC Ottawa TM 2008-284; R & D pour la défense Canada – Ottawa; Mars 2009.

Introduction: Le système de planification d'acquisition d'images de satellites commerciaux (SPAISC) est un système logiciel de planification et d'archivage de données de télédétection. Il vient à l'appui de la planification de l'acquisition à partir de plusieurs capteurs. Mis au point à RDDC Ottawa, il comprend des outils conçus pour venir en aide au personnel du renseignement et aux gestionnaires des collections des Forces canadiennes (FC) du ministère de la Défense nationale (MDN), notamment pour la planification des analyses de détection des modifications cohérentes et non cohérentes, et il donne des conseils à partir de règles définies à l'avance et un système expert pour recommander des satellites afin de répondre à des demandes précises de renseignements. Il intègre, dans un seul système, les modèles de plusieurs satellites électro-optiques (EO) et de radars à synthèse d'ouverture (SAR). Jusqu'à maintenant, il a été configuré pour prendre en charge plusieurs satellites EO et RSO, dont RADARSAT-1, RADARSAT-2, ENVISAT-ASAR (SAR), IKONOS-2, OrbView-3 et QuickBird-2 (EO). Il peut être étendu pour comprendre des modèles de capteurs d'autres satellites.

Résultats: Le SPAISC a été élargi pour comprendre le nouveau capteur SAR allemand TerraSAR-X. TerraSAR-X comprend un SAR fonctionnant dans la bande X qui offre une acquisition à polarisation simple à haute résolution (jusqu'à 1 m x 1 m) et une acquisition à polarisation double à résolution supérieure (jusqu'à 2 m x 2 m). Le présent rapport décrit brièvement TerraSAR-X, en donnant un aperçu des modes de fonctionnement du capteur (plus de 600), et décrit de façon détaillée l'intégration du modèle orbital du capteur de TerraSAR-X au SPAISC.

Les modèles sont validés au moyen de l'outil de planification des acquisitions futures sur l'observation de la Terre sur Internet (EOWEB) de TerraSAR-X, la base de données archivées d'EOWEB et de quelques scènes récemment acquises. Dans le cas des modes carte-bande et *ScanSAR* de TerraSAR-X, la largeur de la bande au sol et le moment de l'acquisition prédits par le SPAISC sont conformes à l'EOWEB et aux données reçues. La comparaison globale du mode *SpotLight* est moins favorable. La précision des valeurs publiées des angles d'incidence minimale et maximale est suspecte en raison de différences entre les valeurs documentées et celles qui ont été obtenues de la base de données archivées d'EOWEB. Comme il s'agit d'information cruciale pour la construction de bons modèles pour le SPAISC, les valeurs prédites de la couverture et de la largeur de la bande au sol ne sont pas aussi précises que dans les deux autres modes, ce qui est accentué par les options de polarisation et de largeur de bande du mode *SpotLight*. Néanmoins, les décalages sont relativement mineurs. Avec l'ajout du TerraSAR-X, le SPAISC est maintenant un outil plus utile en vue d'une comparaison facile de la synchronisation et de la couverture des capteurs de satellite aisément disponibles.

Table of contents

List of figures

List of tables

This page intentionally left blank.

Acknowledgements

I would like to thank Dr. Jeff Secker and Dr. Paris W. Vachon for a very thorough and much appreciated review of this report.

This page intentionally left blank.

Introduction

The Commercial Satellite Imagery Acquisition Planning System (CSIAPS) is a software system for planning and archiving of remote sensing data [4], [5], [6], [7]. It supports multi-sensor acquisition planning. Developed at DRDC Ottawa, CSIAPS includes tools to assist the intelligence staff and collection managers in the Canadian Forces (CF), Department of National Defence (DND), in planning for coherent and non-coherent change detection analyses, and guidance that pre-defined rules and an expert system to recommend satellites/sensors to address a specific request for information (RFI). CSIAPS includes models of several Synthetic Aperture Radar (SAR) and Electro-Optic (EO) satellites into a single system. So far CSIAPS has been configured to handle several SAR and EO satellites including RADARSAT-1, RADARSAT-2 and the ENVISAT-ASAR (SAR), and IKONOS-2, OrbView-3, and QuickBird-2 (EO). CSIAPS can be expanded to include sensor models for other satellites.

This report details integration of TerraSAR-X into CSIAPS. With the capability of predicting the coverage of ENVISAT, RADARSAT-1, RADARSAT-2, and now TerraSAR-X, the user will be able to compare the acquisition timing and coverage extent of all four sensors, making it easier for the user to choose the sensor that most suits his present needs.

The primary purpose of this report is to discuss modeling and integration of TerraSAR-X into CSIAPS, and detail verification of the models. The secondary purpose is to make it easier for integration of other SAR sensors into CSIAPS. The report starts with an introduction to TerraSAR-X and its available modes. It continues with a discussion of modeling of these modes, and integration of these into CSIAPS. The Annex contains two sections that will help others to integrate other SAR sensors into CSIAPS. Annex A lists the procedure for downloading Two-Line Elements (TLEs) for STK. Annex B details configuration of STK and CSIAPS for a new mode or sensor.

Modelling SAR sensors in STK

Satellite Tool Kit (STK) is a commercial off-the-shelf software developed by Analytical Graphics Inc. (AGI) that provides complex satellite propagation models with integrated 2-D and 3-D visualization [4], [6], [8]. It is widely used within the defence, aerospace and intelligence communities for land, sea, air, and space scenarios. It provides various orbital models that the users can apply to a specific commercial satellite. CSIAPS relies on STK to provide it with orbital models for specific SAR satellites which it then uses to predict specific image acquisition times and coverage.

The most exact method of modelling a satellite orbit in STK is using a Two-Line Element (TLE) [6]. The TLE is a file that contains the mean values of the satellite orbit parameters, calculated using recent satellite orbit data. AGI obtains the TLEs from the North American Aerospace Defense Command (NORAD), and makes them available through their web site www.agi.com. NORAD updates the master list of all satellites with any new TLEs daily. The most current as well as historic TLEs are (available at the Historic TLEs) used here to check and compare predicted image acquisition times for dates in the past with the actual values for acquired images. Annex A details the procedure for downloading TLEs.

The methodology for configuring STK and CSIAPS for a new mode or sensor is detailed in Annex B. The user has a choice of several orbital models and sensor types. The sensor type defines the parameters that will be used to model the sensor's field of view. Of the five choices that STK offer, the Complex Conic sensor pattern was selected for this application (SAR sensor) and is consistent with what was used for the other SAR models in CSIAPS [6]. This requires specification of the *Inner* and *Outer Half Angles* and *minimum* and *maximum clock angles* of the sensor's cone. The *Inner* and *Outer Half Angles* define the angular radius of the cone measured from the boresight.

Normally the modes in a SAR sensor are specified in terms of incidence angle, the angle between the normal to the ground surface and the range from that ground point to the sensor. The half angle α is related to the incidence angle $\boldsymbol{\theta}$ by [9]:

$$\alpha = \sin^{-1}((R_E/(R_E+h)) \times \sin(\theta), \qquad (1)$$

Where $\boldsymbol{R_E}$ is the radius of the Earth, and $\boldsymbol{h}$ is the altitude of the satellite above the Earth.

The *Minimum* and *Maximum Clock Angles* define the range of rotation about the boresight relative to the up vector. The clock angles correspond to azimuth angles, which are defined in the sensor pointing direction. The angles are positive in a right-handed sense about the boresight vector for satellites and aircraft. For facilities and targets, the angles are positive in a left-handed sense about the boresight vector. Therefore, the missing variable is the incidence angle.

TerraSAR-X beam modes

The three basic imaging modes of TerraSAR-X have been implemented into CSIAPS. The satellite, the sensor and its modes are described in this section. TerraSAR-X was launched in June 2007[1]. TerraSAR-X is a flexible multi-polarization X-band SAR sensor. It is capable of imaging to the left or right.

Table 1: High Resolution SpotLight (HS) Mode

Scene extension	10 km (ground range) x 5 km (azimuth)
Azimuth resolution	1 m (single pol) 2 m (dual pol)
Ground range resolution (300 MHz)	0.65 m @ 55° incidence angle 1.5 m @ 20° incidence angle
Ground range resolution (150 MHz)	1.34 m @ 55° incidence angle 3.21 m@ 20° incidence angle
Polarization	Single: HH or VV Dual: HH and VV

TerraSAR-X has three basic imaging modes. These include *SpotLight* mode, a *StripMap* mode, and a *ScanSAR* mode. The *SpotLight* mode is essentially divided into two parts. The High Resolution *SpotLight* mode (abbreviated as HS) is available in two bandwidth configurations: a 150 MHz and a large 300 MHz configuration (see Table 1). The 300 MHz HS mode is the highest resolution mode available on TerraSAR-X and according to the DLR Earth Observation on the WEB (EOWEB) web site, it is available only in a single polarization option (HH or VV). It may be taking advantage of pulse stitching to achieve this resolution. The higher resolution comes at the expense of a reduced range extent. The 150 MHz HS mode has double the range extent of the 300 MHz HS mode. The regular *SpotLight* or SL mode has double the range extent of the 150 MHz HS mode. The later is available in a single polarization (HH or VV) or dual polarization (HH and VV) option. The dual polarization option comes at the expense of azimuth resolution.

The second *SpotLight* mode labelled is the *SpotLight* (SL) mode (see Table 2). In terms of polarimetry, the TerraSAR-X *StripMap* mode is the most flexible, providing the user with the

[1] Its clone Tanem-X is due to be launched in the Fall of 2009. The plan calls for placing the two satellites in a tandem orbit for derivation of interferometric DEM to DTED level-3 accuracies.

choice of single of dual polarizations. In the single polarization mode, the user has the choice of HH (H-transmit and H-receive) or VV (V-transmit and V-receive). For the dual polarization mode the user has the choice of HH and VV, HH and HV, or VV and VH. The dual polarization mode comes at the expense of azimuth resolution.

Table 2: SpotLight (SL) Mode

Scene extension	10 km (ground range) x 10 km (azimuth)
Azimuth resolution	2 m (single pol) 4 m (dual pol)
Ground range resolution	1.34 m @ 55° incidence angle 3.21 m @ 20° incidence angle
Polarization	Single: HH or VV Dual: HH and VV

Table 3: StripMap Mode

Swath width (ground range)	30 km (single pol) 15 km (dual pol)
Azimuth resolution	3 m (single pol) 6 m (dual pol)
Ground range resolution	3 m (single pol) 6 m (dual pol)
Polarization	Single: HH or VV Dual: HH and VV, HH and HV, or VV and HV

The *StripMap* Mode is summarized in Table 3. It is polarimetrically the most flexible of TerraSAR-X's mode. The average experimental user has the choice of single polarization or dual polarization modes. It is capable of single polarization (HH or VV) or dual polarization (HH & VV, HH & HV, or VV & VH). The dual polarization comes at the expense of ground swath and resolution. For the single polarization the ground swath is 30 km with a resolution of 3 m x 3 m. For the dual polarization the ground swath is 15 km and resolution 6 m x 6 m.

TerraSAR-X is capable of two additional polarization modes, but these are viewed as experimental and are apparently available only in exceptional circumstances. The first is called the twin polarization mode [2]. In this mode two polarization channels are derived by operating the instrument in a *ScanSAR* like mode, but changing the polarization instead of the elevation beam. The disadvantage compared to dual polarization mode is that the spectra of the two polarization channels are not phase coherent and may show *ScanSAR* specific scalloping artefacts if, for example, the Doppler centroid or the azimuth antenna patterns are not precisely known. The advantage of the twin polarization mode is that the PRF is not doubled as is the case with the dual polarization mode. For that reason, the swath width is the full *StripMap* swath. The second experimental mode is the full quad polarization mode. This mode requires the use of the backup two channels on the system and therefore is used sparingly.

The *ScanSAR* mode is detailed in Table 4. It combines four of the *StripMap* modes to form a very large 100 km swath with a resolution of 16 m in both azimuth and ground range. It is only available in single polarization (either HH or VV).

Table 4: ScanSAR Mode

Number of sub-swaths	4
Swath width (ground range)	100 km
Acquisition length	Max. 3000 km
Azimuth resolution	16 m
Ground range resolution	16 m

Modeling of TerraSAR-X

Detailed beam configuration of TerraSAR-X was published in [1]. Given the incidence angles θ_{min} and θ_{max}, the half angles α_0 and α_1 can be calculated using eq. (1). The incidence and half angles for the 122 *SpotLight* modes are summarized in Table 5. However, only those highlighted in bold, namely spot_010 to spot_110, are available to the average users or researcher. The remaining ones have with very small and very large incidence angles are experimental modes only and require special permission to access.

Based on the lack of details in the TerraSAR-X documentation it is assumed that the configuration of the high resolution 300 MHz *SpotLight* modes is the same as the regular *SpotLight* mode, save for the reduced range extent.

Table 5: TerraSAR-X SpotLight mode beam modelling

Elevation Beam	θ_{min} [°]	θ_{max} [°]	α_1	α_0
spot_001	14.677	16.684	13.55900936	15.40566569
spot_002	15.247	17.244	14.08375100	15.92040939
spot_003	15.815	17.801	14.60643514	16.43215473
spot_004	16.380	18.356	15.12613508	16.94181429
spot_005	16.942	18.907	15.64284502	17.44754608
spot_006	17.501	19.455	16.15655928	17.95026336
spot_007	18.057	20.000	16.66727231	18.44996097
spot_008	18.610	20.541	17.17497863	18.94571775
spot_009	19.159	21.079	17.67875554	19.43844591
spot_010	**19.706**	**21.614**	**18.18043305**	**19.92814063**
spot_011	**20.249**	**22.145**	**18.67817178**	**20.41388273**
spot_012	**20.789**	**22.673**	**19.17288415**	**20.89658323**
spot_013	**21.326**	**23.197**	**19.66456527**	**21.37532432**
spot_014	**21.859**	**23.718**	**20.15229557**	**21.85101616**
spot_015	**22.389**	**24.235**	**20.63698629**	**22.32274242**
spot_016	**22.915**	**24.749**	**21.11771925**	**22.79141231**
spot_017	**23.437**	**25.258**	**21.59449178**	**23.25520016**
spot_018	**23.956**	**25.764**	**22.06821384**	**23.71592638**
spot_019	**24.472**	**26.267**	**22.53888129**	**24.17358726**
spot_020	**24.984**	**26.765**	**23.00557885**	**24.62636150**
spot_021	**25.492**	**27.260**	**23.46830451**	**25.07606604**
spot_022	**25.996**	**27.751**	**23.92705643**	**25.52179011**
spot_023	**26.497**	**28.238**	**24.38274215**	**25.96353264**
spot_024	**26.993**	**28.722**	**24.83354109**	**26.40219872**
spot_025	**27.487**	**29.201**	**25.28217746**	**26.83597495**
spot_026	**27.976**	**29.677**	**25.72592455**	**27.26667197**
spot_027	**28.461**	**30.149**	**26.16568989**	**27.69338343**
spot_028	**28.943**	**30.617**	**26.60237832**	**28.11610915**
spot_029	**29.421**	**31.081**	**27.03508208**	**28.53484912**
spot_030	**29.895**	**31.541**	**27.46380071**	**28.94960353**
spot_031	**30.365**	**31.998**	**27.88853391**	**29.36127312**

spot_032	30.831	32.450	28.30928160	29.76805684
spot_033	31.293	32.899	28.72604386	30.17175533
spot_034	31.752	33.344	29.13972180	30.57146911
spot_035	32.207	33.785	29.54941336	30.96719927
spot_036	32.657	34.222	29.95422002	31.35894709
spot_037	33.104	34.656	30.35594173	31.74760914
spot_038	33.547	35.085	30.75367949	32.13139603
spot_039	33.987	35.511	31.14833097	32.51209880
spot_040	34.422	35.933	31.53810368	32.88882444
spot_041	34.854	36.351	31.92479122	33.26157518
spot_042	35.282	36.766	32.30749886	33.63124374
spot_043	35.706	37.176	32.68622853	33.99605122
spot_044	36.126	37.583	33.06098236	34.35777999
spot_045	36.542	37.986	33.43176271	34.71554281
spot_046	36.955	38.386	33.79946193	35.07022910
spot_047	37.364	38.782	34.16319093	35.42095399
spot_048	37.769	39.174	34.52295265	35.76772111
spot_049	38.171	39.563	34.87963695	36.11141727
spot_050	38.569	39.948	35.23235832	36.45116133
spot_051	38.963	40.329	35.58112027	36.78695751
spot_052	39.353	40.707	35.92592651	37.11968992
spot_053	39.740	41.082	36.26766346	37.44935983
spot_054	40.124	41.453	36.60633199	37.77509123
spot_055	40.504	41.820	36.94105279	38.09688914
spot_056	40.880	42.184	37.27183037	38.41563387
spot_057	41.253	42.545	37.59954747	38.73132735
spot_058	41.622	42.902	37.92332870	39.04309893
spot_059	41.988	43.256	38.24405492	39.35182596
spot_060	42.351	43.607	38.56172793	39.65751083
spot_061	42.710	43.954	38.87547637	39.95928706
spot_062	43.065	44.298	39.18530594	40.25802889
spot_063	43.418	44.639	39.49296448	40.55373924
spot_064	43.767	44.976	39.79671138	40.84555588
spot_065	44.113	45.310	40.09742145	41.13434988
spot_066	44.455	45.642	40.39423026	41.42098738
spot_066	44.455	45.642	40.39423026	41.42098738
spot_067	44.794	45.970	40.68801054	41.70374522
spot_068	45.130	46.295	40.97876544	41.98349114
spot_069	45.463	46.617	41.26649828	42.26022905
spot_070	45.793	46.936	41.55121254	42.53396301
spot_071	46.120	47.251	41.83291186	42.80384118
spot_072	46.443	47.564	42.11074055	43.07158147
spot_073	46.764	47.874	42.38642288	43.33633102
spot_074	47.081	48.181	42.65824537	43.59809455
spot_075	47.396	48.486	42.92792728	43.85772752
spot_076	47.707	48.787	43.19376084	44.11353247
spot_077	48.016	49.085	43.45746021	44.36636659

spot_078	**48.322**	**49.381**	**43.71817474**	**44.61708158**
spot_079	**48.625**	**49.674**	**43.97590939**	**44.86483382**
spot_080	**48.925**	**49.964**	**44.23066928**	**45.10962905**
spot_081	**49.222**	**50.252**	**44.48245973**	**45.35231505**
spot_082	**49.516**	**50.537**	**44.73128620**	**45.59205301**
spot_083	**49.808**	**50.819**	**44.97799850**	**45.82884913**
spot_084	**50.097**	**51.099**	**45.22175536**	**46.06354723**
spot_085	**50.383**	**51.376**	**45.46256272**	**46.29531336**
spot_086	**50.667**	**51.650**	**45.70126646**	**46.52415422**
spot_087	**50.948**	**51.922**	**45.93703014**	**46.75090954**
spot_088	**51.226**	**52.191**	**46.16986018**	**46.97475038**
spot_089	**51.502**	**52.458**	**46.40059844**	**47.19651371**
spot_090	**51.776**	**52.723**	**46.62924712**	**47.41620217**
spot_091	**52.046**	**52.985**	**46.85414417**	**47.63299187**
spot_092	**52.315**	**53.245**	**47.07779320**	**47.84771551**
spot_093	**52.508**	**53.502**	**47.29770409**	**48.05955264**
spot_094	**52.844**	**53.757**	**47.51637388**	**48.26933306**
spot_095	**53.105**	**54.010**	**47.73214638**	**48.47706004**
spot_096	**53.364**	**54.261**	**47.94585445**	**48.68273697**
spot_097	**53.620**	**54.509**	**48.15667842**	**48.88555037**
spot_098	**53.874**	**54.755**	**48.36544743**	**49.08632412**
spot_099	**54.126**	**54.999**	**48.57216480**	**49.28506197**
spot_100	**54.375**	**55.240**	**48.77601611**	**49.48095579**
spot_101	**54.622**	**55.480**	**48.97782605**	**49.67563524**
spot_102	**54.867**	**55.717**	**49.17759833**	**49.86748211**
spot_103	**55.110**	**55.952**	**49.37533674**	**50.05731263**
spot_104	**55.351**	**56.186**	**49.57104521**	**50.24593640**
spot_105	**55.589**	**56.417**	**49.76391822**	**50.43174569**
spot_106	**55.826**	**56.646**	**49.95558072**	**50.61555203**
spot_107	**56.060**	**56.873**	**50.14441958**	**50.79736011**
spot_108	**56.292**	**57.098**	**50.33124876**	**50.97717473**
spot_109	**56.522**	**57.321**	**50.51607277**	**51.15500083**
spot_110	**56.751**	**57.543**	**50.69969725**	**51.33163822**
spot_111	56.977	57.762	50.88052322	51.50550070
spot_112	57.201	57.979	51.05935826	51.67739010
spot_113	57.423	58.195	51.23620736	51.84810121
spot_114	57.644	58.409	51.41186956	52.01684650
spot_115	57.862	58.621	51.58476037	52.18363154
spot_116	58.079	58.831	51.75647124	52.34846202
spot_117	58.294	59.039	51.92621359	52.51134374
spot_118	58.507	59.246	52.09399296	52.67306295
spot_119	58.718	59.451	52.25981497	52.83284165
spot_120	58.927	59.654	52.42368537	52.99068596
spot_121	59.135	59.856	52.58639133	53.14737686
spot_122	59.341	60.056	52.74715381	53.30214219

The TeraSAR-X *StripMap* beam modes are summarized in Table 6. Each beam mode is divided into *stripNear*, strip, and *stripFar* containing the near, mid and far incidence angles, respectively. In total, 27 of these triplicates are available. Only those highlighted in bold from strip_003 to strip_014 are available to the average user.

The *ScanSAR* beam modes are summarized in Table 7. In the *ScanSAR* beam, four *StripMap* beams are combined to form the 100 km swath. Only those in bold that include scan_003 to scan_011 are readily available. Experimental *ScanSAR* beams with large incidence have not been included in this table.

In total, 300 right looking and 300 left looking TerraSAR-X beam modes are available to the average user (this count excludes the available polarization options). Using the information contained in the above three tables and the procedure outlined in Annex B, STK is used to model these sensor modes. A unique ASCII-based file is created for each of these 600 modes. When placed in the CSIAPS "templates/stk" directory with an updated configuration file (config.xml; see Annex B) they become available to CSIAPS. The next section will examine and try to verify a sampling of these models.

Table 6: TerraSAR-X StripMap mode beam modelling

Elevation Beam	θ_{min} [°]	θ_{max} [°]	α_1	α_0
strip_001	14.338	17.906	13.24682690	16.52859610
stripNear_001	14.510	16.396	13.40522944	15.14084891
stripFar_001	15.876	17.739	14.66255524	16.37520422
strip_002	17.058	20.535	15.74946741	18.94022105
stripNear_002	17.226	19.065	15.90386778	17.59251723
stripFar_002	18.559	20.373	17.12816654	18.79179713
strip_003	**19.710**	**23.086**	**18.18410063**	**21.27393725**
stripNear_003	**19.874**	**21.661**	**18.33445877**	**19.97114660**
stripFar_003	**21.169**	**22.929**	**19.52084466**	**21.13051026**
strip_004	**22.287**	**25.556**	**20.54372945**	**23.52657716**
stripNear_004	**22.445**	**24.177**	**20.68818136**	**22.26983733**
stripFar_004	**23.701**	**25.404**	**21.83549950**	**23.38817097**
strip_005	**24.783**	**27.941**	**22.82240237**	**25.69417523**
stripNear_005	**24.937**	**26.610**	**22.96275107**	**24.48547434**
stripFar_005	**26.151**	**27.794**	**24.06807323**	**25.56080825**
strip_006	**27.195**	**30.237**	**25.01703372**	**27.77289870**
stripNear_006	**27.343**	**28.956**	**25.15143697**	**26.61415121**
stripFar_006	**28.513**	**30.096**	**26.21281879**	**27.64548728**
strip_007	**29.520**	**32.445**	**27.12465486**	**29.76355913**
stripNear_007	**29.662**	**31.214**	**27.25310519**	**28.65480611**
stripFar_007	**30.788**	**32.310**	**28.27047296**	**29.64210304**
strip_008	**31.756**	**34.564**	**29.14332515**	**31.66525342**
stripNear_008	**31.892**	**33.383**	**29.26582162**	**30.60648147**
stripFar_008	**32.974**	**34.434**	**30.23915016**	**31.54885038**
strip_009	**33.903**	**36.595**	**31.07301908**	**33.47897218**
stripNear_009	**34.034**	**35.463**	**31.19046339**	**32.46922295**
stripFar_009	**35.072**	**36.471**	**32.11977202**	**33.36850937**

strip_010	**35.961**	**38.540**	**32.91380606**	**35.20667162**
stripNear_010	**36.087**	**37.457**	**33.02620093**	**34.24583930**
stripFar_010	**37.081**	**38.421**	**33.91155916**	**35.10124426**
strip_011	**37.933**	**40.401**	**34.66851579**	**36.85036761**
stripNear_011	**38.054**	**39.364**	**34.77586878**	**35.93564574**
stripFar_011	**39.005**	**40.287**	**35.61827324**	**36.74996128**
strip_012	**39.821**	**42.18**	**36.33913641**	**38.41213350**
stripNear_012	**39.936**	**41.189**	**36.44057827**	**37.54334739**
stripFar_012	**40.846**	**42.071**	**37.24193704**	**38.31672847**
strip_013	**41.625**	**43.881**	**37.92595933**	**39.89583651**
stripNear_013	**41.735**	**42.933**	**38.02239605**	**39.07015137**
stripFar_013	**42.605**	**43.777**	**38.78375564**	**39.80540841**
strip_014	**43.350**	**45.506**	**39.43373220**	**41.30362163**
stripNear_014	**43.456**	**44.601**	**39.52605788**	**40.52080744**
stripFar_014	**44.287**	**45.406**	**40.24848274**	**41.21727714**
strip_015	45.053	47.008	40.91217195	42.59568682
stripNear_015	45.153	46.142	40.99865260	41.85184866
stripFar_015	45.946	46.913	41.68307016	42.51424105
strip_016	46.626	48.494	42.26795779	43.86453179
stripNear_016	46.722	47.666	42.35037672	43.15873963
stripFar_016	47.480	48.403	42.99976981	43.78711571
strip_017	48.129	49.915	43.55378676	45.06829676
stripNear_017	48.221	49.123	43.63216909	44.39857667
stripFar_017	48.945	49.828	44.24763813	44.99488105
strip_018	49.565	51.106	44.77271608	46.06940927
stripNear_018	49.644	50.423	44.83948619	45.49620843
stripFar_018	50.268	51.031	45.36578516	46.00658784
strip_019	50.804	52.285	45.81626419	47.05287167
stripNear_019	50.880	51.628	45.88001557	46.50579554
stripFar_019	51.480	52.212	46.38222165	46.99220745
strip_020	51.994	53.417	46.81086291	47.98953517
stripNear_020	52.067	52.786	46.87161876	47.46836862
stripFar_020	52.643	53.348	47.34992495	47.93266439
strip_021	53.138	54.506	47.75939849	48.88309942
stripNear_021	53.208	53.899	47.81718393	48.38597336
stripFar_021	53.762	54.439	48.27344229	48.82834582
strip_022	54.238	55.553	48.66390716	49.73476985
stripNear_022	54.305	54.969	48.71874957	49.26064887
stripFar_022	54.837	55.489	49.15315822	49.68292785
strip_023	55.295	56.561	49.52560544	50.54737313
stripNear_023	55.360	55.999	49.57834598	50.09523074
stripFar_023	55.872	56.499	49.99273426	50.49760821
strip_024	56.312	57.531	50.34733609	51.32210032
stripNear_024	56.375	56.990	50.39799172	50.89091272
stripFar_024	56.868	57.472	50.79335978	51.27518888
strip_025	57.292	58.466	51.13189763	52.06172735
stripNear_025	57.352	57.944	51.17968999	51.64969216

stripFar_025	57.827	58.408	51.55702879	52.01605887
strip_026	58.235	59.367	51.87967168	52.76741717
stripNear_026	58.293	58.864	51.92542499	52.37432913
stripFar_026	58.751	59.311	52.28571451	52.72376546
strip_027	59.145	60.236	52.59420408	53.44110864
stripNear_027	59.200	59.751	52.63715832	53.06597572
stripFar_027	59.642	60.182	52.98136575	53.39945099
strip_023	55.295	56.561	49.52560544	50.54737313
stripNear_023	55.360	55.999	49.57834598	50.09523074
stripFar_023	55.872	56.499	49.99273426	50.49760821
strip_024	56.312	57.531	50.34733609	51.32210032
stripNear_024	56.375	56.990	50.39799172	50.89091272
stripFar_024	56.868	57.472	50.79335978	51.27518888
strip_025	57.292	58.466	51.13189763	52.06172735
stripNear_025	57.352	57.944	51.17968999	51.64969216
stripFar_025	57.827	58.408	51.55702879	52.01605887
strip_026	58.235	59.367	51.87967168	52.76741717
stripNear_026	58.293	58.864	51.92542499	52.37432913
stripFar_026	58.751	59.311	52.28571451	52.72376546
strip_027	59.145	60.236	52.59420408	53.44110864
stripNear_027	59.200	59.751	52.63715832	53.06597572
stripFar_027	59.642	60.182	52.98136575	53.39945099

Table 7: TerraSAR-X ScanSAR mode beam modelling

Elevation Beam	**θ_{min} [°]**	**θ_{max} [°]**	**α_1**	**α_0**
scan_001	14.338	25.556	13.24682690	23.52657716
scan_002	17.058	27.941	15.74946741	25.69417523
scan_003	**19.710**	**30.237**	**18.18410063**	**27.77289870**
scan_004	**22.287**	**32.445**	**20.54372945**	**29.76355913**
scan_005	**24.783**	**34.564**	**22.82240237**	**31.66525342**
scan_006	**27.195**	**36.595**	**25.01703372**	**33.47897218**
scan_007	**29.520**	**38.540**	**27.12465486**	**35.20667162**
scan_008	**31.756**	**40.401**	**29.14332515**	**36.85036761**
scan_009	**33.903**	**42.180**	**31.07301908**	**38.41213350**
scan_010	**35.961**	**43.881**	**32.91380606**	**39.89583651**
scan_011	**37.933**	**45.506**	**34.66851579**	**41.30362163**

.

TerraSAR-X model verification

Validation of incidence angles

In this section a sample of the TerraSAR-X models created for CSIAPS are verified. The first step was to compare the incidence angles for the various modes that are given in the TerraSAR-X documentation [1] against those provided in the Earth Observation on the WEB (EOWEB) . We relied on those values to determine each of the modes. TerraSAR-X products are accessed from EOWEB using a user-id and a password login. From this web site future products & acquisitions can be determined and viewed. As well, acquisition information from archived data for any given area can be accessed.

The test site chosen for this cross-comparison was Ranger Mine, Australia (latitude=-12.685°, longitude=132.915°). For a sampling of available modes, EOWEB's 'Future Product/Acquisition' was accessed, and dates, sensor modes and incidence angles noted. The comparison of the EOWEB listings for this test site with those listed in reference [1] is shown in Table 8.

The agreement of the incidence angles between the EOWEB listing and reference [1] is fair. For all except the high resolution SpotLight mode, the minimum and maximum incidence angles are normally accurate to within a fifth to a tenth of a degree. For the high resolution SpotLight mode the minimum and maximum incidence angles are off by up to nearly 0.7 degrees. The same holds true for the maximum incidence angle. No explanation for this offset is given in [1].

EOWEB's listings for the High Resolution *SpotLight* modes mostly fall well within the range specified by [1]. Table 9 shows the same comparison as the previous table, except in this case the incidence angle range as provided in reference [1] has been reduced by 50 percent. Agreement between the incidence angles of the modified those documented in the reference and EOWEB has improved. The difference in coverage between the HS and SL *SpotLight* modes should only be a difference in the range extent, but it seems the acquisition timing is also affected. Special models for these HS modes have been created, but are not currently integrated with CSIAPS, pending more data.

Table 8: Comparison between the incidence angles given by the TerraSAR-X EOWEB and the TerraSAR-X document TX-GS-DD-3302 for Ranger Mine, Australia

Start Date	Sensor Mode	Polar-ization	Beam	EOWEB		Doc.: TX-GS-DD-3302 [1]	
				Min Inc angle (deg)	Max Inc angle (deg)	Min Inc angle (deg)	Max Inc angle (deg)
2008-08-02T09:05:46,988	*ScanSAR*	HH	scan_004	22.213	32.502	22.287	34.564
2008-08-03T08:51:36,338	*StripMap*	HH	strip_007	29.473	33.089	29.520	32.445
2008-08-03T10:27:55,346	*StripMap*	VV	strip_006	27.028	30.500	27.195	30.237

2008-08-04T10:11:57,554	*StripMap*	VV	strip_007	29.489	32.470	29.520	32.445
2008-08-04T20:28:11,621	*StripMap*	HH	strip_004	21.746	26.031	22.287	25.556
2008-08-05T21:45:14,665	*HighResSpotLight*	VV	spot_051	39.308	40.211	38.963	40.329
2008-08-05T21:45:14,665	*HighResSpotLight*	VV	spot_051	39.308	40.211	38.963	40.329
2008-08-06T21:36:10,956	*StripMap*	HH	strip_014	43.405	45.552	43.350	45.506
2008-08-07T09:14:48,009	*ScanSAR*	HH	scan_004	22.152	32.567	22.287	34.564
2008-08-09T10:20:09,464	*StripMap*	VV	strip_008	31.436	34.641	31.756	34.564
2008-08-09T22:11:10,520	*StripMap*	VV	strip_006	27.167	30.260	27.195	30.237
2008-08-10T20:19:51,516	*StripMap*	HH	strip_011	37.618	40.694	37.933	40.401
2008-08-11T21:36:43,972	*HighResSpotLight*	VV	spot_098	54.164	54.716	53.874	54.755
2008-08-11T21:36:43,972	*HighResSpotLight*	VV	spot_098	54.164	54.716	53.874	54.755
2008-08-11T21:36:58,496	*StripMap*	HH	strip_014	43.276	45.511	43.350	45.506
2008-08-12T09:24:08,049	*HighResSpotLight*	HH/VV	spot_023	26.806	27.462	26.497	28.238
2008-08-12T09:24:08,049	*HighResSpotLight*	HH/VV	spot_023	26.806	27.462	26.497	28.238
2008-08-12T09:24:08,049	*HighResSpotLight*	HH/VV	spot_023	26.806	27.462	26.497	28.238
2008-08-12T09:26:56,398	*StripMap*	VV/VH	stripFar_010	37.075	38.438	37.081	38.421
2008-08-14T08:51:35,550	*StripMap*	HH	strip_008	31.827	34.947	31.756	34.564
2008-08-14T10:27:57,565	*StripMap*	VV	strip_007	29.489	32.681	29.520	32.445
2008-08-15T22:02:54,834	*HighResSpotLight*	VV	spot_088	51.328	51.964	51.226	52.191
2008-08-15T22:02:54,834	*HighResSpotLight*	VV	spot_088	51.328	51.964	51.226	52.191
2008-08-16T21:45:29,579	*StripMap*	HH	strip_005	24.612	27.942	24.783	27.941
2008-08-18T09:13:59,394	*ScanSAR*	HH	scan_008	31.703	40.445	31.756	40.401
2008-08-18T09:14:59,404	*ScanSAR*	HH	scan_008	31.694	40.488	31.756	40.401
2008-08-18T09:14:59,404	*ScanSAR*	HH	scan_008	31.694	40.488	31.756	40.401
2008-08-18T10:53:32,408	*SpotLight*	HH/VV	spot_039	34.455	35.464	33.987	35.511
2008-08-19T10:35:32,402	*StripMap*	VV/VH	stripFar_008	32.981	34.458	32.974	34.434
2008-08-20T20:42:43,957	*HighResSpotLight*	HH	spot_068	45.583	46.033	45.130	46.295
2008-08-20T20:42:43,957	*HighResSpotLight*	HH	spot_068	45.583	46.033	45.130	46.295
2008-08-22T21:36:43,416	*HighResSpotLight*	VV	spot_098	54.168	54.715	53.874	54.755

2008-08-22T21:36:43,416	*HighResSpotLight*	VV	spot_098	54.168	54.715	53.874	54.755
2008-08-27T21:45:15,690	*HighResSpotLight*	VV	spot_051	39.306	40.209	38.963	40.329

Table 9: Comparison between the incidence angles given by the TerraSAR-X EOWEB and a 50percent reduction in incidence angle range quoted in TX-GS-DD-3302 for Ranger Mine, Australia

Start Date	Sensor Mode	Polar-ization	Beam	EOWEB		TX-GS-DD-3302 [1] with 50% reduction in incidence angle range	
				Min Inc angle (deg)	Max Inc angle (deg)	Min Inc angle (deg)	Max Inc angle (deg)
2008-08-05T21:45:14,665	HighResSpotLight	VV	spot_051	39.308	40.211	39.3045	39.9875
2008-08-11T21:36:43,972	HighResSpotLight	VV	spot_098	54.164	54.716	54.09425	54.53475
2008-08-11T21:36:43,972	HighResSpotLight	VV	spot_098	54.164	54.716	54.09425	54.53475
2008-08-12T09:24:08,049	HighResSpotLight	HH/VV	spot_023	26.806	27.462	26.93225	27.80275
2008-08-12T09:24:08,049	HighResSpotLight	HH/VV	spot_023	26.806	27.462	26.93225	27.80275
2008-08-12T09:24:08,049	HighResSpotLight	HH/VV	spot_023	26.806	27.462	26.93225	27.80275
2008-08-15T22:02:54,834	HighResSpotLight	VV	spot_088	51.328	51.964	51.46725	51.94975
2008-08-15T22:02:54,834	HighResSpotLight	VV	spot_088	51.328	51.964	51.46725	51.94975
2008-08-20T20:42:43,957	HighResSpotLight	HH	spot_068	45.583	46.033	45.42125	46.00375
2008-08-20T20:42:43,957	HighResSpotLight	HH	spot_068	45.583	46.033	45.42125	46.00375
2008-08-22T21:36:43,416	HighResSpotLight	VV	spot_098	54.168	54.715	54.09425	54.53475
2008-08-22T21:36:43,416	HighResSpotLight	VV	spot_098	54.168	54.715	54.09425	54.53475
2008-08-27T21:45:15,690	HighResSpotLight	VV	spot_051	39.306	40.209	39.3045	39.9875

Table 10: Comparison between EOWEB prediction and CSIAPS for Connaught Range

Elevation Beam	Date	EOWEB- predicted		CSIAPS	
		Start time	Stop time	Start time	Stop time
Spot_026r	18-Oct-08	11:20:32.186	11:20:32.186	11:20:45.640	11:20:54.833
Spot_048r	15-Oct-08	22:52:36.583	22:52:36.583	22:52:48.363	22:52:58.066
Spot_059r	13-Oct-08	11:11:58.829	11:11:58.829	11:12:09.004	11:12:18.226
Spot_081r	20-Oct-08	23:01:10.259	23:01:10.259	23:01:02.758	23:01:09.953
Spot_092r	19-Oct-08	11:03:25.223	11:03:25.223	11:03:39.449	11:03:48.700
Spot_114r	14-Oct-08	23:09:44.302	23:09:44.302	23:01:25.736	23:01:35.413
stripFar_006r	18-Oct-08	11:20:33.733	11:20:33.733	11:20:26.129	11:20:35.311
stripNear_011r	15-Oct-08	22:52:37.733	22:52:37.733	22:52:32.380	22:52:42.066
stripNear_013r	13-Oct-08	11:11:59.733	11:11:59.733	11:11:56.651	11:12:05.828

Validation of start and stop times

A comparison of the predicted start and stop acquisition times between EOWEB and CSIAPS for a nine beams are shown in Table 10. The CSIAPS and EOWEB predictions were made on the same date. The TLEs for CSIAPS were updated prior to the predictions (following the procedure detailed in Annex A). It is not known which TLEs EOWEB would have used. Even though EOWEB clearly uses the labels 'Start time' and 'Stop time', the two values are the same. It likely reflects the timing of the scene centre rather then the start and end of the scene.

The number of samples used in this comparison is not large enough to draw any firm conclusions. Six of the nine samples use the *SpotLight* mode. For five of these *SpotLight* modes the discrepancy in the timing is on the order of 5 to 15 seconds. In the sixth case the timing is off by 25 seconds. The match is much better for the *StripMap* modes. The timing discrepancy is on the order of a couple of seconds only. Comparison of the acquisition timing using acquired TerraSAR-X data is needed.

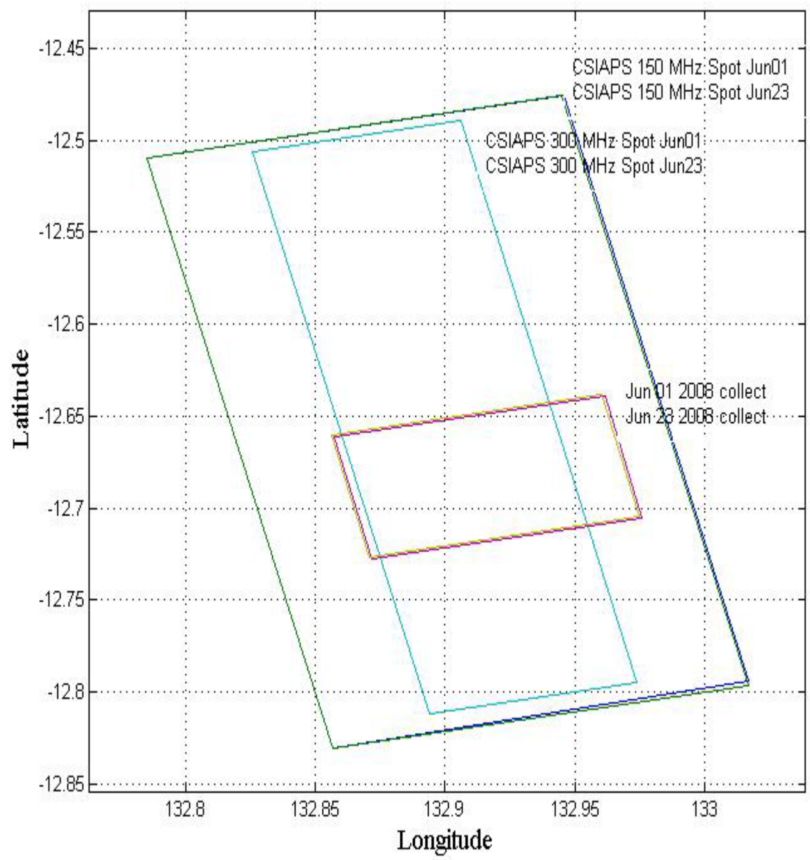

Figure 1: Comparison of swaths from acquired data verses CSIAPS prediction for June 1 and June 23 2008 collect over Range.

To date we have only received two TerraSAR scenes, the June 1 and June 23 acquisition over Ranger Mine, Australia. The collects were both dual polarization, right looking and ascending. The information contained with the data received indicates that it was a high resolution HS collect with a 150 MHz bandwidth. The coverage is shown in Figure 1. The two smallest (almost coincident) rectangles in red and yellow were constructed based on the corner coordinates provided with the data. Near range follows the left side of the rectangle. Also shown are the CSIAPS predictions using HS *SpotLight* mode as provided by [1]. These are depicted by the two almost coincident very large green and dark blue rectangles. The light blue rectangle in the figure depicts CSIAPS' prediction using the HS mode with 50 percent of the incidence angle swath. In all cases there is almost no difference between the coverage of the June 1 and the June 23 acquisitions.

The CSIAPS prediction of the swath width (largest rectangle) is overestimated. The 50 percent reduced swath width prediction is underestimated, but closer to the truth. This is not very surprising considering that all incidence angles are based on the values in reference [1], and these proved inaccurate when compared to EOWEB (results summarized in Table 8).

The acquisition timing for the Ranger Mine data set are compared in Table 11. In this case the EOWEB archive listing of the timing reflects the actual time the data was acquired. In each case the archived TLEs for the image acquisition were downloaded and made available to CSIAPS. Three *SpotLight* modes are shown; two in 300 MHz modes and one in the 150 MHz mode. The start and stop acquisition time for the 150 MHz mode is off by a less then a third of a second.

Figure 2 shows a comparison of the coverage for a TerraSAR-X *ScanSAR* mode for a coastal area in NE Australia. On the left is the CSIAPS predicted coverage. On the right is the actual coverage according to EOWEB archived data. In this CSIAPS' prediction of the swath width is visually accurate. The acquisition timing is less important since that would be adjusted by the operator prior to acquisition.

Table 11: Comparison between EOWEB archive and CSIAPS over Ranger Mine

Elevation Beam	Date	EOWEB-archive		CSIAPS	
		Start time	Stop time	Start time	Stop time
Spot_068r (BW: 300MHz)	1-Jun-08	09:32:33.691	09:32:34.773	09:32:32.494	09:32:37.138
Spot_068r (BW: 300MHz)	23-Jun-08	09:32:34.579	09:32:35.649	09:32:33.386	09:23:38.029
Spot_023r (BW: 150MHz)	12-Aug-08	09:24:06.712	09:24:11.500	09:24:07.045	09:24:11.827

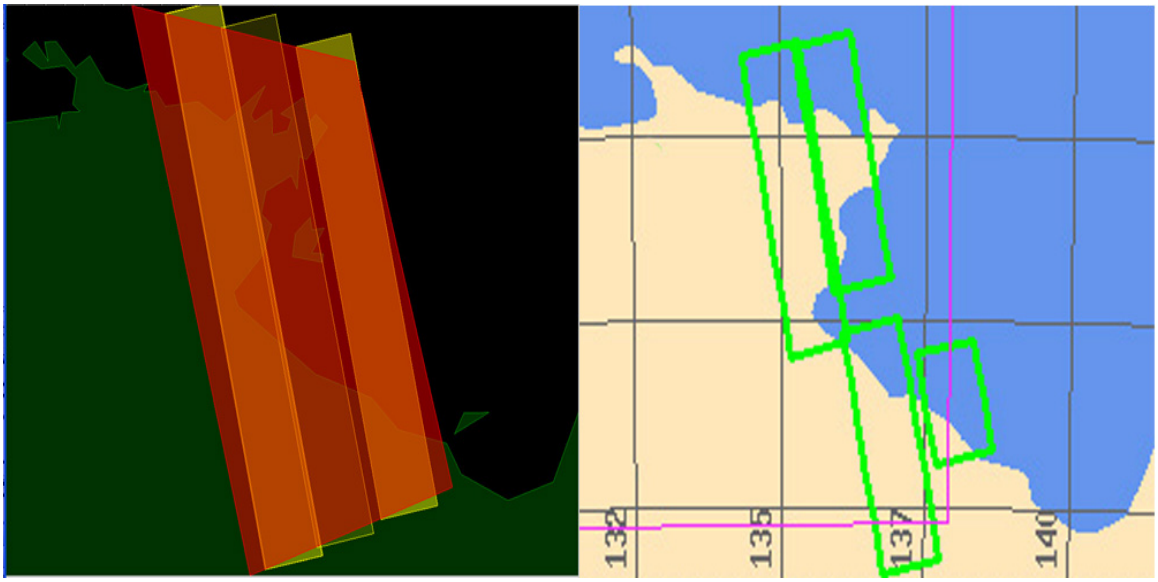

Figure 2: Comparison of predicted TerraSAR-X swaths from CSIAPS (left) and EOWEB (right) in NE Australia.

Conclusion

This report details integration of TerraSAR-X into CSIAPS, and makes a preliminary validation of the results. A lot of information about the various modes of TerraSAR-X has been published. Some comparison of this information is made in this report with the accessible portion of TerraSAR-X's Earth Observation on the WEB (EOWEB) archived data, as well as with the swath width and acquisition timing for future acquisitions as predicted by EOWEB. In turn, these have been compared with CSIAPS. For the *StripMap* and *ScanSAR* modes the data obtained through EOWEB corroborates fairly well the published data. The swath width and acquisition timing predicted by CSIAPS is in good agreement with EOWEB. The overall comparison of the *SpotLight* mode is less favourable. This is made more difficult by the polarization and bandwidth options that come with the *SpotLight* mode. The accuracy of the published values of minimum and maximum incidence angles are suspect because of differences with those obtained from EOWEB. Since these are key to building good models for CSIAPS, the predicted coverage and swath width are not as accurate as with the other two modes. Nevertheless the offsets are relatively minor. With the addition of the TerraSAR-X sensor modes, CSIAPS can now be used to compare acquisitions between RADARSAT-2 and TerraSAR-X.

References

[1] Cluster Applied Remote Sensing, "TerraSAR-X Ground Segment: Basic Product Specification Document", Doc. TX-GS-DD-3302, Issue: 1.5, PP. 103, Date: 24.02.2008.

[2] Cluster Applied Remote Sensing, "TerraSAR-X Ground Segment: Experimental Product Description", Doc. TX-GS-DD-3303, Issue: 1.3, PP. 11, Date: 06.10.2006.

[3] Cluster Applied Remote Sensing, "TerraSAR-X Ground segment: Level 1b Product Format Specification", Doc. TX-GS-DD-3307, Issue: 1.3, PP. 257, Date: 10.12.2007.

[4] Secker, J. (2006). Commercial Satellite Imagery Acquisition Planning System (CSIAPS): Concept of Operations (CONOPS) for Implementation on the General Purpose Network (GP Net). DRDC Ottawa TM 2006-257. Defence R&D Canada - Ottawa.

[5] Secker, J., Vachon, P.W., Robson, M., Rowe, J. and Leung, W. (2006). Assisted Acquisition Planning for Maritime Surveillance with Commercial Satellite, Proc. OceanSAR 2006 – The Third Workshop on Coastal and Marine Imagery Applications of SAR, St. John's, NL, Canada, 23-25 October 2006.

[6] Norris, J. and Secker, J., (2005). Commercial Satellite Imagery Acquisition Planning System (CSIAPS): Modelling IKONOS-2, QuickBird-2, and OrbView-3 Electro-Optical Sensors Using STK. DRDC Ottawa TM 2005-174. Defence R&D Canada – Ottawa.

[7] Norris, J. (2005). Sensor Modelling for the Commercial Satellite Imagery Acquisition Planning System: Modelling ENVISAT and RADARSAT-1 Synthetic Aperture Radar Sensors Using STK. DRDC Ottawa TM 2005-183. Defence R&D Canada – Ottawa.

[8] Secker, J. and Norris, J. (2003). Commercial Satellite Imagery Acquisition Planning System (CSIAPS): Concept Document. DRDC Ottawa TR 2003-210. Defence R&D Canada – Ottawa.

[9] Koudogbo, F. Lanzl, R., "TerraSAR-X Mission: The New Generation in High Resolution Satellites," http://www.sovzondconference.ru/pdf_2008/0021e_report_eng.pdf.

[10] Oliver, C., and S. Quegan, Understanding Synthetic Aperture Radar Images, ARTECH HOUSE, INC., Norwood, MA, 1998

This page intentionally left blank.

Annex A Downloading TLEs

The TLE is a file that contains the mean values of the satellite orbit parameters, calculated using recent satellite orbit data. Analytical Graphics Incorporated (AGI) obtains the TLEs from the North American Aerospace Defense Command (NORAD), and makes them available through their web site www.agi.com. NORAD updates the master list of all satellites with any new TLEs daily. The most current as well as historic TLEs are available at the Historic TLEs are used here to check and compare predicted image acquisition times for dates in the past with the actual values for acquired images. The TLEs are downloaded from the AGI web site www.agi.com. Click on '*SUPPORT*', '*DOWNLOAD DATA*', '*SATELLITE DATABASE*'. Then on '*Current satellite database for PC*' or '*archived satellite database*'.

The user should use the TLE that is closest in time to the acquisition time being predicted. To examine data from an old acquisition, the TLE from that period should be downloaded. Several databases are available. The one required for CSIAPS is ***stkSatDb***. The user would download it normally to the directory:

C:\Program Files\AGI\STK 8\STKData\Databases\Satellite,

overriding the file already in that directory.

CSIAPS is normally configured to automatically update the TLE's. CSIAPS users can turn the auto update feature off in the '*File*', '*Preferences*', by unselecting the checked box next to: '*STD Database Auto Online Update*'.

CSIAPS configuration parameters related to STK are controlled through an XML file ***stkConfig.xml***. This STK configuration file is normally found in the first level of the CSIAPS installations. For example:

C:\CSIAPS_Version1.3/stkConfig.xml

Annex B Configuring STK and CSIAPS for a new TerraSAR-X sensor mode

To configure CSIAPS for a new mode or sensor:

In STK:

1. File → New [scenario];
2. Insert → Satellite From Database;
3. Check ‘common name’;
4. Enter e.g. ‘TerraSAR-X’ → perform search;
5. Highlight the sensor and press OK;
6. Close ‘Satellite Database’ window;
7. Highlight sensor;
8. Insert → New → highlight ‘Sensor’ on object Catalog window;
9. Highlight sensor;
10. Right click on Sensor and choose ‘Property Browser’;
11. ‘Sensor #: Basic Definitions’ window will come up (where # is an integer);
12. Under ‘Sensor Type’ choose ‘Complex Conic’;
13. Enter the required information, i.e. Half Angles, Clock Angles;
14. The Clock angle is between 89.9° and 90.1° for right looking zero Doppler sensors like RADARSAT-2 and TerraSAR-X. The clock angle is between -90.1° and -89.9° for left looking zero Doppler sensors;
15. File → Save, creates two files with a ‘.sc’ and a ‘.sn’ extension;
16. Create a new directory for the sensor under, for example, ‘c:\CSIAPS_ Version1.3\templates\stk’ and copy the files with the ‘.sn’ extension to that directory. This is the only file of the two created by STK that CSIAPS requires;
17. Repeat steps 14 to 16 for each mode of the sensor.

In CSIAPS:

New additions have to be made to the ‘config.xml’ file in the CSIAPS directory. In the TerraSAR-X example:

<satellite name="TerraSAR-X" expertSystemName="TerraSAR-X" sscNumber="31698" sensorType="SAR" passPerCycle="167.0" repeatDur="950400">

<sensorMode name="spot_003r" stkName="spot_003r" expertSystemName="spotRight003" identifier="7241" resolution="2"/>

> The ‘satellite name’ is the name that will be displayed in CSIAPS to the operator. It must be the same as the directory name that contains the STK sensor information.
>
> The SSC number is the mission number of the satellite and is available from the STK satellite database.
>
> The name attribute of the sensorMode element is the name that will be displayed to the Operator in the CSIAPS GUI.
>
> RepeatDur defines the number of seconds it takes the spacecraft to repeat its cycle. It is used for determining CCD pair compatibility. A cycle is defined as the period between when a spacecraft leaves a given position and when it reoccupies that same position on a future orbit. For TerraSAR-X this is 24 hours/day x 3600sec/hour x 11 days/cycle = 950400 sec/cycle [9].
>
> PassPerCycle is used for those spacecraft that have the concept of a cycle. It is also used for determining CCD pair compatibility. A pass is defined by STK as the number of times the spacecraft has crossed the equator since launch. The passPerCycle parameter defines the number of passes within a cycle. For TerraSAR-X the passPerCycle is 11 days/cycle x 15.18182 passes/day = 167 passes/cycle [9].

The second line of XML code is repeated for each of the modes, but with the various fields changed to reflect the names and properties of the added beam modes. For TerraSAR-X it is repeated 600 times for the 600 various TerraSAR-X modes that are included in CSIAPS.

This page intentionally left blank.

List of symbols/abbreviations/acronyms/initialisms

AGI	Analytical Graphics Inc
BW	Bandwidth
CSIAPS	Commercial Satellite Imagery Acquisition Planning System
DEM	Digital Elevation Model
DLR	Deutsche Forschungsanstalt für Luft-Und Raumfahrt *(German Aerospace Research Establishment)*
DND	Department of National Defence
DRDC	Defence Research & Development Canada
DRDKIM	Director Research and Development Knowledge and Information Management
DTED	Digital Terrain Elevation Data
EO	Electro-Optical
HH	Horizontal transmit; horizontal receive
HS	High Resolution SpotLight Mode of TerraSAR-X
HV	Horizontal transmit; vertical receive
NORAD	North American Aerospace Defense Command
PRF	Pulse Repetition Frequency
R&D	Research & Development
SAR	Synthetic Aperture Radar
SL	SpotLight Mode of TerraSAR-X
STK	Satellite Toolkit
TLE	Two-Line Element
TM	Technical Memorandum
VH	Vertical transmit; horizontal receive
VV	Vertical transmit; vertical receive

This page intentionally left blank.

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

<table>
<tr><td colspan="3">1. ORIGINATOR (The name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Centre sponsoring a contractor's report, or tasking agency, are entered in section 8.)

Defence R&D Canada – Ottawa
3701 Carling Avenue
Ottawa, Ontario K1A 0Z4</td><td colspan="2">2. SECURITY CLASSIFICATION (Overall security classification of the document including special warning terms if applicable.)

UNCLASSIFIED</td></tr>
<tr><td colspan="5">3. TITLE (The complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S, C or U) in parentheses after the title.)

Modelling of the TerraSAR-X sensor modes in CSIAPS</td></tr>
<tr><td colspan="5">4. AUTHORS (last name, followed by initials – ranks, titles, etc. not to be used)

Mattar, K.E.</td></tr>
<tr><td colspan="2">5. DATE OF PUBLICATION (Month and year of publication of document.)

March 2009</td><td colspan="2">6a. NO. OF PAGES (Total containing information, including Annexes, Appendices, etc.)

40</td><td>6b. NO. OF REFS (Total cited in document.)

10</td></tr>
<tr><td colspan="5">7. DESCRIPTIVE NOTES (The category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.)

Technical Memorandum</td></tr>
<tr><td colspan="5">8. SPONSORING ACTIVITY (The name of the department project office or laboratory sponsoring the research and development – include address.)

Defence R&D Canada – Ottawa
3701 Carling Avenue
Ottawa, Ontario K1A 0Z4</td></tr>
<tr><td colspan="2">9a. PROJECT OR GRANT NO. (If appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant.)

15dh01</td><td colspan="3">9b. CONTRACT NO. (If appropriate, the applicable number under which the document was written.)</td></tr>
<tr><td colspan="2">10a. ORIGINATOR'S DOCUMENT NUMBER (The official document number by which the document is identified by the originating activity. This number must be unique to this document.)

DRDC Ottawa TM 2008-284</td><td colspan="3">10b. OTHER DOCUMENT NO(s). (Any other numbers which may be assigned this document either by the originator or by the sponsor.)</td></tr>
<tr><td colspan="5">11. DOCUMENT AVAILABILITY (Any limitations on further dissemination of the document, other than those imposed by security classification.)

Unlimited</td></tr>
<tr><td colspan="5">12. DOCUMENT ANNOUNCEMENT (Any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected.))

Unlimited</td></tr>
</table>

13. ABSTRACT (A brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual.)

The Commercial Satellite Imagery Acquisition Planning System (CSIAPS) was designed by Defence R&D Canada – Ottawa to help collection managers plan satellite image acquisition. Its strength is in its capability to integrate models of Synthetic Aperture Radar (SAR) and Electro-Optical (EO) satellite sensors into a single system. This enables the collection manager to plan image acquisition from several different sensors at the same time, providing a comparison of coverage and image acquisition times.

CSIAPS relies on the Satellite ToolKit (STK) for orbital models of the various satellites. So far CSIAPS has been configured to handle several SAR and EO satellites including RADARSAT-1, RADARSAT-2 and the ENVISAT-ASAR (SAR), as well as IKONOS-2, OrbView-3, and QuickBird-2 (EO).

This report details integration of TerraSAR-X into CSIAPS. TerraSAR-X provides higher resolution single polarization acquisition (up to 1 metre x 1 metre) and higher resolution dual-polarization acquisition (up to 2 metres x 2 metres) than any of the above SAR sensors. This report will briefly describe TerraSAR-X, outlining the more then 600 modes this sensor provides. It will describe integration of the TerraSAR-X sensor model into CSIAPS, and provide validation of the results using TerraSAR-X's own acquisition planning tool available at its website as well as using recently acquired data.

Le système de planification d'acquisition d'images de satellites commerciaux (SPAISC) a été mis au point par R & D pour la défense Canada (RDDC) – Ottawa comme outil d'aide à l'intention des gestionnaires de collections pour la planification de l'acquisition d'images de satellite. Son point fort est sa capacité à intégrer, dans un seul système, des modèles de capteurs de radar à synthèse d'ouverture (SAR) et de satellites électro-optique (EO), ce qui permet aux gestionnaires de collections de planifier l'acquisition d'images à partir de plusieurs capteurs en même temps, ce qui assure une comparaison des délais d'acquisition d'images et de couverture.

Le SPAISC dépend de la trousse d'outils satellites (STK) pour obtenir des modèles orbitaux de divers satellites. Jusqu'à maintenant, il a été configuré pour prendre en charge plusieurs SAR et satellites EO, dont RADARSAT-1, RADARSAT-2 et ENVISAT-ASAR (SAR), ainsi que IKONOS-2, OrbView-3 et QuickBird-2 (EO).

Le présent rapport décrit en détail l'intégration de TerraSAR-X au SPAISC. TerraSAR-X offre une acquisition à polarisation simple à résolution (jusqu'à 1 m x 1 m) et une acquisition à polarisation double à résolution (jusqu'à 2 m x 2 m), toutes deux supérieures à n'importe quel des capteurs SAR susmentionnés. Le présent rapport décrit brièvement TerraSAR-X en donnant un aperçu des modes offerts par ce capteur (plus de 600). Il décrit l'intégration du modèle de capteur de TerraSAR-X au SPAISC et assure la validation des résultats au moyen du propre outil de planification de l'acquisition de TerraSAR-X, disponible sur son site Web, ainsi que l'utilisation de données récemment acquises.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

TerraSAR-X, CSIAPS, STK, SAR

Defence R&D Canada

Canada's leader in Defence
and National Security
Science and Technology

R & D pour la défense Canada

Chef de file au Canada en matière
de science et de technologie pour
la défense et la sécurité nationale

DEFENCE R&D DÉFENSE

www.drdc-rddc.gc.ca