

Assisted Acquisition Planning for Maritime Surveillance with Commercial Satellite Imagery

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ABSTRACT

The Commercial Satellite Imagery Acquisition Planning System (CSIAPS) is a mission planning system under development by Defence R&D Canada – Ottawa (DRDC Ottawa). CSIAPS is intended to assist Collection Managers within operational centres with planning for the acquisition of Commercial Satellite Imagery (CSI). One aspect of CSIAPS is a guidance (expert system) component that uses pre-defined rules to recommend sensors that can be used to ensure that the acquired imagery will permit the Image Analyst (IA) to address the specific Request for Information (RFI). The first two expert system scenarios to be addressed within CSIAPS are Maritime Surveillance and Arctic Surveillance.

Within CSIAPS, the Maritime Surveillance scenario is divided into three categories: Shipping; Sea Ice; and Oil Spill. Within the Shipping category there are three items: Detection; Classification; and Heading and Speed Estimation. Within the Sea Ice category there are two items: Iceberg Detection; and Ice Type and Ice Edge Detection. Within the Oil Spill category there are two items: Detection; and Tracking. For each item there may be one or more details (parameters) that need to be defined. For each of these items, and with knowledge of the AOI size, rules have been defined that permit the system to make a recommendation for the most appropriate satellite and sensor mode.

CSIAPS was built with a custom Graphical User Interface (GUI) that invokes algorithms in the commercial software Satellite Tool Kit (STK) for access calculations, coverage analysis and visualisations. CSIAPS was developed using Python, an open-source object-oriented programming language. The display and manipulation of raster and vector data was developed using OpenEV, an open-source library of raster and vector classes. The expert system was developed using the open-source software C-Language Integrated Production System (CLIPS). The database system for the imagery archive was developed using the open-source software MySQL.

Keywords: Commercial satellite imagery, acquisition planning, CSIAPS, Satellite Tool Kit, RADARSAT, ENVISAT, expert system.

1 INTRODUCTION

The Collection Managers (CMs) within operational centres that make use of CSI to address intelligence, surveillance and reconnaissance (ISR) tasks are often faced with significant complexities in planning the acquisition of images to address a specific RFI. There are a large number of commercial satellites currently available, and many more that will be launched over the next several years. With each satellite there are one or more sensors – electro-optical (EO), infrared (IR) or synthetic aperture radar (SAR) – and the possibility that these sensors have multiple modes and imaging geometries. Considering the number and variety of CSI imaging sensors, the operational centres will benefit from assistance in selecting the optimal sensor and configuration for a given target, area of interest (AOI), and ISR scenario.

In most ISR scenarios, imagery needs to be acquired quickly and repeatedly; in some cases imagery may be required at discrete times throughout a specified date range. Because of the coverage cycles of space-borne

remote sensing platforms and the time required to plan out and uplink the acquisition schedule, it is usually not possible to acquire imagery on-demand from any given satellite at a specific point in time. As a result, CMs who are tasked with acquiring imagery must obtain the best-available imagery that meets the needs of their scenario. The complexities associated with this include: deciding which imaging sensors meet the needs of the scenario, and understanding the orbits from different satellites to determine which passes are closest to the required time window.

The CSIAPS is an acquisition planning system being developed by DRDC Ottawa that addresses the complexities within the satellite tasking and image acquisition process. CSIAPS is being built with a custom Graphical User Interface (GUI) that invokes algorithms in the commercial software STK [1] for access calculations and coverage analysis. CSIAPS also invokes STK for visualisations: STK facilitates the generation of realistic 3D animated visualizations of the coverage analysis and target acquisition by displaying ground- and space-based objects, orbit trajectories, and high-resolution imagery coupled with Digital Elevation Models (DEMs) and thematic vector information. Note that the analytical fidelity of STK has been independently validated and verified [2]. The CSIAPS GUI was developed using Python, an open-source, object-oriented programming language [3]. Display and manipulation of raster and vector data within the Map Viewer component was implemented using OpenEV, an open-source library of raster and vector classes [4]. The database system for the imagery archive was developed using the open-source software MySQL [5].

CSIAPS is composed of the following components:

- i. Sensor models (validated against actual data) for commercial satellites with EO and SAR imaging sensors;
- ii. A knowledgebase of pre-defined rules and an expert system component to advise the CM of the preferred sensor(s) and mode(s) for their specific scenario, so that the imagery acquired will permit the IA to respond to or address an RFI;
- iii. An orbit modeling component that provides nominal orbit paths for a selected list of platforms;
- iv. Orbit model correction that updates orbit paths based on the latest two-line elements (TLEs);
- v. A Map Viewer component that enables the CM to visualize a geographic region and draw their AOI, and that will display vector data in ESRI shape file format and raster imagery in a number of standard formats;
- vi. A coverage analysis component that calculates the imaging opportunities for the preferred sensor modes within the specified time window and AOI;
- vii. A conflict resolution component that calculates and visualizes conflicts between the potential imaging opportunities;
- viii. A visualization service that enables the CM to view a time-series of the platform movements during the time periods of selected imaging opportunities;
- ix. XML-based imagery acquisition plan (IAP) files that contain information from the CM regarding the time window and AOI, and information returned from the expert system, map viewer, coverage analysis and imaging opportunity selection component;
- x. A reporting service that produces both summary and detailed reports in HTML format; the summary report could be sent to a Satellite Imagery Vendor (*i.e.*, printed and sent by FAX or attached to an email);
- xi. An imagery archive that supports searching and retrieval of browse imagery, metadata and full image products; and
- xii. Context-sensitive on-line help.

Figures 1 and 2 provide screen captures of four of the CSIAPS windows. The Basic Properties window is used for date/time and area of interest specification. The Scenario Properties window is used for entry of information required by the expert system component. The Mission Selection window is used to select satellites, sensors and modes. It is illustrated here with the output of the expert system component (in green). The Acquisition Opportunities window is used to display the available opportunities, the conflicts between these opportunities, and the opportunities that have been scheduled.

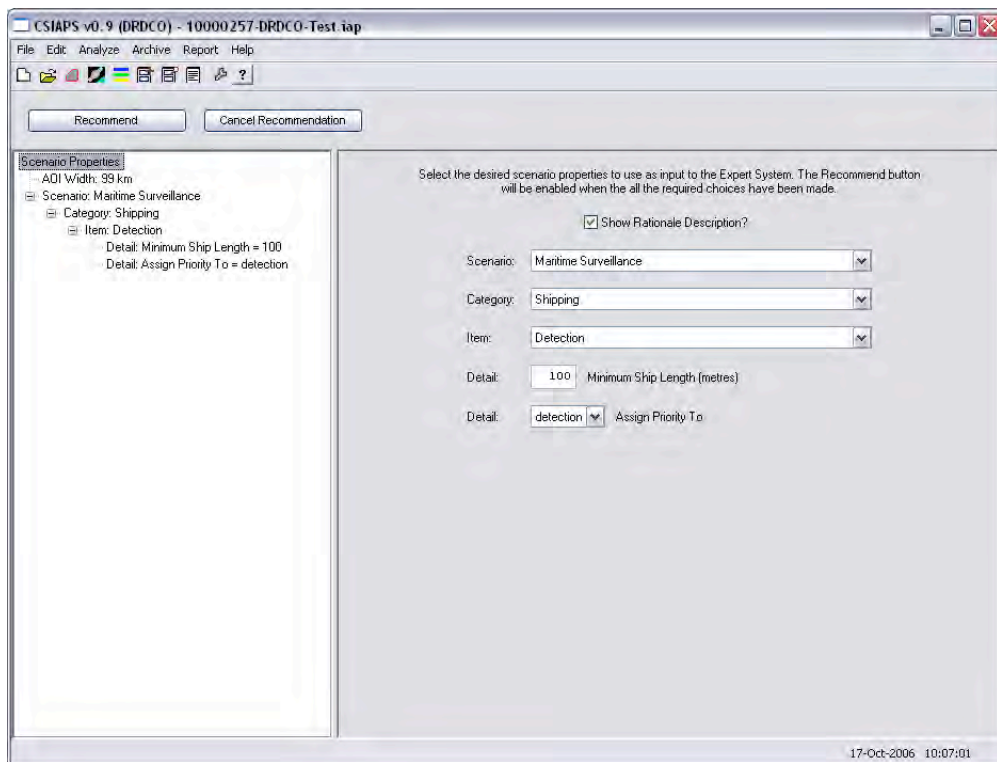
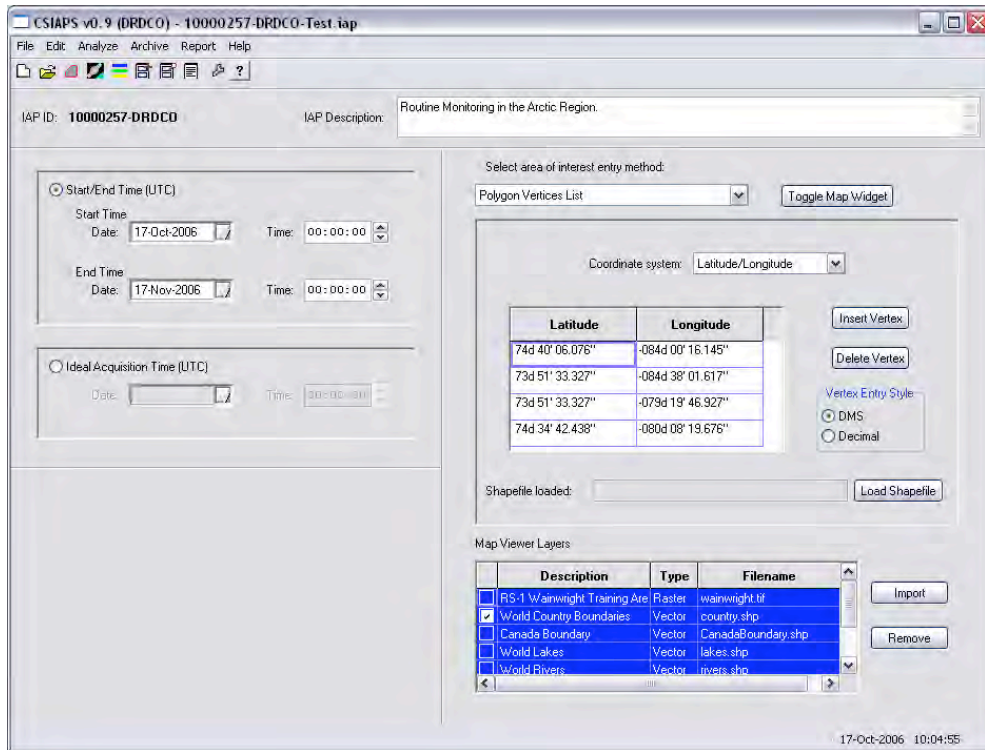


Figure 1. Screen captures of CSIAPS windows (top-to-bottom): Basic Properties; Scenario Properties.

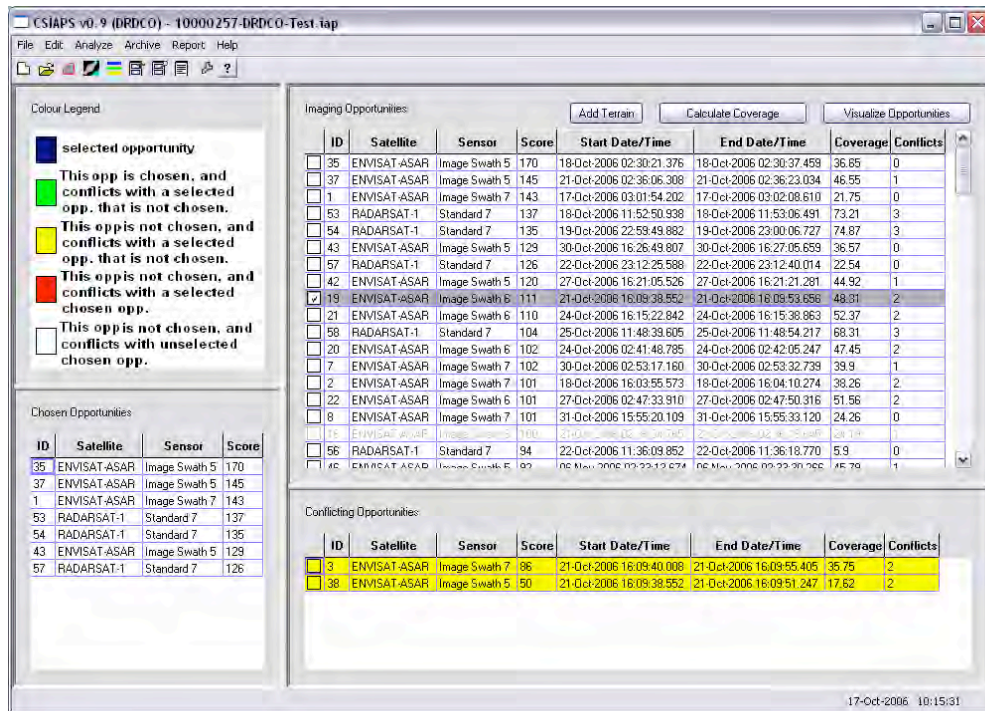
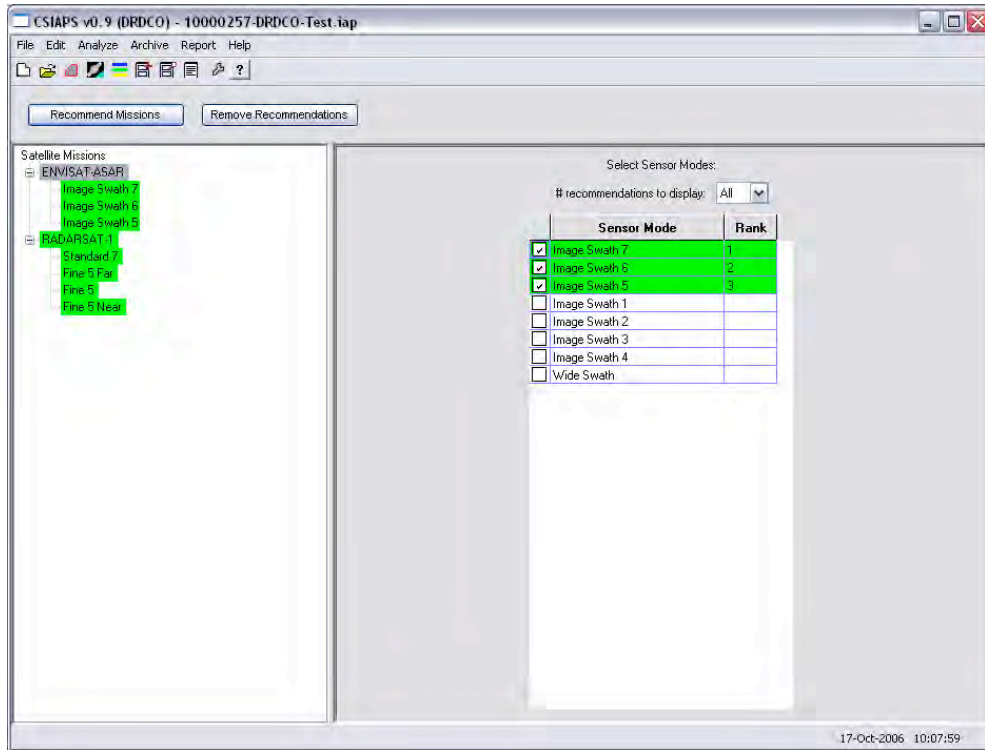


Figure 2. Screen captures of CSIAPS windows (top-to-bottom): Mission Selection; Acquisition Opportunities.

2 THE GUIDANCE COMPONENT

The guidance component of CSIAPS is an RFI-driven expert system that uses a predefined set of decisions (based upon the advice of subject matter experts) to recommend sensors to the CM for specific ISR scenarios (Figure 3). The expert system is implemented in CSIAPS as an optional component, and is especially useful for training and/or validation. Within the satellite and sensor selection (mission) GUI, the operator has the option to select the “Make Recommendation” button, which invokes the GUI for scenario selection and parameter entry required for the expert system. Once the required information is input, the operator may select the “Recommend” button which invokes the expert system. When invoked, the expert system component processes the input information (*i.e.*, category, item, details, AOI) and searches through the SAR and EO sensor beam modes and sensor parameters to determine which one(s) meet(s) the requirements (as defined by the rules); a ranked list is then returned to the CM. The recommended satellite(s) and sensor(s) are then highlighted in the mission selection GUI as a ranked list, and a pop-up window provides a justification for recommendation of the selected sensors. The results of the expert system component can be fed directly into the CSIAPS coverage analysis module, with the output being a list of opportunities for imaging the AOI with the recommended sensor(s) within the specified date and time period.

In its current state, the recommendations made by the expert system can include any of the modes available on the six commercial satellites that have so far been implemented within CSIAPS. The SAR satellites included in the expert system are: RADARSAT-1; ENVISAT; and RADARSAT-2. The latter is currently scheduled for launch in 2007. The high-resolution EO satellites included in the expert system are: IKONOS-2; QuickBird-2; and OrbView-3. The expert system accesses the sensor mode definitions by searching through a set of text files that list the characteristics for each sensor mode. For each mode of a SAR sensor, the following sensor properties are tabulated: mode name; mean incidence angle; resolution; swath width; and polarization. For each mode of an EO sensor, the following sensor properties are tabulated: mode name; number of bands; minimum and maximum off-nadir (across track) angles; resolution; and swath width. Other sensor properties could be added to these tables if new rules are defined that need them: dynamic range; number of looks; and noise floor are examples. Note that DRDC Ottawa plans to add additional sensors to the expert system.

The expert system component for CSIAPS has been developed using the C-Language Integrated Production System (CLIPS), an open-source tool developed by the Software Technology Branch at the National Aeronautics and Space Administration (NASA)/Lyndon B. Johnson Space Centre [6].

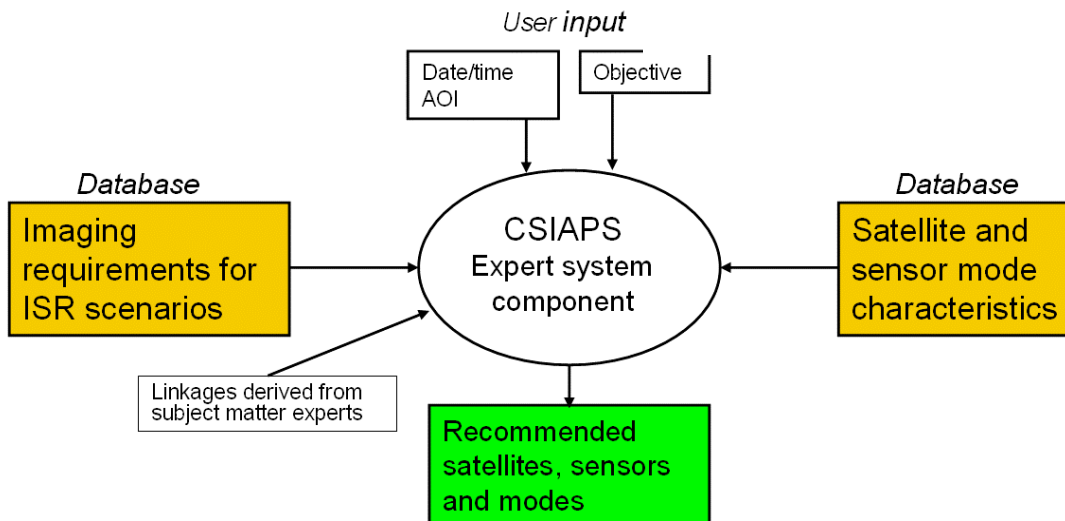


Figure 3. Functional block diagram of the Expert System component.

3 THE MARITIME SURVEILLANCE COMPONENT

The first scenarios to be implemented in the expert system are Maritime Surveillance and Arctic Surveillance. The Maritime Surveillance scenario is described in this paper.

Maritime surveillance is the systematic observation of ships and other vessels, activities, and the environment in a marine area of interest. Typical objects of interest in the maritime domain include ships, submarines, marine platforms and aircraft. Environmental parameters of interest include sea ice, icebergs, oil spills, weather phenomena, oceanographic phenomena, bottom topography and shoreline. Anthropogenic events of interest include fishing, resource exploration and exploitation, threats to sovereignty, pollution, and illegal activities such as drug smuggling, immigrant smuggling, and terrorism.

Within CSIAPS, the Maritime Surveillance scenario is divided into three categories: *Shipping*; *Sea Ice*; and *Oil Spill*. Within the *Shipping* category there are three items: Detection; Classification; and Heading and Speed Estimation. Within the *Sea Ice* category there are two items: Iceberg Detection; and Ice Type and Ice Edge Detection. Within the *Oil Spill* category there are two items: Detection; and Tracking. For each item there may be one or more details (parameters) that need to be defined. For each of these items, and with knowledge of the AOI size, rules have been defined that permit the system to make a recommendation for the most appropriate satellite and sensor mode. As an example, the Ship Detection item is described in Section 3.1.

3.1 Ship Detection

For the Detection item within the Shipping category, the expert system component of CSIAPS bases its recommendations on the following. In a SAR image, the ship/water interface and structure on board the ship results in strong backscatter of the incident radiation, thus ships appear as bright returns against a darker ocean background. Mature detection algorithms exist for ship detection with SAR imagery [7, 8], and SAR provides essentially all-weather and daylight-independent imaging. Thus the use of SAR imagery is recommended for the detection of ships in the open-ocean and littoral regions. An HH-polarized SAR beam mode is preferred: HH polarization is less sensitive than VV polarization to ocean roughness (short-scale waves), and HH polarization can yield a higher Peak-to-Clutter Ratio (PCR) for ships.

In addition to the above, the user should choose a beam mode that maximizes the SAR incidence angle. Ocean backscatter decreases with increasing incidence angle, while ship cross-section changes more slowly. Thus imaging of ships at a larger incidence angle can result in a higher PCR. For example, ship detection performance degrades for ScanSAR Wide towards the near edge as the incidence angle decreases. While wind speed and sea state is a risk factor – it increases the ocean clutter and therefore reduces the detection efficiency, *i.e.*, lower probability of detection (PD) and higher false alarm rate (FAR) – this risk factor does not change the recommendation for best SAR beam mode; it only acts to moderate the user's expectations.

The reasoning described above is derived from analysis of ship detection as a function of beam mode and incidence angle for RADARSAT-1, ERS and ENVISAT [7, 8]. Example results from this analysis (for the case of the wind blowing towards the radar) are illustrated in Figure 4. The ship detectability model contains validated, semi-empirical models for ocean clutter as a function of wind speed and ship cross section as a function of ship length [7]. The plot shows the minimum detectable ship length (m) as a function of incidence angle (deg). For this analysis, specific values were used for several parameters, including a wind speed of $U = 12$ m/s towards the sensor ($\phi = 0^\circ$); K -distributed clutter with an order parameter of $\nu = 4$; and a constant false alarm rate (CFAR) of 2.5×10^{-9} . The plot of Figure 4 is intended to be a compact intercomparison of various beam modes and radars and does not necessarily represent the absolute ship detection performance of a specific radar system. The plot shows how the size of the ship that can be detected improves (*i.e.* decreases) as the incidence angle increases for a given resolution (*i.e.* Standard or Fine beam modes). A higher value for the wind speed shifts the curves upwards (*i.e.*, more difficult to detect smaller ships), while a lower value for the wind speed shifts the curves downwards (*i.e.*, better able to detect smaller ships).

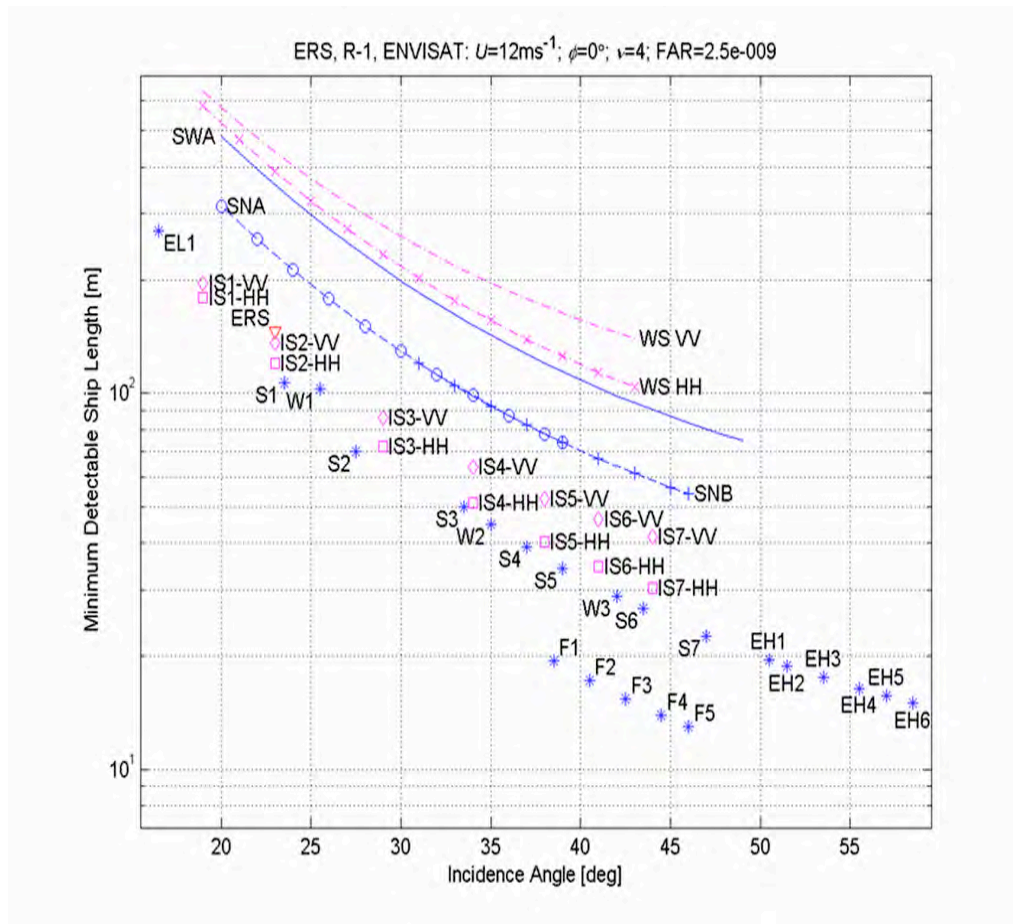


Figure 4. Analysis of ship detection as a function of beam mode and incidence angle, for the case of wind blowing towards the radar ($\phi = 0^\circ$).

4 USE CASES

This section provides a general description of how CSIAPS is used for planning and ordering CSI. The Collection Manager is referred to here as the user (*i.e.*, of CSIAPS).

1. The user receives the RFI directly or through the chain of command. The user reviews the RFI and extracts the AOI, relevant time period and reasons for image acquisition.
2. The user logs onto the CSIAPS workstation, that is, a computer running the Windows 2000 or XP operating system, with the CSIAPS and STK software installed and configured.
3. The user starts the CSIAPS program by double-clicking on the desktop icon.
4. The user chooses to open an existing IAP or create a new IAP. If a new IAP is to be created, the user is prompted for a short descriptive text string that is used (along with the CSIAPS site identifier and a unique number) to create a unique filename for the IAP.
5. On the *Basic Properties* pane of the main CSIAPS window, and with the *CSIAPS Map Viewer* window, the user:
 - a. Enters the start date and start time and the end date and end time;
 - b. Enters the AOI definition in one of three ways: (i) by using the type-in widget on the *Basic Properties* pane; (ii) graphically, by drawing the AOI in the *Map Viewer* window, or (iii) by using a pre-defined vector definition (an ESRI format shape file); and
 - c. Provides a descriptive text string for the IAP comment field.

6. On the *Mission Selection* pane, the user chooses one or more of the available satellites, and for each satellite the user chooses one or more sensors or modes. The user may optionally choose to have CSIAPS recommend the appropriate satellite and sensor combination(s) for a given ISR scenario. If the user selects this option, they must select a scenario, category and item from the *Make Recommendation* pane, and then click on the “Recommend” button.
7. On the *Imaging Opportunities* pane, the user selects “Calculate Coverage” to execute the coverage analysis and determine if and when the selected satellite/sensor combinations can image the AOI. On this CSIAPS pane, the user has options to:
 - a. Use Digital Terrain Elevation Data (DTED) in the coverage analysis, by specifying the path and file name after selecting “Add Terrain”;
 - b. Visualize each imaging opportunity, by either looking at the footprint for the opportunity in the *Map Viewer* window, or by selecting “Visualize Opportunity” and examining the acquisition geometry and coverage in a 2D or 3D simulation;
 - c. Determine if a selected opportunity conflicts with any of the other opportunities, and if so, choose one of the opportunities; and
 - d. Revisit the *Basic Properties* and/or *Mission Selection* panes to modify the date and time interval, the AOI and/or the satellite/sensor combinations that were selected, and then re-run the coverage analysis to generate a new list of opportunities.
8. On the *Imaging Opportunities* pane, the user then chooses the opportunities that are most suitable for the RFI.
9. Optionally, the user can choose to export the AOI information into the format required by satellite specific planning tools (*i.e.*, SPA for RADARSAT-1, APT for RADARSAT-2, DESCW for Landsat-5 and -7), and then use one or more of these planning tools to assist with the acquisition planning process for the corresponding satellite.
10. On the *Reporting* pane, the user selects “Generate a Summary Report” which contains the most important aspects of the mission plan extracted from the IAP file. There are options to print the Summary Report and to save the report to a file in HTML format. On the *Reporting* pane, the user may optionally select “Generate a Detailed Report”, which contains the majority of the information found within the IAP file.
11. In a future version of CSIAPS, it may be possible for Canadian Government users to (optionally) create an APT-compatible output file that could be used for ordering RADARSAT-2 data through the Canadian Government Order Desk (CGOD).
12. Note that executing an explicit File → Save command at each step in the above procedure is not required, as CSIAPS automatically saves the user input and CSIAPS-generated data to the IAP file.
13. On the *Archive Search* pane, the user may search the local imagery archive to determine whether suitable imagery is already available. If available, the user may retrieve these data from the archive.
14. The user may send the Summary Report to the appropriate Satellite Imagery Vendor (SIV), by FAX (for the hardcopy) or by email (for the HTML file).
15. The user may receive feedback from the SIV on several factors:
 - a. Are the satellite(s)/mode(s) available at the requested time(s)?;
 - b. Is there sufficient advanced notice so that the required lead time can be met?;
 - c. The cost of the imagery;
 - d. The time after acquisition required to deliver the imagery; and
 - e. Iterative interaction with the SIV, using CSIAPS as required, until convergence to an acceptable acquisition plan with the SIV.
16. For the case of RADARSAT-1/2 data, the Canadian Government user may order the data through the CGOD.

17. The user may receive the imagery data from the SIV or for the Canadian Government user from the CGOD.
18. On the *Archive Add* pane, the user may add these data to the CSIAPS imagery archive. Optionally, the user may populate the metadata fields by selecting the “Automatic Metadata Extractor”.
19. The context sensitive on-line help is available to the user at all times.

5 DISCUSSION

CSIAPS provides the CM with a single, integrated planning system for the acquisition of SAR and EO imagery from commercial satellites. Future enhancements may include: the addition of sensor models for a wider range of existing satellites and for future satellites; the inclusion of a weather/climate component and the addition of rules that consider these inputs; and the addition of new expert system scenarios relevant to operational users.

5 REFERENCES

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