Sprint Advanced Concept Training (SACT): A renaissance in collaborative international space operations

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ABSTRACT

A new international exercise series, the *Commercial Sprint Advanced Concept Training (SACT),* was established in 2019 to advance joint space operations. The Commercial SACT evolved from early collaborations with the United States Space Command (USSPACECOM), Department of Commerce (DoC) and US Air Force (USAF) to explore the potential of commercial companies augmenting traditional Space Domain Awareness (SDA) and civil Space Traffic Management (STM). The SACT team recognized substantive SDA capabilities existed in pockets of commercial services and believed that providing an environment to coalesce and experiment with these in real-world events may accelerate the state-of-the-art. Since then, the SACT commercial experiments have quickly grown to include multiple international partners in the Americas, Europe, and Pacific continents. Conducted three times a year, the week-long space operations event series includes a broad mix of commercial, government, and academic participants coalescing to execute multiple day cycles. Each cycle is crafted to measure and mature an array of space operations 'desired learning objectives' (DLOs) using real-world end-to-end operational systems. The DLOs are designed by representative sponsoring agencies, including USSPACECOM and DoC, to understand where the true commercial capacity in space surveillance stands with respect to operational SSA and STM needs. Example DLO categories include: Search and Recovery (SAR), Closely Spaced Object (CSO) discrimination, satellite characterization, high-cadence surveillance, conjunction assessment, Rendezvous and Proximity Operations (RPO) analysis, and many others. As an unclassified event, the Commercial SACT draws from across the international spectrum, including some of the latest commercial space operations technologies around the globe. During the last SACT, the exercise series had representation from multiple foreign partners across more than 40 commercial companies, seven universities, and 25 government agencies. Operational control seamlessly transitioned from Australia, to Europe, to the United States in rotating shifts. The event exercised full spectrum SDA processing including: multi-phenomenology surveillance; advanced orbit determination; command and control (C2); dynamic tasking; image processing; public source; artificial intelligence (AI) supported pattern of life (PoL) analysis; anomaly detection; and others. The SACT benefit all stakeholders, especially the surveillance and commercial system developers. The SACT offers a rare opportunity for government and commercial participants to learn from real-world situation and the understand needs of its customers through all space surveillance regimes including Low Earth Orbit (LEO), Medium Earth Orbit (MEO), Geostationary Earth Orbit (GEO), and Cislunar. For example, as a Canadian start-up company develops its constellation of space-based optical sensors, the company is learning from the SACT and able to tailor product development to better meet market needs. One of the elements that make the SACT so challenging is the heavy emphasis on performing real-world operations in real-time. This paper conveys how the SACT exercise series is serving as an '*innovation and collaboration testbed*' for advancing all aspects of space operations and how it has become a foundational element of advancing civil-space traffic management through a renaissance (or revival and renewed interest in) of international collaboration.

INTRODUCTION / BACKGROUND

In 2019, a new international experimentation series evolved called the "*Commercial Sprint Advanced Concept Training (SACT)*", it serves as an '*innovation and collaboration testbed*' for advancing all aspects of Space Operations. Although the United States military version of SACT has existed for many years, the new *Commercial-focused* element of the SACT was established to demonstrate how today's rapidly maturing commercial space operations services are advancing to augment both military and civil space organizations. SACT events are unique compared to many other unclassified space operations exercises in that they are expressly focused on '*real-time and real-world operations*', emphasizing collaboration throughout a world-wide commercial surveillance network. Commercial participants are presented with limited information leading up to the start of a 24-hour exercise window and challenged to cooperatively execute a broad series of Space Traffic Management (STM) and Space Custody missions under the direction of centralized operations cells. Each mission is designed around specific 'desired learning objectives' (DLOs) that have been nominated by representatives from a military or civilian agency, such as the Department of Commerce (DoC), US Space Command (USSPACECOM), US Air Force (USAF), and others. DLO categories include: Search and Recovery (SAR); Closely Spaced Object (CSO) discrimination; satellite characterization; high-cadence surveillance; conjunction assessment; Rendezvous and Proximity Operations (RPO) analysis; and several others. As an unclassified event, the Commercial SACT draws from across the international spectrum of latest commercial space operations technologies in: surveillance; orbit determination; command and control (C2); image processing; public source analysis; artificial intelligence (AI) supported pattern of life (PoL) analysis; anomaly detection; and other emergent developments.

Each SACT is composed of dozens of real-world operational experiments tailored to stress test various DLOs. In one CSO mission, the Aerospace Corporation AeroCube (AC-10) 1.5U Cubesat satellite staged an atmospheric probe deployment *during* the 2020 event, providing teams a challenging real-world target to assess whether commercial systems could: detect the separation; track the satellites in close proximity; and properly correlate two nearly identical systems throughout the event. Another example of a common DLO in the SACT is injecting surprise 'wide area search' requests of the geosynchronous equatorial orbit (GEO) belt to test how rapidly teams can identify maneuvers, resolve uncorrelated tracks (UCT), or spot anomalies. These examples demonstrate how commercial teams can work together across multiple sensor phenomenologies (e.g., radar, passive radio frequency [RF], electro-optical) to address real-time, real-world mission operations objectives. The adoption of the Unified Data Library (UDL) provided dozens of companies a method to dynamically share information through a real-time machine-to-machine (M2M) interface.

To date there have been five Commercial SACT events, occurring three times in 2019 and in twice in 2020. The initial event in 2019 was exclusively focused on servicing the USSPACECOM and consisted of eight commercial companies. Each subsequent event has gained in momentum/size. The cap-stone event in late 2019 was co-sponsored by both the USSPACECOM and DoC's Office of Space Commerce and included participation from 40 commercial companies, seven universities, and more than 22 government and/or federal institutions. The cumulative surveillance network supporting the Commercial SACT is one of the largest commercial space surveillance network ever assembled, demonstrating the ability of coalescing and fusing millions of observations per day (e.g., active radar, passive RF, optical telescopes) across several hundred geographically distributed surveillance sites.

Table 1 shows the diversity of the participants in the SACT experiment series across the variety of stakeholder communities in Space Domain Awareness (SDA) and civil space.

Table 1- SACT Participants List as of April 2020

20-2 Participants & Observers

- **Commercial**
  - AGI
  - A.I. Solutions
  - Asia Pacific Aero Consultants (AUS)
  - AstroLabs
  - ATA
  - Atlas Space Ops
  - Bluestaq
  - Braxton Technologies
  - Centauri (PDS, TDKC)
  - CS Group (FRA)
  - DF&NN
  - EOS (AUS)
  - Eutelsat
  - ExoAnalytic
  - IBM
  - Inmarsat
  - Iridium
  - Kayhan Space
  - L3Harris/ADS
  - LeoLabs
  - Lockheed Martin
  - Maxar
  - Node Centric
  - NORSS (GBR)
  - Northrop
  - Northstar (CAN
  - Numerica
  - PatchPlus
  - Planet
  - Polaris Alpha
  - Raytheon
  - RedSpace
  - RINCON
  - RT Logic / Kratos
  - Saber Astro (AUS, USA)
  - SAFRAN/Zodiac (FRA)
  - Seradata (GBR)
  - Slingshot Aerospace
  - SpaceX
  - Spire
  - SSC
  - Stottler/Henke
  - Tech7
  - Thoth-X (CAN)
  - Vigilant
- **Academia**
  - CU - Boulder ROTC (UCCS, Mines, etc.)
  - Embry Riddle Aeronautical University
  - New Mexico Tech
  - The Ohio State University
  - United States Air Force Academy
  - University of New South Wales/ADFA (AUS)
  - University of North Dakota
  - Virginia Polytechnic Institute & State Univ.
- **Allied Govt & Military***
  - Air Force HQ Australia
  - Australian Space Agency (AUS)
  - DRDC (CAN)
  - DST (AUS)
  - DSTL (GBR)
  - EU SST (EU)
  - French Space Command (FRA)
  - French Space Agency (FRA)
  - Japan Air Self-Defense Force (JPN)
  - New Zealand Space Agency (NZL)
  - Phantom Echoes TTCP (FVEY)
  - UAE Space Agency (UAE)
  - UKSPOC (GBR)
- **US Govt* & FFRDC**
  - Aerospace Corporation
  - US Air Force
  - US Space Command (USSPACECOM)
  - CSpOC, CIC
  - Dept of Commerce (DoC)
  - FFRDC/UARCs (JHUAPL, MITLL, MITRE)
  - NASA
  - NSDC
  - SMC
  - SSDP
  - USSF

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The Commercial SACT exercises provide opportunities to test innovative concepts and rehearse in real-world events. One innovation example includes exploring methods to reduce the cost and complexity of manning a 24-hour space operations center by establishing distributed Command & Control (C2) centers in key geographic locations around the world, letting the local crews work standard 8-hour shifts (referred to as “chasing the sun”), and innovating on the technologies that facilitate smooth transitions between rotations. During one event, the SACT explored the use of Virtual Reality (VR) three dimensional (3D)-immersive environment technology to allow Mission Directors (MD) Pacific Cell to pass situational awareness task reports to their counterparts in the Meridian Cell. In turn, this same method was used to transition from the Meridian Cell to the main Americas Cell. Other innovative technology concepts included: fusing satellite insurance data to support analysis, utilizing particle manifolds to represent satellite search and recovery zones, and developing Notice to Space Operator (NOTSO) messages that are analogies to air domain equivalent Notice to Airmen and Mariners (NOTAM) produced by the Federal Administration Agency (FAA).

SACT coalesces tool sets from dozens of vendors encompassing every facet of the traditional space operations Tasking, Collection, Processing, Exploitation and Dissemination (TCPED) cycle. Fig. 1 illustrates a sampling of products and artifacts utilized for RPO, maneuver detection, and characterization.

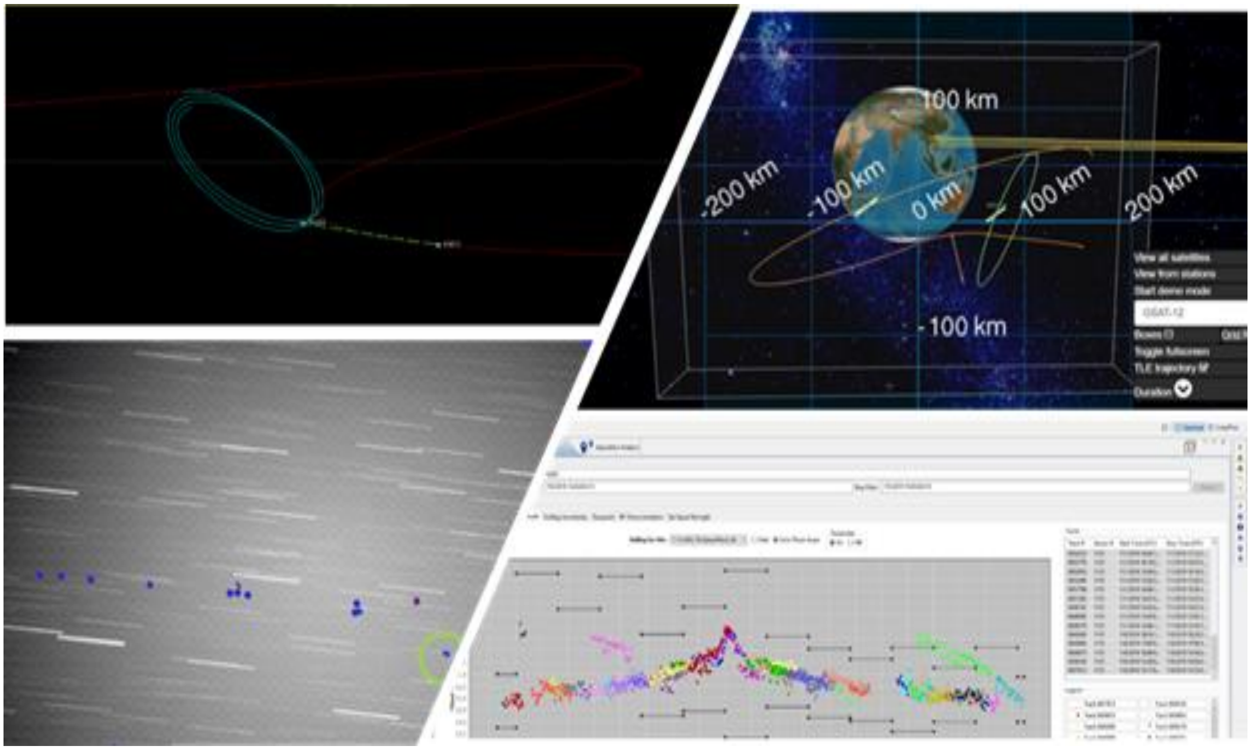

Fig. 1 - SACT Analysis Snapshot

This technical paper, written from the perspective of several of the operations crew (representatives from the five major participating countries), details some of the findings and results throughout the SACT, focusing on several commercial systems' performance against select DLOs during the two days of active operations. It provides numerical analysis results illustrating commercial situational awareness services. The paper covers innovations in:

- Transitioning space operations control across multiple continents
- Applying advanced software and visualizations
- Coalescing hundreds of remote world-wide distributed surveillance systems
- Integrating public research data as an integral element of mission operations
- Using 'sim-over-live' data injects during real-world space operations experiments
- Using active data curation to understand and improve applications of space data

The examples in this paper aim to: demonstrate the value in *international commercial collaboration to conduct civil STM*; describe foundational technologies that are rapidly maturing to enable continuous 24-hour space operations through geographically distributed operations centers; and convey how the Commercial SACT exercises are helping to lay a foundational model that could serve as an effective blueprint for a *future international space collaboration renaissance,* accelerating establishment of a true commercial STM capability.

OPERATIONAL CONTROL ROTATION ACROSS THREE CONTINENTS

The Commercial SACT embraces international collaboration as a foundational tenet of the operations. This is motivated by the assumption/assertion that safe STM is an international concern and many international partners have significant surveillance equities that could positively contribute to maintaining safety of flight and augment civil operations. The Commercial SACT looks to include other friendly government and commercial entities in the effort as co-sponsors and leaders of the event. One innovative element of the SACT is the distribution and transition of Space Operations Centers (SOC) to geographic locations to locations around that world that would support three contiguous normal 8-hour shifts.

Fig. 2 illustrates the shift rotations utilized for the 2019 SACT. Rotations began at Pacific location, then rotated in sequence to the European/Meridian facility, then to the US Civil Commercial Operations Center.

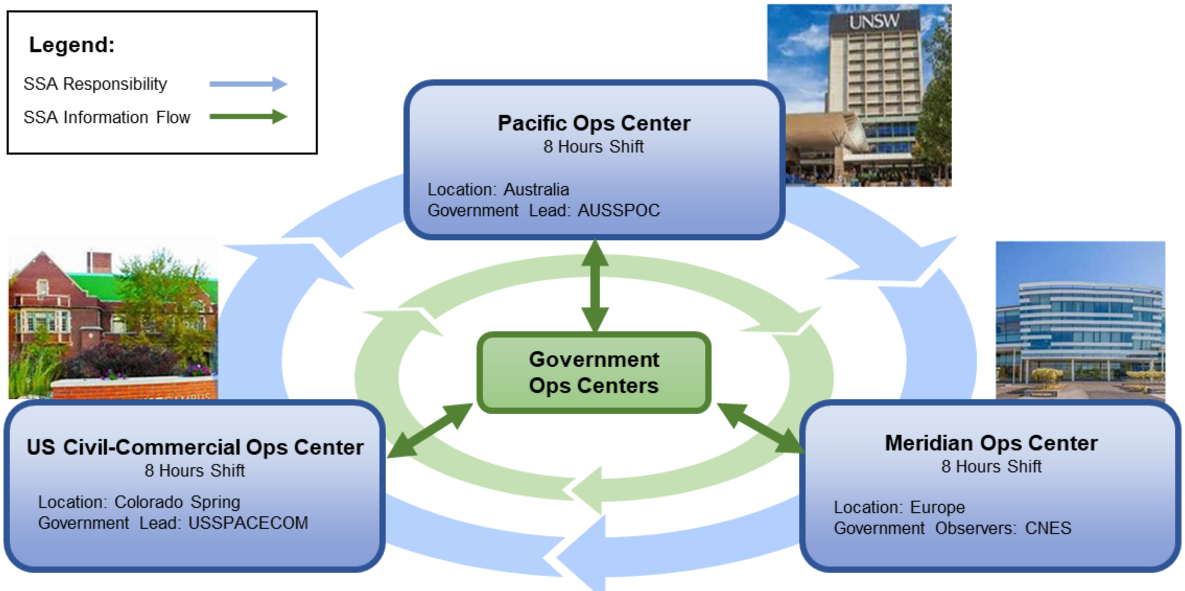

Fig. 2- Multiple Global Centers Integration Cycle

The benefits of this approach include:

- Reducing operations costs because only one staffing team is required per location; in contrast to the typical 5-team configurations for single location's 24/7 operations
- Accommodating analysts by removing mid-shifts throughout the night
- Distributing civil space responsibilities to a multinational team

One of the side-effects of running a single operations cell over a full 24-hour period, divided into shifts, is the inherent inconsistency of crew quality composition throughout the day. Although there are exceptions to the rule, typically the 'Day' staff in an operations center (i.e., those crew taking the premium day shift slots) will have the highest concentration and be more highly trained. The SACT model improves on this as each crew rotation only occurs during normal work hours and will therefore likely attract the highest qualified candidates to operate during these rotations.

A key element/challenge of this model is the operational 'hand-off' that occurs during the regional transition. The SACT extensively leverages experienced space operations subject matter experts (SMEs) to develop procedures and 'Job Aids' to methodically and efficiently work through geographically separate transitions. Through the USAF software development teams, the Commercial SACT are developing collaboration tools. Examples include web-portal Mission Management Tasking Boards (MMTB) and Surveillance Tasking Boards (STB) that enable the Site Lead, Mission Directors, SDA Leads, and all other respective sensor or domain phenomenology teams to pass assignments and reports off to one another throughout the operations period.

The Pacific Operations Center was established through repurposing a facility at a local University. The site brought together commercial providers from all over the world, with each company providing data and analysis. The collaborative environment enabled close interaction between the commercial providers, site leads, and observers from academia and defense (Fig. 3).

Fig. 3- Pacific Cell

Additionally, the university participants (faculty/students) gained deep insight into the operational cadence, analysis, and products that enable real-time SDA. This hands-on experience inspiring developments in data collection and processing that will feed into future SACT events. An important outcome from the event was the realization that a remote/distributed operations model offers improved scope for Pacific participation, owing to the distribution of sensors and SDA capability across Australia's large landmass. Foreshadowing the restrictions placed on the April 2020 event (SACT 20-1) due to COVID-19, participants faced logistical challenges travelling to/from the site due to environmental challenges and transportation delays.

Fig. 4 shows some of the Meridian (European) cell's operations and team composition at the Meridian/European site.

Fig. 4 - Meridian (European) Cell

Similar operations were conducted in the America's cell in the United States. As the largest of the SACT cells, the America's team was split into several conference rooms to accommodate the commercial teams represented.

Observations from government agencies included the USSPACECOM, DoC, and National Aeronautics and Space Administration (NASA) teams.

Fig. 5 – Americas Cell

Significant contributions are made during each SACT cycle by the USAF software development team. The US Air Force team employed Agile software program practices in advancing collaboration tools that facilitate the mission operations across the spectrum of space operations support. The concentration of real-world STM-related events over the two-day SACT experiment, as well as fast recurring pace of the SACT experiment cycle, provides a unique opportunity to rapidly advance on procedural efficiency in the 24/7 global event. Challenges executing DLOs are quickly identified due to the fast-paced operational tempo. Commercial SACT acts as a experimentation lab to rapidly identify what works and what should be improved. These DLO challenges provide each of the commercial and academic teams a set of objectives to improve upon for the next SACT cycle.

The geographically dispersed and rotating C2 control center model of the commercial SACT high-lighted the need for improved methods of tracking and conveying specific mission elements. The first SACT utilized white-boards and sticky notes. Critical mission operations information was lost as much of the data were lost during hand-over from one region to another since the white boards could not effectively be shared. This drove subsequent commercial SACT to innovate and develop sharable collaborations boards for the teams. Fig. 6 illustrates the Mission Management Board (MMB). The MMB is just one example of previous DLO challenges that manifest into improved products over each cycle. The MMB maintains status on active and recently closed mission objectives. Each tracked element includes class of event, satellites involved, priority, risk assessment, orbit regime, required follow-up actions and other pertinent information. The MMB is available to all SACT participants and observers so that the mission objective status may be effectively conveyed throughout all teams.

Mission Management Board

Who has the ball? AMERICAS | Automatic Refresh | Hide Columns

ID	Class Event	NOTSO	Status	Time Message ...	Priority	SatId(s)	Sat Com...	Orbit Regime	Event Description	Possible Impact	Follow-up Assessm...	PSRA Asses
c1	Simulated Break up event	2020_06_23_03b	Open	23/1845ZJUN20	1	38740	INTELSA...	DS	Initial notification Simulated break up event of OBJ 38740 INTELSAT 20	conduct SoF analysis of UCT pieces clear for object conjunction	SAFRAN - Last Passive RF collect at 11:57.29 UCT Target of close approach: 41747 (IntelSat 36) • Time of close approach: 2020-06-24T17:59:27.012Z Piece: 90023	23/1845ZJU https://www.s norad=3874 Satbeams - your fingertip footprin
41	Safety of Flight		Closed	23/1758ZJUN20	1.5	44909	DOSAAF-85/RS-44	NE	Community notification of unstable OBJ OBJ is roported as unstable as of 15 APR no predicted conjunctions w/in the next 7 days. Continue to monitor for SoF Priority 1. Human Space flight 2. Payload 3. deb potentially causing additional deb	Confirm stability, Orbit Health & SOF		23/1758ZJU DOSAAF-85/RS44/449 intentionally operational/ https://space 85.htm
d2	Manuever Detection		Open	23/1851ZJUN20	2	43450	APSTAR 6C	DS	Manuever detected on APSTAR 6C, Pattern of life, Combo run; Cued Search 123-140E During last ops day, 9 June, APSTAR 6C had some potential maneuvers....is it in a stable orbit now and is it emitting? Is it in close proximity to any US satellites? Multi-phenomenology verification (Optical and passive RF) establish Safety of flight for surrounding objects		POCA 55k o/a 24/0818zJUN20	23/1851ZJU daniel.huffma https://www.s norad=4345 Satbeams - your fingertip footprints, ne https://www.r
75	manuever detection	2020_6_23_2	Open	23/1654ZJUN20	1.5	45611, 45612	XJS - G, XJS-H	NE	U.S. military tracking data indicated the Long March 11 launch Friday released its two satellite payloads in an orbit roughly 300 miles (480 kilometers) above Earth, with an inclination of 35 degrees to the	Verify stability , Relative Orbit Visualization and data fusion	Indications are that OBJs are slowly drifting apart. Continuing to monitor	

Fig. 6 - Mission Management Board for SACT collaboration, facilitating shift rotation across continents

ADVANCED ANALYSIS AND VISUALIZATION TOOLS

A common challenge in space operations is the contextualization and visualization of data, especially presenting it in three-dimensional (3D) domain. The SACT experiment series benefits from incorporating of dozens of custom tools that have been developed to address this unique Space Battle Management Command Control (BMC2) trade space. Additionally, the success of the SACT in attracting numerous sensor providers has resulted in abundant space situational awareness information that must be collated and analyzed prior to any meaningful decision making. The SACT exposes operators to multiple perspectives of situations (i.e., each commercial vendor may have a different perception of when an individual satellite maneuvered); this further increases the complexity of visualization applications. Simple examples question includes: "How will visualization tool decide to convey the location of a single GEO satellite? How are LEO and GEO regimes handled? How are RPO and CSO perspectives handled with respect to useful reference frames?

SACT allows operators to find new and innovative answers to these and other questions; it provides an excellent opportunity to experiment with a wide variety of available commercial tools under real-world operational conditions. Through the SACT, the space community can experiment with a wide variety of space BMC2 tools being run on the same real-world data side-by-side.

The following subsections present a variety of BMC2 applications commonly used in the SACT and highlight notable features of these systems.

Fig. 7 illustrates SDCCS, a multi-functional space BMC2 system utilizing glyphs, operator customizable dashboard layouts, multiple RPO perspective views, custom alert triggers, and broad source data imports.

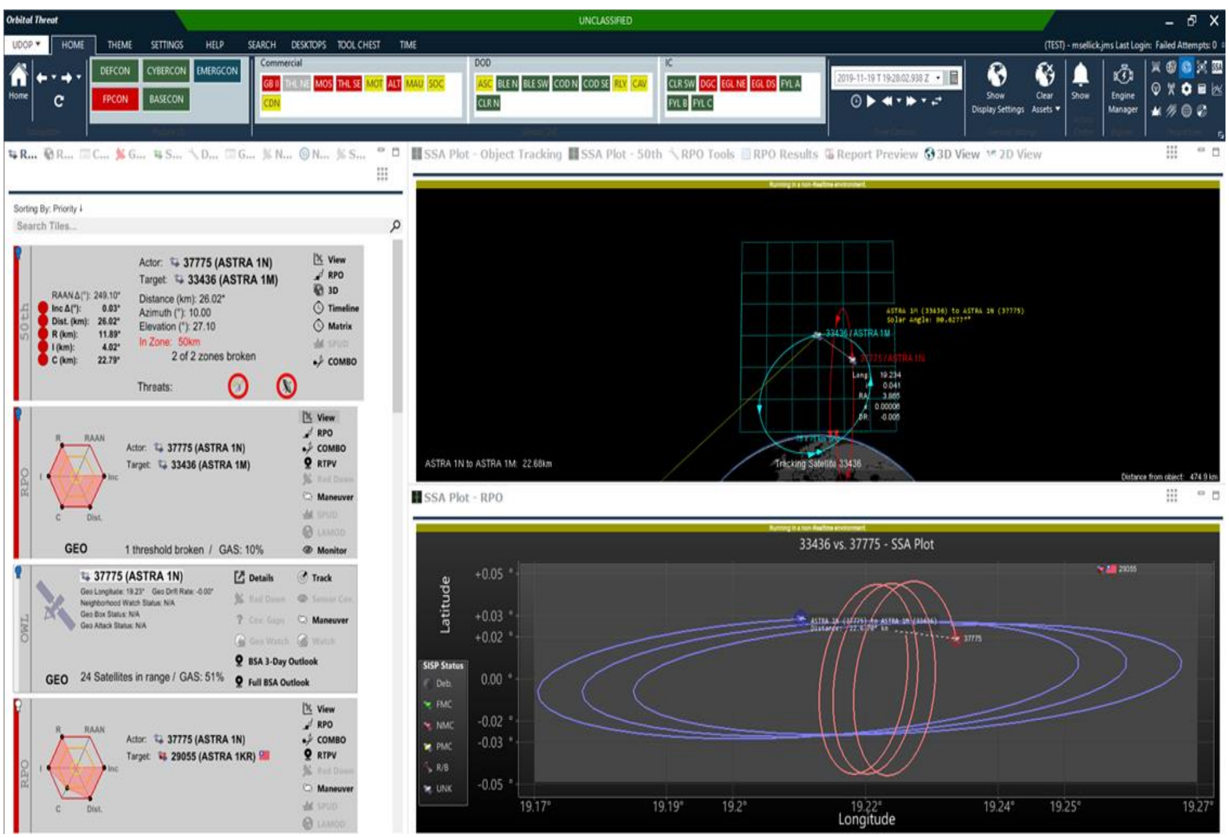

Fig. 7 - Centauri SDCCS RPO assessment tools with RPO orbit plane matching glyphs

Fig. 8 illustrates intuitive user interface controls, display of mouse-over data cards for measurement observations, and dynamic status boards. It includes options for Virtual Reality (VR) headsets allowing multiple participants to join a single group session with projected operator avatars.

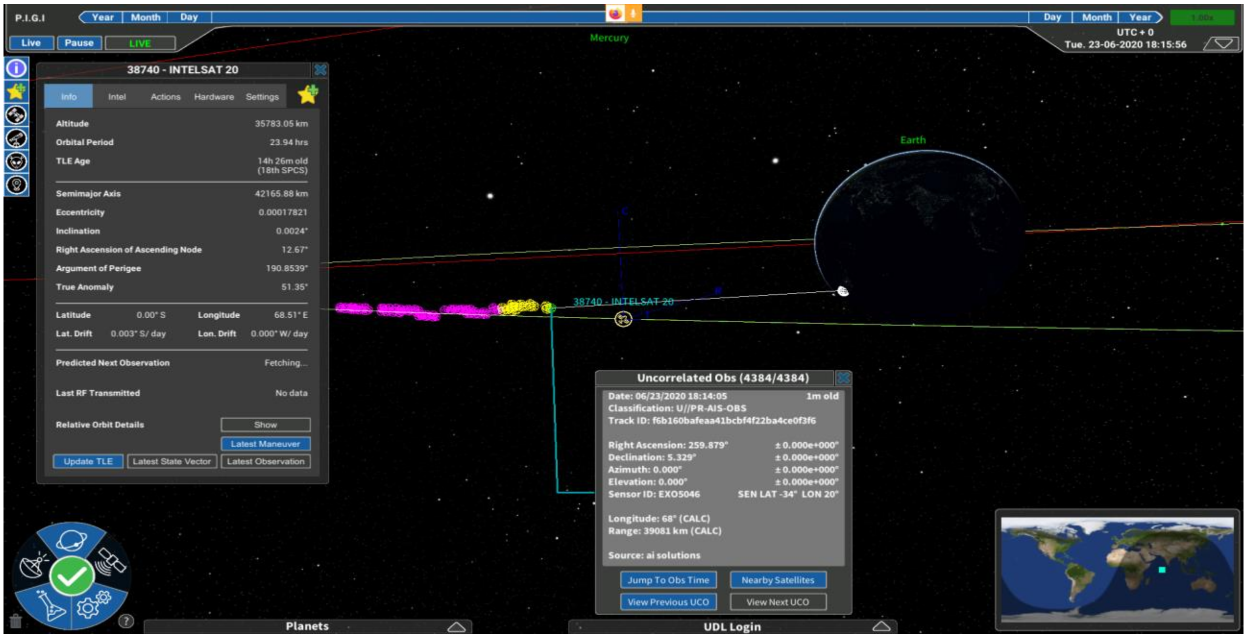

Fig. 8 – Virtual Reality User Interface Controls

Fig. 9 illustrates tool that automatically triggers operations to potential maneuvers when profiled orbit state parameters begin to trend outside of nominal.

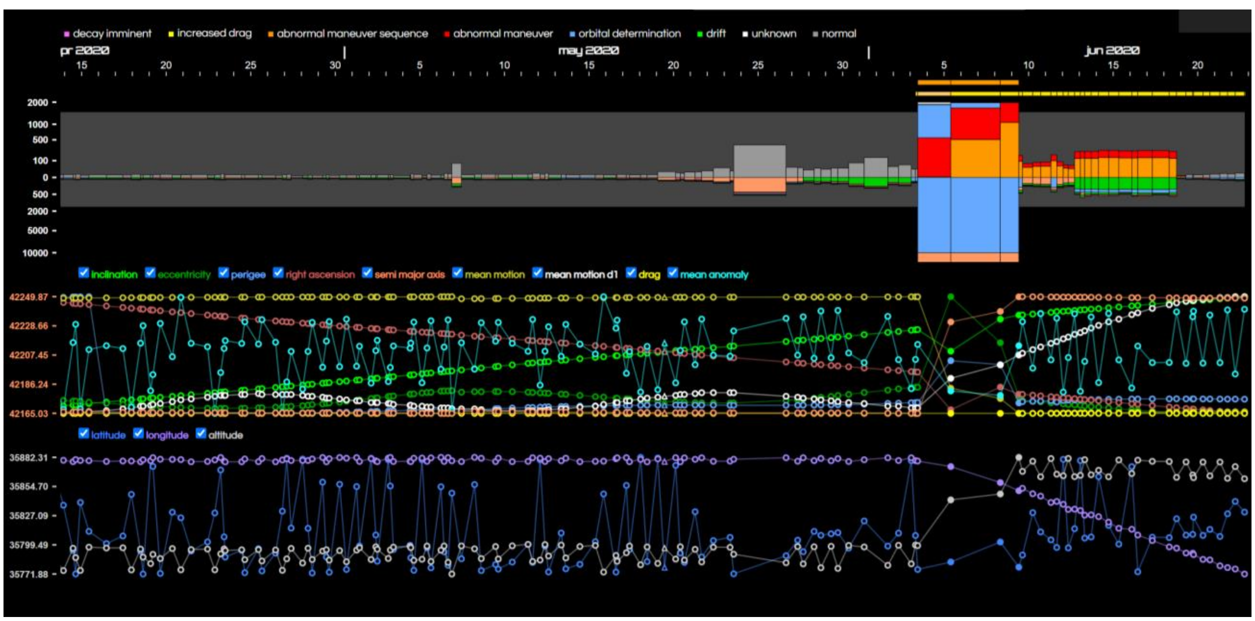

Fig. 9 – Detecting potential maneuver

Fig. 10 illustrates a web-portal visualizing the orbits of two SES satellites with superimposed proximity grids (blue) and nominal operations boxes (grey). Orbit information derived from Passive RF analysis is used to maintain a high cadence of revisit on tracked objects in GEO; routinely updating every 12 to 22 minutes.

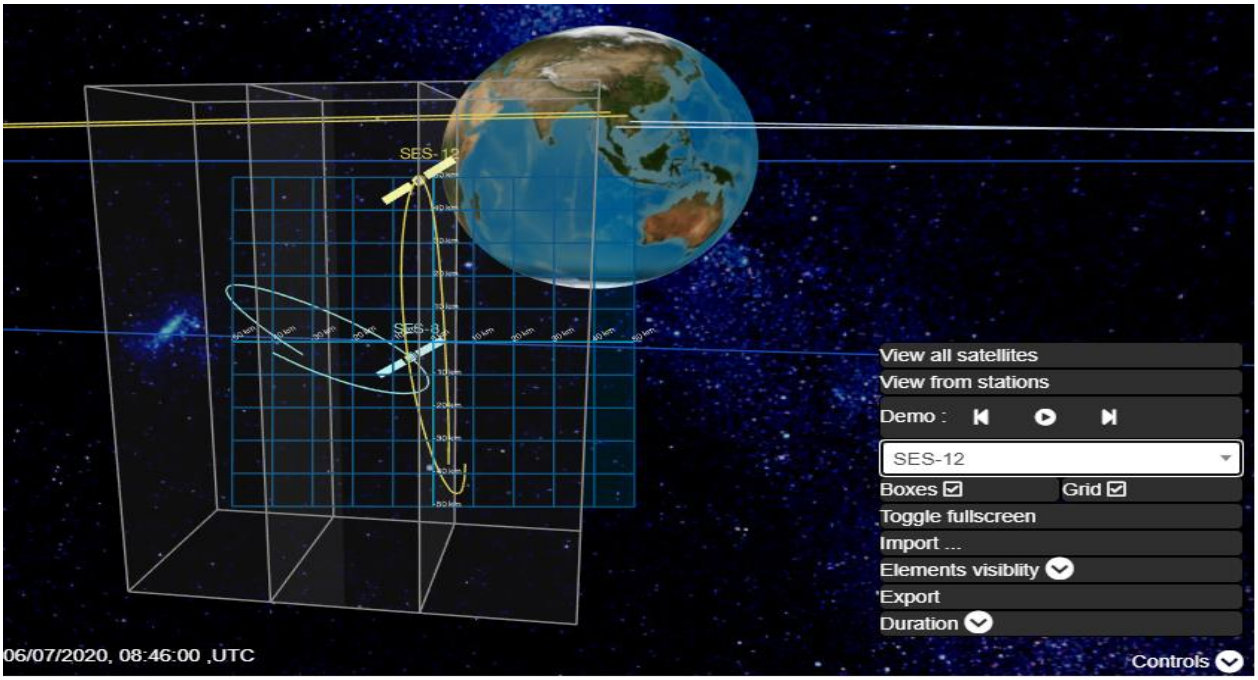

Fig. 10 - Displaying closely space GEO in nominal control PoL boxes

Fig. 11 illustrates a BMC2 tool, showing an overview of high interest objects in GEO with associated country code flags. In the left panel, multiple control sectors are defined with summary counts of how many tracked objects in each cell are considered in high drift/moving.

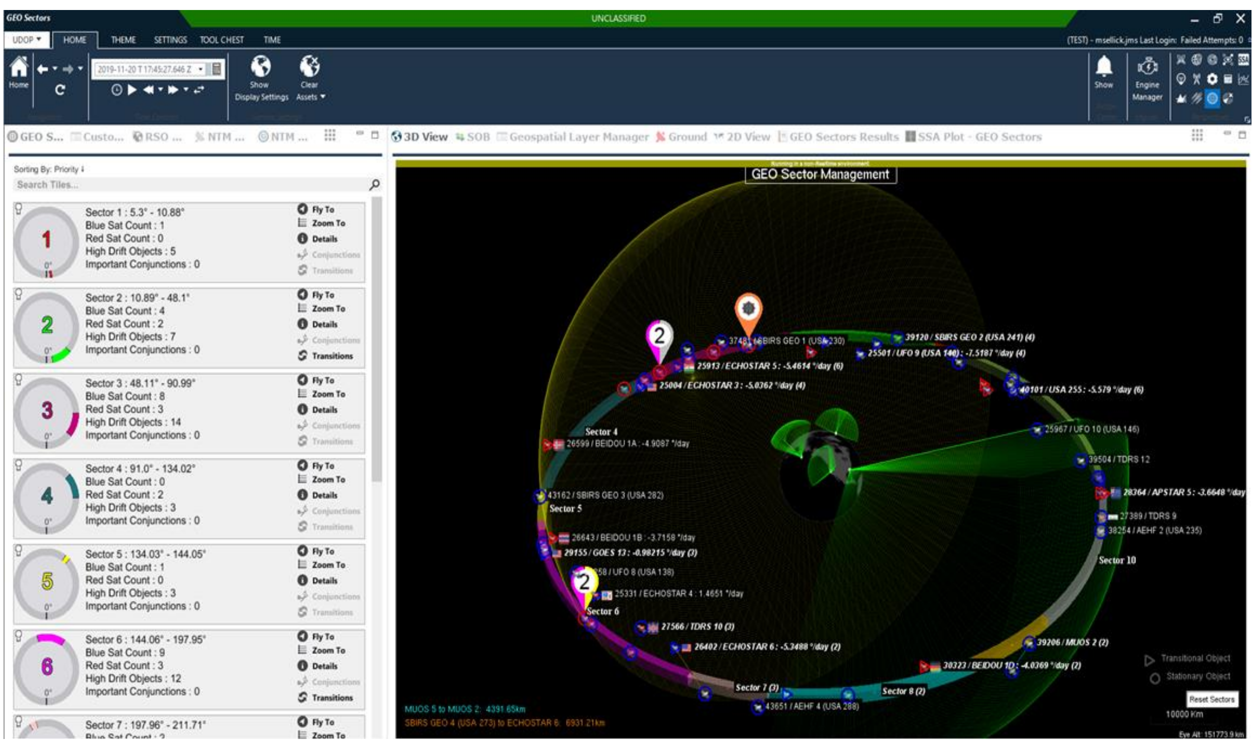

Fig. 11 – Graphical UI providing GEO-belt overview graphics with embedded country code flags

The SACT is also a venue for experimenting with state-of-the-art technology in distributed collaboration, such as Augmented Reality (AR) and VR. These technologies have the potential to further improve efficient central operations handovers between regions. Traditionally, when operations control handovers occur, Site Leads use communications or screen share to pass pertinent information over from one cell to another. In the last 2019 SACT, the team utilized their space cockpit VR to explore more immersive methods. Through the use of VR, it enabled Site Leads from different regions (i.e. Australia to Europe) to join in a single VR room to review specific mission sets. In the VR room, the leading Site Lead was able to display the recent 'Sim-Over-Live' breakup scenario and convey their current situational awareness of the event. Each of the leads in the scenario was able to "see" each other within the headsets as avatars. In the VR environment the two leads could talk to one another face-to-face, manipulate the graphics, see one another moving and talking within the vignette, and review key timeline elements with specific satellite anomaly events. Fig. 12 shows Pacific site lead (left) briefing Meridian Observers (right) for a breakup alert NOTSOs during a SACT shift changeover. These types of experiments are examples of how the SACT attempts to push the boundaries in collaborative international space operations.

Fig. 12 - Virtual Reality (VR) connecting Pacific and Meridian (European) to convey simulated breakup

SURVEILLANCE OBSERVATIONS: PASSIVE RF, RADAR AND ELECTRO OPTICAL

The SACT benefits from surveillance contributed by many leading commercial ground-based electro-optical (EO), passive RF, and radar providers in the industry. Each Commercial SACT has seen significant and valuable contributions from international companies with world-wide surveillance networks. These networks continue to grow and mature in space surveillance capability each year. Fig. 13 is a snapshot of the individual observations collected during the SACT 19-2 event and coverage against select satellites of interest.

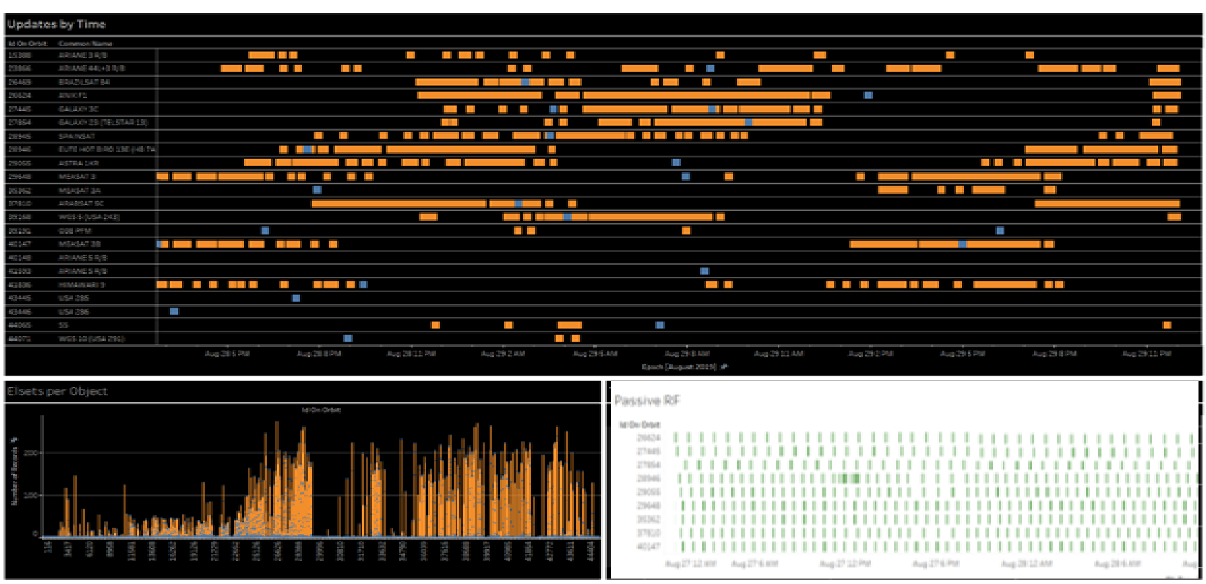

Fig. 13 - Tableau Dashboards and Statistics

Each of the SACT cycles generates millions of routine surveillance and dynamically tasked metric observations on satellites in all regimes of the catalog (i.e., LEO, MEO, Highly Elliptical Orbit [HEO], GEO, and Cislunar). The 2019 SACT accumulated more than seven million observations, resulting in 375 separate maneuver detections and more than 150K state vector updates on select monitored satellites during the week and through two days of operational processing. Much of the raw data is made available to a variety of supporting mission operations tools. These two tools are just examples of the many mission support applications that consume the raw surveillance data to perform advanced orbit determination, maneuver detection, catalog maintenance, and Pattern of Life (PoL) change detection for anomaly alerts. The use of Tableau Dashboards above facilitates the SACT Site Directors and mission management teams in maintaining awareness of the surveillance architecture's operational status and throughput. The lower-center graph in Fig. 13 shows the high passive RF collection cadence from the passive RF systems on select satellites, averaging a revisit rate the same bird once every 22-minutes.

Fig. 14 is a Tableau Dashboard depicting the number of collections on satellites over time. The y-axis of the graph represents the NORAD satellite identification number (commonly used by the United States through the SpaceTrack.Org) and the x-axis representing time. Although not as beneficial to discriminate information on any specific/one satellite, this ‘Full Catalog Observation Flow’ dashboard is exceptionally useful in quickly identifying which surveillance systems are contributing and when, as well as when systems might be inadvertently dropping out of network publication coverage; a form of network Status of Health (SoH).

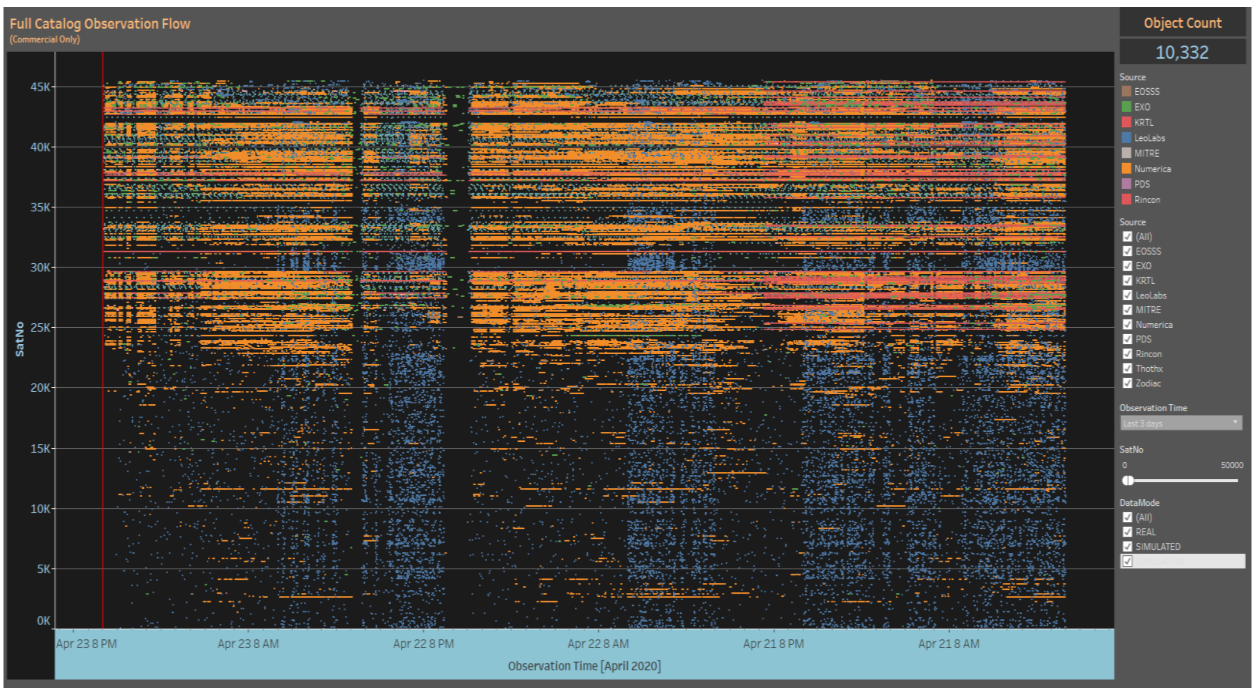

Fig. 14 - Tableau Dashboard of individual EO observations during first 2020 event

Fig. 15 is another Tableau Dashboard used to convey both location of certain surveillance locations as well as the color-coding Operational Capability (OPSCAP) and SoH of the systems. Sensor systems that have recently reported (contributed measurements) within the last several minutes are tagged in green.

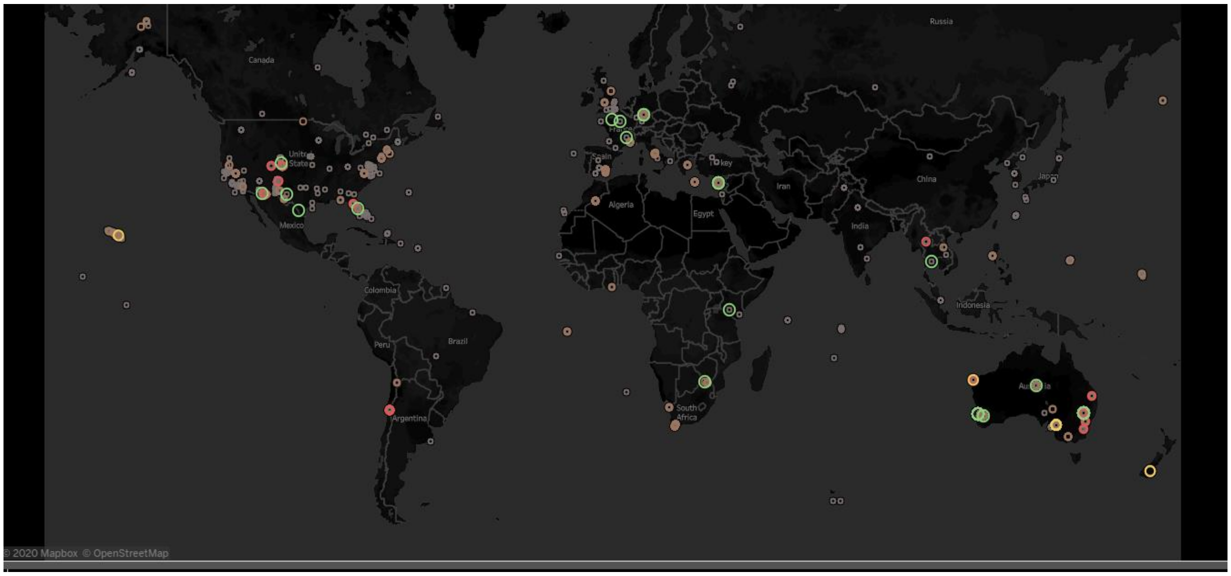

Fig. 15 - Tableau Operational Capability Board Overview Dashboard

The majority of our current space surveillance network consists of an extensive ground-based EO network. The EO telescope network is, by the nature of the system, limited to only collecting during photometrically pristine evening conditions. This limits EO systems from collecting during the day or during weather obscuring conditions (e.g., overcast clouds, precipitation [rain/snow], excessive wind, humidity, temperature, etc.). In aggregate, EO are still only able to achieve roughly 60% usable photometric nights despite the intentional placement of EO sites in arid or high-altitude locations to limit weather obscuration. The SACT events have demonstrated an evolved use of Passive RF to augment and support traditional SSA monitoring. The primary benefit of a Passive RF surveillance system is that it can maintain positive track identification (ID) on satellites that are transmitting within specified frequency ranges and are less susceptible to losing positive identification/track due to weather or solar exclusion. As such, the SACT have slowly begun to incorporate more surveillance phenomenologies, such as Passive RF and more radars, into the architecture.

The passive RF surveillance architecture performs surveillance monitoring of GEO satellites transmitting in specific frequencies. The company has geographically distributed sixteen (16) antenna in the regions of Europe, Asia, and the United States. These antennas work in coordinated sets of four to continuously revisit satellites to measure Time Difference of Arrive (TDOA) and Frequency Difference of Arrival (FDOA) measurements. Use of a dedicated Global Navigation Satellite System (GNSS) receiver signal has been developed to maximize accuracy/performance. Processing the TDOA/FDOA in real time, these systems can generate useful derived SDA products such as satellite position/ephemeris, maneuver detection (along each radial component), and RF PoL behavior.

Fig. 16 illustrates some of the benefits of the passive RF system available through their web-portal interface. In this example the four satellites of SES ASTRA 19.2° East Cluster are depicted in their tight station-keeping orbits.

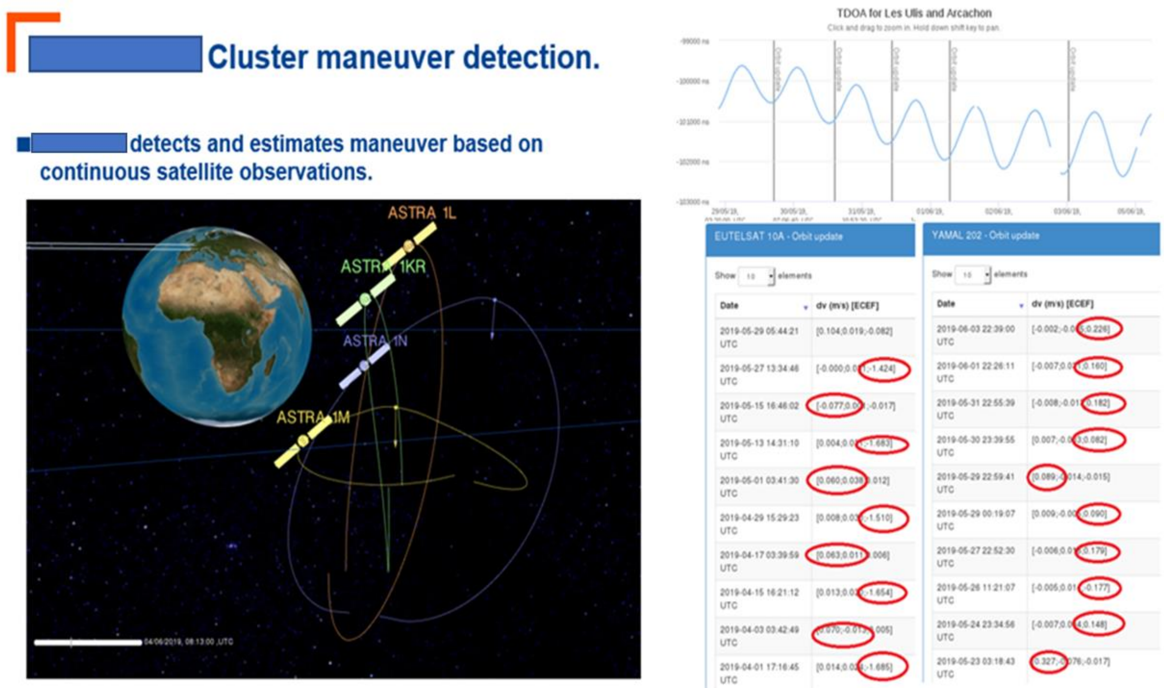

Fig. 16 – Passive RF system illustrated maneuver detection of tight cluster GEO's

In addition to traditional Passive RF frequency spectrum plots, Fig. 16 shows derived 3D flightpath graphics with embedded manuevers, TDOA with overlaid maneuver markers, and historical maneuver detection histories. The Passive RF is especially useful in tight formation flying clusters, such as the ASTRA, as they can clearly distinguish signals from unique satellites and, therefore, do not inadvertently cross-tag satellites in the way that telescope-only systems are known to do. (Note the velocity vectors superimposed on the orbit track of satellites to denote direction and magnitude of the burns.) In the lower right of Fig. 16, the separate vector components for each delta velocity (delta-V) burn are provided in tangential, normal, omega (TNW) are provided. The dominant magnitude in red circled highlight here indicating to operators the likely intent of the burns as North/South or East/West station-keeping.

Fig. 17 illustrates one of the key discriminating benefits of the use of Passive RF as a key element of the multi-phenomenology surveillance strategy of the SACT exercise – including high revisit rate on satellites for monitoring situational awareness. As an example, the passive RF system can routinely revisit each satellite in its surveillance sweeps at least once every ~30-minutes, which is shown in the figure through the spacing along the y-axis. The red circles in Fig. 17 illustrate where the system was deliberately tasked to increase collection cadence on specific satellites to once every several minutes. The ability to selectively increase collection cadence can be particularly useful during times of operational high interest or increase position resolution.

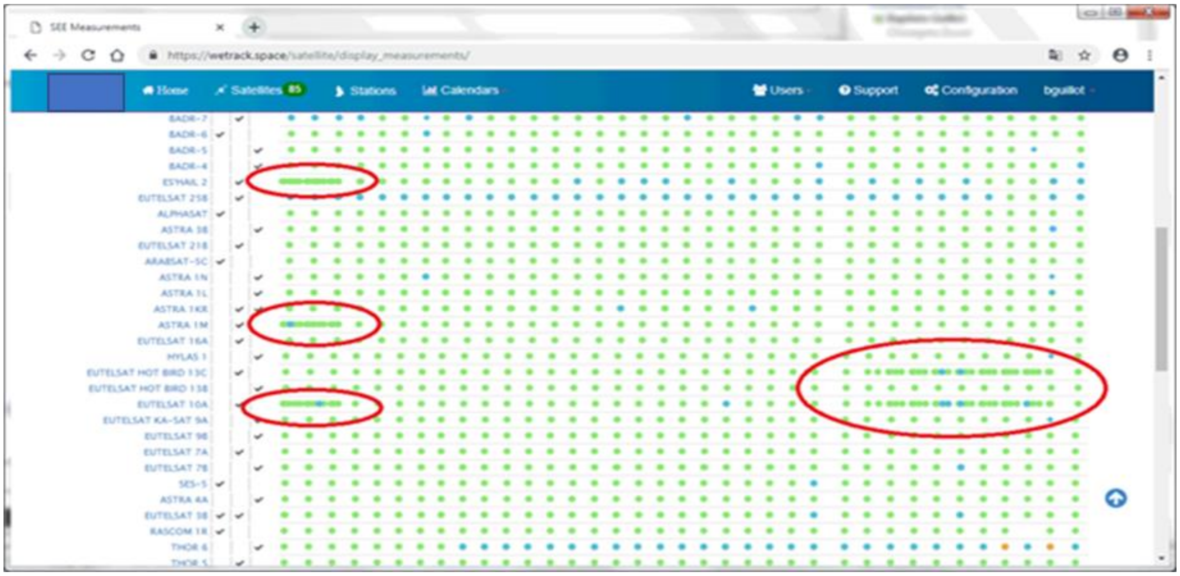

Fig. 17 - Passive RF high-cadence revisit rate

Through services such as these, the SACT can maintain an intense revisit rate cadence on select satellites for space operations. A core SACT DLO are designed to encourage and advance the ability to fuse multiple sensor phenomenologies together, thereby maximize catalog accuracy and situational awareness. By coalescing the best of multiple commercial surveillance providers, the SACT forms one of the largest single commercial space operations centers.

PUBLIC SATELLITE RESEARCH ANALYST (PSRA)

Another area where SACTs are significantly advancing standard civil space operations is renewed emphasis on fusing public satellite research (open source data), as one of the primary 'sensor phenomenologies'. Traditional space surveillance operations centers rely heavily on metric observations and they focus almost exclusively on the satellite position state updates as the primary metric. In addition to traditional real time surveillance feeds, the SACT exercises also include the use of public source data to bring the satellite meta-data to the forefront as context to facilitate understanding satellite behavior. Whenever satellites are identified as objects of interest during the event, the PSRA team will use a variety of tools to data mine for information including: owner/operator, country of operations, mission, International Telecommunications Union (ITU) frequency filings, size/weight class, maneuverability limits, know communications operating frequencies, age (years of operation), station-keeping parameters, insurance claims, primary payloads, satellite bus manufacturer, number of other satellites operating with bus type, current assumed operational status, anomaly history, etc. Each team in the SACT has dedicated PSRA's assigned to constantly monitor a variety of sites for interesting/relevant information. Ready access to this data assists the other surveillance phenomenologies and mission directors. For example, as soon as a satellite is identified as being of interest, the PSRA team research which downlink frequency bandwidths it operates on to understand whether it may or may not be collected on with existing Passive RF providers.

One of core SACT PSRA sources includes services from Europe. These provide a rich satellite data repository consisting of independent and authoritative information on every launch since Sputnik in 1957. It contains comprehensive unclassified data on upcoming launches, satellite missions, satellite manufacturers, launch services, bus types, and more. The service is predominantly used by insurance companies and satellite owner operators. The SACT leverages the service to augment operations and help design missions. The information is made available to the SACT participants in two ways, via an intuitive user-friendly browser-based tool and via machine-to-machine streaming through the UDL. The commercial teams also provided analysts during the Meridian cell and frequently participates in the SACT "Operations" rehearsals. Ready access to public source information helps the SACT operators understand context to satellites in the mission. That means quick answers to key questions such as:

- What are the objects?
- Who owns and operates them?
- What is their status and health? (i.e., active, inactive, unknown)?
- Are there any relevant public observations or announced intent?
- Is the ‘form’ for this type of satellite or owner behavior?
- Are there any know insurance claims indicating degraded capability

Fig. 18 shows the main page of the PSRA site and is one example of how the intuitive web-portal is used by analysts. The site provides instant access to the upcoming launches and latest satellite anomalies. PSRA analysts needing to know more about each of these can simply click on select text to continue data mining on each of the specified satellites, launch vehicles, or organizations.

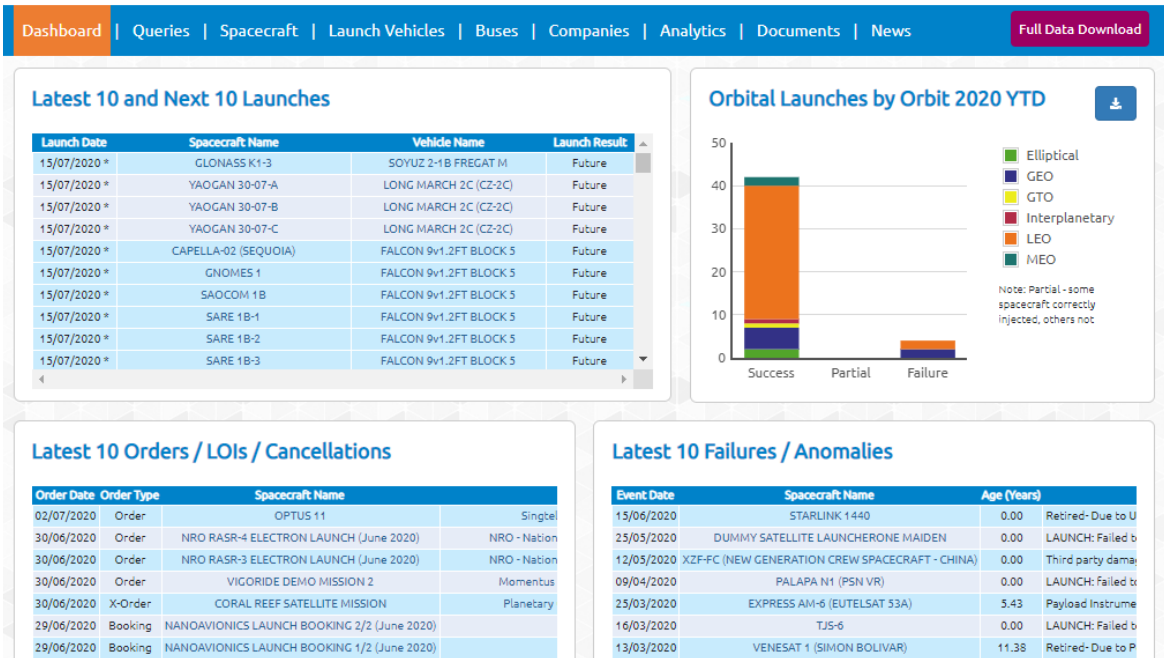

Fig. 18 - PSRA summary data on new launches and recent satellite anomalies

Fig. 19 illustrates what information is available in a common satellite summary page. These are intuitive ‘at-a-glance’ reports of the satellites and provide quick access to some pertinent information elements for SACT analysts including bus type, years of operation, size/weight category, and orbit regime.

INTELSAT 39

☆ Add to tagged spacecraft

Summary

Name:	INTELSAT 39	**Original Manufacturer Prime:**	SSL (Space Systems/Loral - Part of Maxar)
Spacecraft Quantity:	1	**Original Bus Manufacturer:**	SSL (Space Systems/Loral - Part of Maxar)
Status:	Active	**Bus/Kit Designer:**	SSL (Space Systems/Loral - Part of Maxar)
Owner (Country):	Intelsat S.A. (United States)	**Bus Type:**	SSL-1300 (LS-1300)
Operator:	Intelsat S.A.	**Launch Mass:**	6600.00 kg
Leased:	No	**Mass Category:**	> 5000kg – Extra Large Satellite
Spacecraft Order Date:	12/05/2016	**Stabiliser:**	3-Axis
Launch Date (Age):	06/08/2019 (0 years old)	**Sector:**	Commercial
Vehicle Minor Variant:	ARIANE 5 ECA - ARIANE 5 ECA	**Mission Group / Type:**	Communications / Communications - General
Launch Characteristic:	Expendable		
International Number:	2019-049B	**Orbit/Orbit Sub Category:**	GEO/Geostationary
Catalogue Number:	44476	**Design Life:**	15.0 years
Seradata ID:	10805	**Expected Life:**	18.0 years
Total Mission Capability Lost:		**Number of Humans Carried:**	0
Programme Name:		**Reusable Flights:**	0
		Spacecraft Hull Serial No/Name:	

Fig. 19 – Satellite common information card

SACT experiments are advancing the use of public satellite information into the core space operations cycle. Novel uses of international databases are examples of how the SACT are coalescing non-traditional sources (commonly used by insurance companies and satellite owner/operators) to further civil space operations. The SACT event series is evolving to practice PSRA Event Insertion (like what was performed during SACT 20-1) as ‘simulation-over-live’ triggers in event and anomaly detection.

SAFETY OF FLIGHT / CONJUNCTION ASSESSMENT

A major DLO in the SACT series always include Conjunction Assessment (CA) and safety of flight. The volume of satellites operating in space is anticipated to double from 2000 by 2025. SpaceX’s Starlink mega-constellation is projected to have as many as 12,000 small satellites in orbit by 2027. Fig. 20 includes projections of new satellite launches from the Union of Concerned Scientist (UCS). The figure belies the significant potential increase in volume of satellites, including nano satellites, microsatellites, cube sats, and traditional size payloads. The potential hazards of conjunction will be a critical issue to address in the future. The DoC puts a heavy emphasis on maturing conjunction assessment capabilities for the whole international community because it is essential that space remain a safe environment for commercial and government systems to operate.

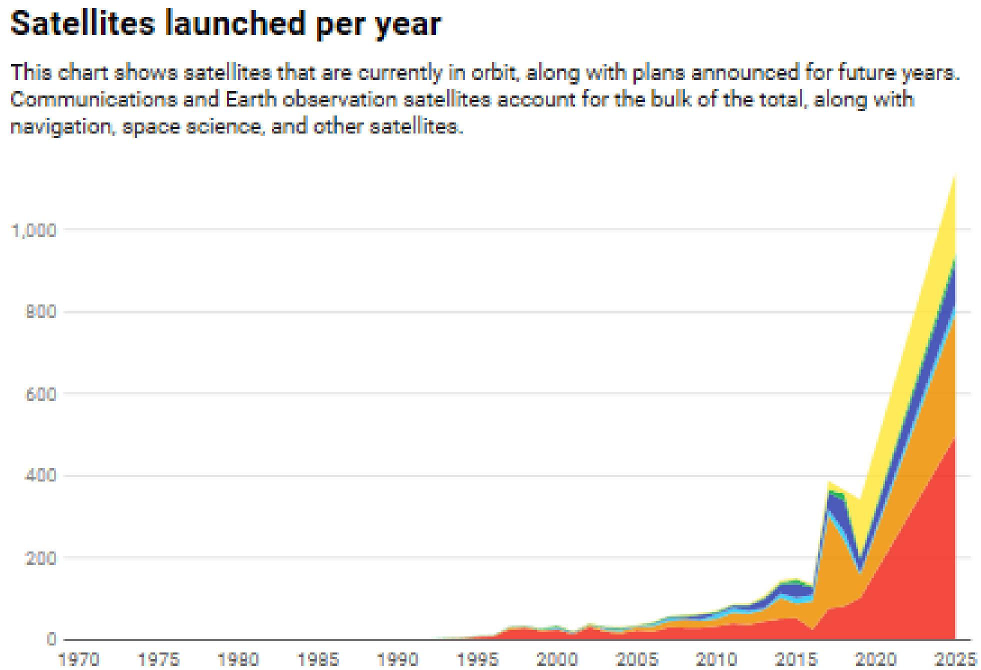

Fig. 20 - Projections of new satellite launches thru 2025 (courtesy of MIT Technology Review)

The DoC has worked to establish relationships and design exercises to address CA and flight safety with a variety of groups, including the NASA, USSPACECOM, Combined Space Operations (CSpOC) Commercial Integration Cell, commercial satellite owner/operators, and other stakeholders. These DLOs focus on discovering ways that the SACT can further improve civil space safety of flight for the space community.

One such experiment includes the SACT collaboration with NASA. Twice a day, NASA publishes a list of its top conjunction concerns for the next several days. They generate a redacted version of this list which may be freely distributed throughout all the participants in the SACT. The text file contains a list of primary and secondary satellite pairs (by SSC number) along with corresponding time of closest approach. These statistics are fed into a variety of tools including the "NASA Conjunction Big Board" list seen in Fig. 21.

Primary ID	Secondary ID[1]	Update Status	Time of Closest Approach (TCA)	Time to TCA[2]	Epoch Age of Secondary	Pc	OD Quality Score	Laseable?	Notes
25991	41217	NO	4/27/2020 20:52	00:00:00:00	4/22/2020 9:07	2.40E-04	1		CDM Provided - S
28054	15950	NO	4/28/2020 13:20	00:00:00:00	4/22/2020 19:24	4.90E-04	1	YES	No Current CDM -
37849	7411	YES	4/26/2020 20:24	00:00:00:00	4/23/2020 7:03	2.48E-04	1	YES	Updated by LeoLa
28376	82429	NO	4/29/2020 16:58	00:00:00:00	4/20/2020 4:08	1.13E-03	1		Not Cataloged Sec
29108	31809	NO	4/28/2020 8:56	00:00:00:00	4/18/2020 20:11	3.81E-06	1.00E+00	YES	
23613	43355	YES	4/22/2020 22:17	00:00:00:00	4/22/2020 11:49	4.76E-07	1		Updated by EOS :
28654	41358	NO	4/29/2020 5:36	00:00:00:00	4/22/2020 8:46	1.06E-07	1		
26998	43347	YES	4/26/2020 11:39	00:00:00:00	4/21/2020 11:35	5.60E-07	1		Updated by LeoLa
26998	43347	YES	4/26/2020 10:03	00:00:00:00	4/21/2020 11:35	3.60E-05	1		Updated by LeoLa
41891	28332	YES	4/26/2020 10:33	00:00:00:00	4/22/2020 23:52	1.65E-06	1		Updated by LeoLa
25994	81559	NO	4/28/2020 18:46	00:00:00:00	4/22/2020 12:14	2.56E-05	1		
40376	32102	NO	4/29/2020 10:42	00:00:00:00	4/22/2020 10:21	1.90E-06	1		
25682	34316	YES	4/24/2020 10:14	00:00:00:00	4/23/2020 2:28	1.74E-139	1.00E+00	YES	Updated by LeoLa
26998	43347	YES	4/26/2020 13:16	00:00:00:00	4/21/2020 11:35	5.60E-10	1		Updated by LeoLa
40376	82835	NO	4/23/2020 17:40	00:00:00:00	4/22/2020 0:26	2.62E-10	1		
25991	81716	NO	4/22/2020 16:17	00:00:00:00	4/18/2020 9:02	6.97E-10	1		
20580	40804	NO	4/24/2020 7:18	00:00:00:00	4/18/2020 4:15	1.16E-10	1		
25338	30437	YES	4/24/2020 6:58	00:00:00:00	4/23/2020 9:05	4.21E-08	1		Updated by LeoLa
38771	82277	NO	4/25/2020 22:13	00:00:00:00	4/16/2020 22:40	1.06E-10	1		
26998	43347	YES	4/26/2020 8:26	00:00:00:00	4/21/2020 11:35	9.89E-10	1		Updated by LeoLa
29108	31809	NO	4/28/2020 10:43	00:00:00:00	4/18/2020 20:11	7.40E-09	1	YES	

Fig. 21 - NASA Conjunction Priority List

As illustrated in Fig. 21, the candidate conjunctions are color-coded by priority based on their Probability of Collision (Pc). Utilizing a NASA Standard, the priorities are assigned by the rule:

Red = Pc < 1.0 e^{-4}
Yellow = Pc >= 1.0 e-4 and Pc <= 1 e-7
Green = Pc > 1.0 e-7

The SACT team develops and monitors a 'NASA Big Board' to provide situational awareness about the current status of our surveillance collection efforts, including: 'Time of Closest Approach', countdown timer to event, age of secondary satellite epoch, and determination if secondary is a candidate for laser range finders. Each surveillance team is presented with the DLO task to collect as frequently as possible on these satellites in order to improve accuracy and drive down covariance uncertainty. Updates are made in both the measurement space (raw observations) and state vector ephemeris updates. It is the responsibility of the SACT commercial providers to use commercial resources to locate and increase tasking priority on the satellites. A wide variety of companies and tools are employed to perform conjunction assessment in support of the DLO. Additionally, the SACTs are beginning to work closely with commercial laser range providers in attempts to determine if very precise orbit solutions may be derived on the secondary targets through lasing. Future SACT events will include actual lasing of satellites as a nominal collection tactic to support DoC and NASA to further enhance flight safety. The next SACT experiment series will utilize quick the Debris Analysis Response Team (DART) to build debris projection volumes and issue alert warnings in the form of NOTSO to the space community.

An interesting and, initially non-intuitive, element of the analysis is the heavy focus on reducing the uncertainty (error covariance) of the secondary. Typically, the NASA team has a good orbit solution on the primary object they are responsible for. The high conjunction Probability of Collision ($P_{c)}$ is usually a result of a poor covariance on the secondary object. The main objective of the experiment is to then focus on collecting and improving the orbit solution of the secondary. The DLO measure of success during the SACT is how often the commercial teams can update the raw observations or the orbit state epoch compared to NASA. From the snapshot of the 'NASA Big Board' in Fig. 21, the SACT team was able to update nine of the 21 NASA nominated conjunction candidates. All data that was collected as a result of the NASA DLO is coalesced and submitted to NASA for further analysis to understand how this data would or would not have significantly improved their understanding of conjunction assessment.

The Safety of Flight DLO illustrates how the DoC participation in the SACTs is working to improve civil-space flight safety through these international experiments.

DATA CURATION AND STANDARDIZATION

A fundamental challenge of any space operations cell that is incorporating multiple sources of independent source measurements is data curation and standardization. Previous attempts at coalescing space data from multiple source, including academic and government programs, spent considerable time and energy trying to address questions in ensuring that data received from commercial providers was in a well-defined coordinate systems, time frames, units, and stellar aberration correction transforms. The SACT are faced with similar challenges and devoted companies to focus almost exclusively on these ends.

One example of this work includes a company's Ensemble Catalog analysis where they compare/contrast commercial solution providers' results against the community standard USSF Two Line Element (TLE) set catalog. One company performs this analysis during each SACT by comparing companies' solutions to TLE as well as high-accuracy calibration satellite (CALSAT) data pulled from a variety of sources such as Wide Area Augmentation Solution (WAAS) satellites and US-based company constellation data. Data curation is performed on orbit updates from other surveillance companies to understand through direct measurement how well solutions agree in accuracy, timing, and reference frame. These analyses also highlight the improvements commercial systems have over standard USSF TLE. Fig. 22 illustrates a sampling of USSF TLE versus commercial sensor provider state updates for a broad set of GEO/MEO CALSAT throughout the experiment. The data shows total delta position at the time of orbit epoch for each satellite as measured from the CALSAT. The further a point is from the bottom, the higher the variance from the CALSAT position. The graph shows how commercial solutions are generally higher accuracy than corresponding TLE.

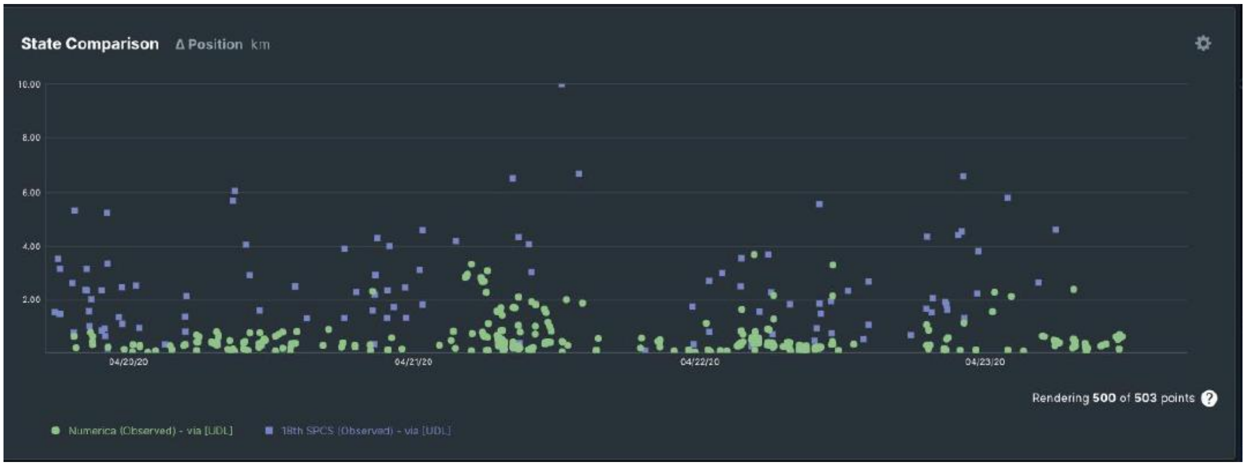

Fig. 22 –Ensemble Catalog analysis of USSF public TLE vs provider CALSAT state updates

Another example of curation includes one company's work assessing the accuracy/quality of space Owner/Operators (O/O) flight plan predictions (with embedded maneuver plans) to support conjunction assessment. This DLO aims to understand how O/O predicted satellite solutions may be used to improve conjunction assessment out to seven days in advance. The hypothesis is that, if O/O have higher accuracy flight plan data over their active birds, then these flight plans would lower predicted position error covariance calculation over time (compared to traditional propagation without maneuvers) and, therefore, result in improved conjunction assessments. A Canadian company performed a collaborative exercise during SACT 20-1 with spacecraft O/O in support of this DLO for near Earth objects.

The objectives of the exercise were:

- Understand the formats/frequency and quality of flight plan data set
- Determine a suitable platform for data sharing/querying (Currently, this is hosted by space-track.org)
- Identify pros and cons on the use of flight plan data with respect to maneuver planning to support conjunction assessment
- Evaluate trends between flight prediction data and other sources of ephemerides such as TLEs and commercial surveillance providers

The results of the early 2020 event were instructive to understand how well each O/O could predict their satellites trajectories into the near future. In general, O/O flight plan prediction data shows a much better orbit predictor than externally predicted ephemerides, especially in the case where maneuvers are embedded. The results of the analysis showed that using O/O is beneficial for STM. The SACT analyses measured the degree the O/O companies' accuracy improved from seven days out until real-time. An interesting finding was how this data differed between company's and also between different satellites within a company. Measuring and understanding to what degree of confidence should be applied to satellite predicted ephemeris is a foundational DLO in the SACT.

This data curation example illustrates the benefit, from an international perspective, of close collaboration between several parties from the civil and commercial domains.

ON-ORBIT BREAKUP ANALYSIS / SIMULATION-OVER-LIVE

One element of civil space flight safety that concerns the SACT is rapid identification and assessment of significant satellite anomalies, especially when these may pose additional unintentional risks to neighboring satellites. On-orbit breakups are fairly common and, as such, represent a major DLO element of the SACT. On-orbit breakup can occur due to several anomalies, including: collision, unspent rocket fuel combustion, significant battery overheating, deliberate breakups, etc. Recent examples of on-orbit breakup anomalies occurring include; AMC-9 (GE-12); RISAT 1; HAIYANG 2A; WORLDVIEW 2; BLITS; COSMOS 2399; etc.. These debris-causing events can represent dangerous conditions in civil space operations, especially as the population of satellites in LEO orbit begins to escalate rapidly with the introduction of mega constellations.

A core tenet of the SACTs is to perform all DLO as real-world, live events. However, there are some events that are inherently dangerous (e.g., on-orbit breakups); the experiment series emulates these as 'sim-over-live' events. In these events the SACT inject or modify apparent data feeds to superimpose breakups in normal data streams. Most of the participants in the event are unaware of what satellite is breaking up or when a breakup may occur. The DLO's main objective is to test if and how commercial providers can automatically detect that a breakup has occurred and then race to find all resulting debris, perform an initial orbit determination (IOD), assess any conjunction risk with neighboring satellites, and use PSRA team to perform an initial forensics assessment for root cause (particularly looking for any similar anomalies in the same satellite bus class).

These experiments include as many surveillance phenomenologies and companies as possible. For example, candidate satellite transmissions are discontinued at the time of the breakup emulating a sudden drop of communications. Early SACT coordinated directly with the passive RF suppliers to turn off publications of the data to the UDL. Since then, the SACTs have significantly increased in sophistication levels and now all emulated data is pushed through the Trogdoor emulation database. Trogdoor is a mirrored interface to the UDL, but it will allow data to appear added, modified, or deleted to achieve the perceived emulated breakup event. The main benefit of this approach is that data fed into the UDL can remain pristine, even as a multiple breakup experiments are virtually conducted during a single SACT event. Similar techniques are applied to ground-based telescope data. The breakup events are conducted without complex coordination with multiple surveillance vendors. The complex design and execution of the breakup scenarios, including fragments deliberately designed to conjunct with nearby satellites, are designed by multiple companies. The simulations include realistic lightcurve solutions for the fragments as well as emulated telescope imagery of breakups.

Fig. 23 illustrates the general sequence of vendor interaction during a 'sim-over-live' breakup event in the SACT.

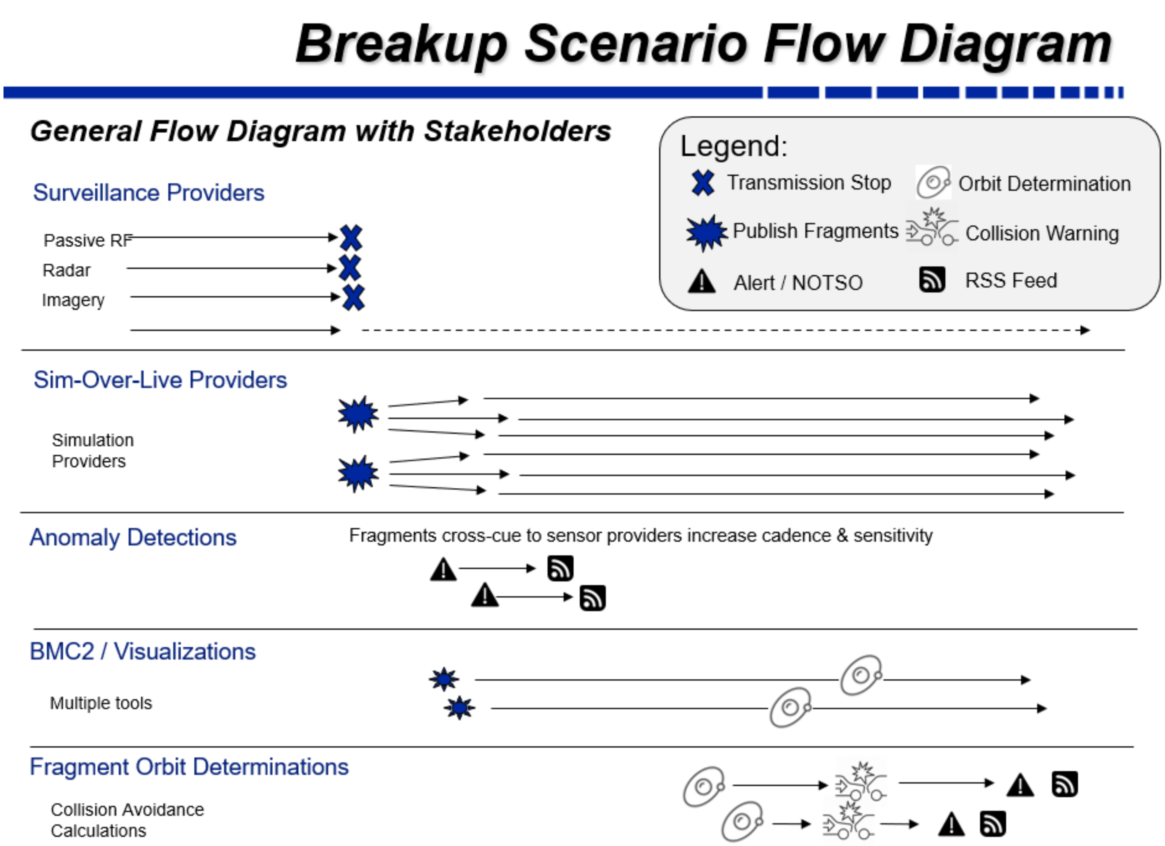

Fig. 23 - SACT Breakup Scenario General Information Flow Diagram

Fig. 23 shows that multiple elements of the breakup are experimented in the event, including: surveillance providers ceasing or initiating data flow; breakup emulation pushing pseudo observations into the system; automated anomaly detection algorithms searching for and triggering on event detection; visualization tools representing anomaly; and finally IOD services performing follow-up on tracking fragments.

Table 2 provides a listing of all the breakup scenarios that were conducted during the latest SACT event in early 2020. Starting from the "Initiating Cell" column, the figure shows how events were intentionally designed to occur at least once during each of the main SACT operations regions of Australia, Europe, and US. This enabled each of the regional teams at least one opportunity to experiment with the sequence.

Table 2- SACT Early 2020 Satellite Breakup Vignettes

SACT 20-1 Satellite Break Up Scenarios

Satellite	Mode	Date	Event Time	Primary	Initiating Ce	Fragme	Owner/Operat	Bus Type	Bus Builder	Intelligence Story:
42950 (IntelSat 37)	Event 1	4/21	2:34:30	Centauri	Australia	5	US	BSS 702MP	Boeing	Sister Satellite: Same Bus: INT
43226 (GOES 17)	Event 2	4/21	9:45:10	AI Solutions	France	9	US	A2100A	Lockheed	No significant mechanical failur
37150 (SINOSAT 6)	Event 3	4/21	17:31:05	Centauri	United States	7	China	DFH-4	ITS (Chinese)	Has a leak in its helium pressur
28868 (ANIK F1R)	Event 4	4/23	3:44:30	AI Solutions	Australia	15	Canada	E3000S	SAS	Sister Satellite AMAZONAS 1:
31307 (Galaxy-17)	Event 5	4/23	9:57:32	Centauri	France	12	IntelSat (US)	SpaceBus 3000B3	Alcatel	Sister Satellite: AMC-9. A mech
37834 (IntelSat 18)	Event 6	4/23	17:28:00	AGI	United States	5	IntelSat (US)	GeoStar 2.4E	Northrop	Sister Satellite: It was reported
32478 (Express AM-33)	Event 7	4/23	18:15:30	AI Solutions	United States	20	Russion Comms	Express-AM	NPO Prikladnoi	Sister Satellite: Same Bus: Exp

The table also indicates the number of large fragments and specific bus types that were used. This information was not published to the majority of the SACT operators prior to the event, particularly the time and identity of the primary satellite that would suffer the emulated anomaly. Many tools were used to monitor all data coming in real-time through respective and the UDL to discover the events, primarily through the identification of multiple fragment headcounts in the optical observations. Automated alerts are generated as soon as one of the tools detects the breakup. The alerts trigger the SACT site directors to immediately issue dynamic tasking on the suspected breakup. The additional collection cadence on the breakup observations from multiple sites assists in the fragment IOD calculations.

Fig. 24 illustrates two visual products from the SACT series supporting the breakup events. The far left represents suspect fragment observations collections as they are collected in 3D space within the visualization tools. Fragment projects turn from yellow to pink as they age within the scenario run time.

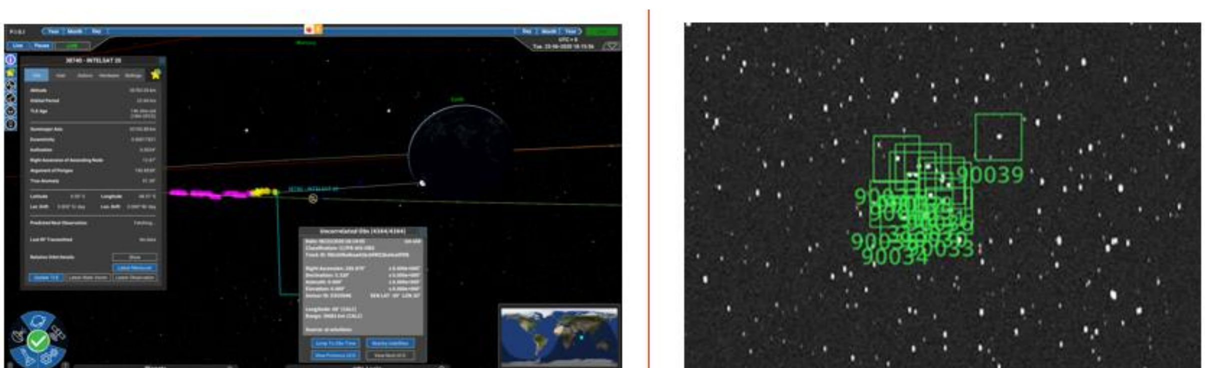

Fig. 24- VR Visualization (right) and Breakup emulation of 1-meter telescope (left) during breakup

The tool enables operators to mouse-over suspect fragment pieces to see detailed information about telescope collection, timing, source of data. On the far right of Fig. 24, a single frame screenshot of Centauri Sensor IQ video is shown depicting the breakup as viewed by an emulated Numerica Argus telescope. Each of the fragments is assigned a temporary 90,000 series identification and centered in a green box. The emulated star background is real starfield and is in the common Electro Optica SSA (EOSSA)/Flexible Image Transport System (FITS) image format commonly used in the space community. Beginning with a physics-based emulation of the surveillance network will enable future SACT experiments to start from the very beginning of the Tasking, Collection, Processing Exploitation and Dissemination (TCPED) chain and exercise the full end-to-end architecture.

The SACT Breakup Scenarios demonstrate an initial use of ‘sim-over-live’ in the event series. Use of the Trogdoor will enable the SACT to extend and further refine more complicated scenarios without risk of tampering with source databases, like the UDL. These scenarios allow the SACT to explore the full end-to-end SSA capabilities of many tools throughout the information chain. Future SACT will expand on the ‘sim-over-live’ to include RPO.

CONTINUED EVOLUTIONS AND WAY AHEAD FOR SACT

The Commercial SACT’s have seen incremental and steady growth since inception in early 2019, and this trend is likely to continue as the experiment receives positive feedback and increased participation from the commercial community. The plan is that it will continue to occur approximately three times a year. The international element of the event is expanding to include more countries and participants. Significant examples include the Australian civil agencies, UK, and US government Joint Task Force (JTF) Commercial Cell.

<u>Australian</u>:

The Department of Industry, Science, Innovation, and Resources in conjunction with the Australian Space Agency has awarded a $6 Million grant for the development of Australia’s Mission Control Centre. It will bring next generation space mission control technologies to make it easier to fly new spacecraft. Capabilities include concurrent design, pre-flight testing, and launch support, as well as live operations during flight. The Australian civil agency will also be the first professional control center in the world to use machine learning in spacecraft day-to-day operations along with 3D gaming technologies.

<u>United Kingdom</u>:

The UK’s Defense and Security Accelerator programs are teaming with US Air Force program to further commercial space technology integration to:

- Increase collaboration with allies and similar ‘innovation’ organizations
- Provide awareness of emerging capabilities in global marketplace
- Use purpose-built solutions on mission-driven problems
- Provide capabilities through “fast contracting” to new companies

The program is run by the UK including participation the UK Ministry of Defense (MOD), Royal Air Force (RAF) and USAF. The SACT teams are part of the Problem Curation team and help establish what issues will be addressed in each cycle of the program. Companies awarded contracts to this effort will be invited to demonstrate their new capabilities live during the USAF ‘Ops Days’ and SACT events. In this way, the SACT will be able to provide the UK MOD a real-world experiment venue to allow their teams to demonstrate the efficacy of the new applications.

<u>US Government JTF Commercial Cell</u>:

The USSSPACECOM has recently authorized the standup of the JTF Commercial Cell to augment operations through a cell. The decision to initiate this new cell was based on certain notable successes in previous SACT events to use multi-phenomenology surveillance systems in tactical timelines during real world experiments. The JTF Commercial Cell will be based on the SACT process and derive from many of the core companies in the series. Following the SACT format, the cell Site Lead and Mission Director will be JTF operators that lead a team of commercial companies running their systems from their remote locations. The USAF Agile software team will serve as the technical baseline for the cell and maintain its role as lead in the software architecture program for both the SACT and JTF Commercial Cell efforts.

CONCLUSION

This experiment series is an emerging international SDA experiment event that is rapidly accelerating how commercial and friendly government space surveillance organizations collaborate to augment the state-of-the-art and realize transformative changes in both military SDA and civil STM. Leveraging foundational advances in M2M architecture such as the UDL, the SACT events are enabling multi-surveillance phenomenologies services (e.g., radar, EO, passive RF, laser ranging, etc) and supporting operational mission capabilities to coalesce into a seamless federated SDA architecture. This assertion is demonstrated through the near real-time collection and distribution of more than seven million independent surveillance measurements in near real-time, from hundreds of world-wide sites (see Table 1). Measurements are processed and utilized by dozens of commercial, academic, and government applications to address experiment DLOs in each SACT cycle. Benefits of the SACT experiment series include (but are not limited to):

- The diversity of international countries and organizations participating enables rotating operational cells of control to transition seamlessly across continents from Pacific (Australia) to Meridian (Europe) to the Americas (US). Distributed space operations centers provide inherent benefits such as inclusion of 'best of breed' technologies from around the world, staff operating during nominal hours, and reduction of costs/inefficiencies in operating a single, full 24-hour center.
- The experiments are pioneering work on how public space research analysis, such as UK companies, can be used to support real-time operations and supporting rapid advancement of how new technologies like VR may be used in operations support.
- Active support of initiatives in the domains of civil space and STM such as the DoC work with NASA is helping mature conjunction assessment capabilities. SACT contributes to these efforts by highlighting operational conjunction threats during the experiment cycle and increasing collection cadence on these specific satellites to enhance tracking and situational awareness.
- Our understanding of the precision, accuracy, and timeliness of existing systems is increasing. Data curation efforts from various companies are steadily maturing our understanding of the data quality, reliability, and utilization. The SACT teams continuously monitor the millions of raw observations and derivative SDA products flowing through the system to measure volume and production timing.
- The USAF Agile software development team continues to play a critical role in enabling the international collaboration efforts of the Commercial SACT through mission support collaboration software.
- Development of collaboration software like the Mission Management Board and the Tableau 'Status of Health/Summary Statistics' tools facilitates operations, increases situational awareness, and enables smooth transition handoff between regions.
- The SACT encourages true data fusion across multiple surveillance types (including traditional radar, EO, and passive RF), but also PSRA and active laser ranging.
- Use of novel data types, such as the space insurance records within Seradata, are examples of some of these innovations.

In summary, the Commercial SACT experiment series are accelerating the pace of international space surveillance development across the globe, akin to a renaissance (def: a revival of or renew interest), as exemplified by the innovative rotating commercial space operations centers in Pacific, Meridian, and US. Collaborative commercial integration of technologies is significantly advancing pace and maturity of services across broad spectrum of STM and SDA needs. The Commercial SACT offer an exceptional venue to experiment with real-world surveillance systems on real-world satellite operations scenarios. Integration with other international programs, including the Australian programs will serve to further accelerate the state-of-the-art with respect of space surveillance technologies. The need for the enhanced SDA and STM services has never been greater. As the cost of launch services decreases, the rate of satellites launched and operating in LEO and GEO is significantly increasing. New mega-constellations are increasing new satellites production at rates that could quadruple the number of active payloads in orbit by 2027. These advances will bring significant new and beneficial services, but the international community must be prepared to address the multitude of challenges these present, including conjunction services, frequency deconfliction, on-orbit servicing, and anomaly detection. The Commercial SACT has helped inspire the formation of new commercial-based space operations organizations like the Australian civil agencies and US JTF Commercial Operations Centers. The Commercial SACT has demonstrated new capabilities in international collaboration enabling sharp increases in capacity for high-rate revisit, maneuver detection, and conjunction assessment. Future Commercial SACT will continue to serve as experimental testbeds to further bridge international, academic, and commercial capabilities to accelerate the broad spectrum of SDA and STM for all, helping to ensure a safe environment to support space operations and space exploration.