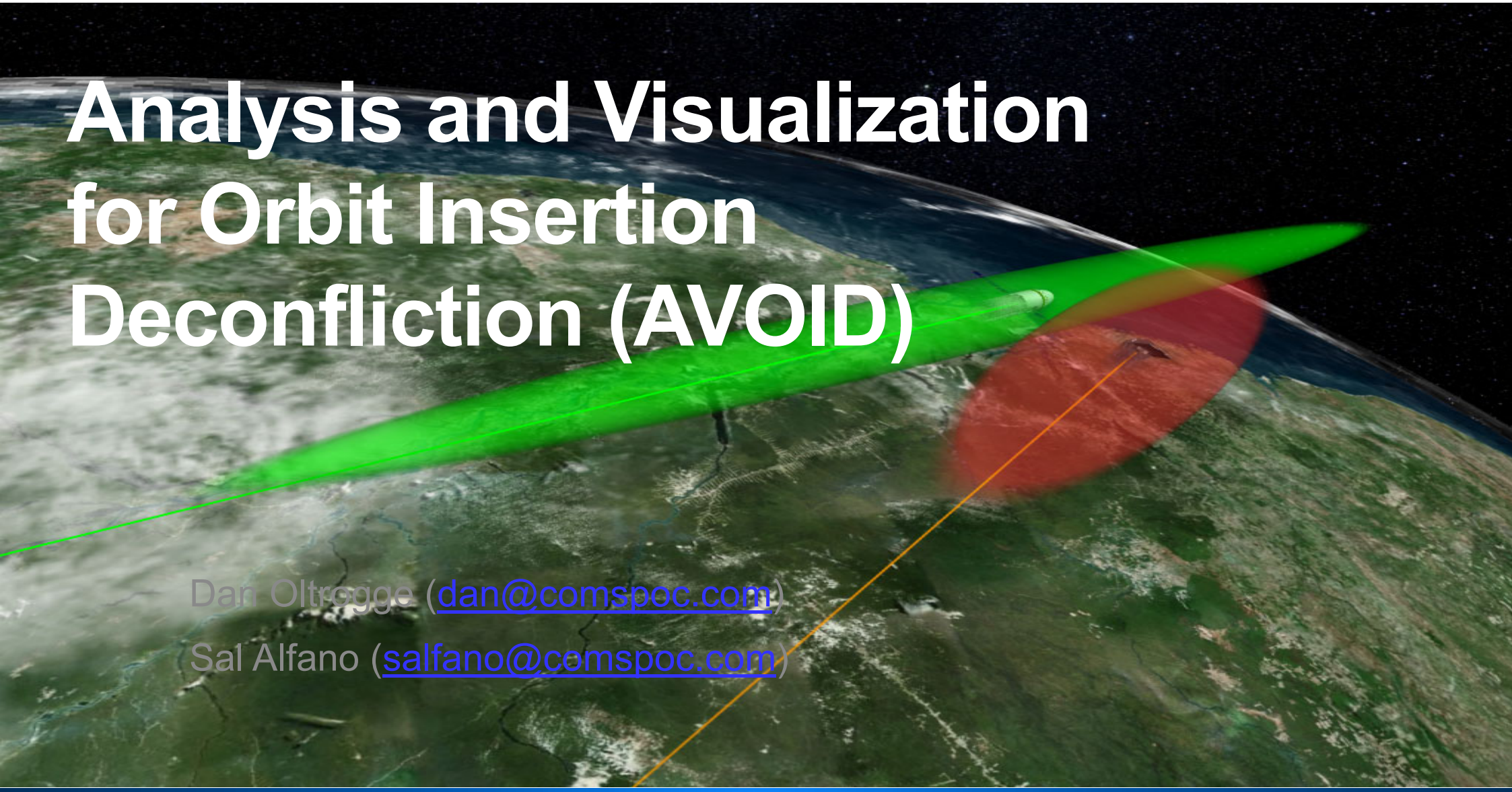
Analysis and Visualization for Orbit Insertion Deconfliction (AVOID)



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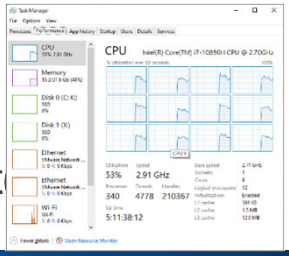
Typical “Discretized” LCOLA process

- Filters out secondaries based upon perigee and apogee of launched/deployed objects
- Digitally sample times across launch window (“Top of the minute”, 10 sec, 1 sec, etc.)
- For each sampled time:
  - Transform launch trajectory to inertial frame
  - Identify close approach to secondaries and report launch closures
- Assimilate all results to create integrated set of closure intervals

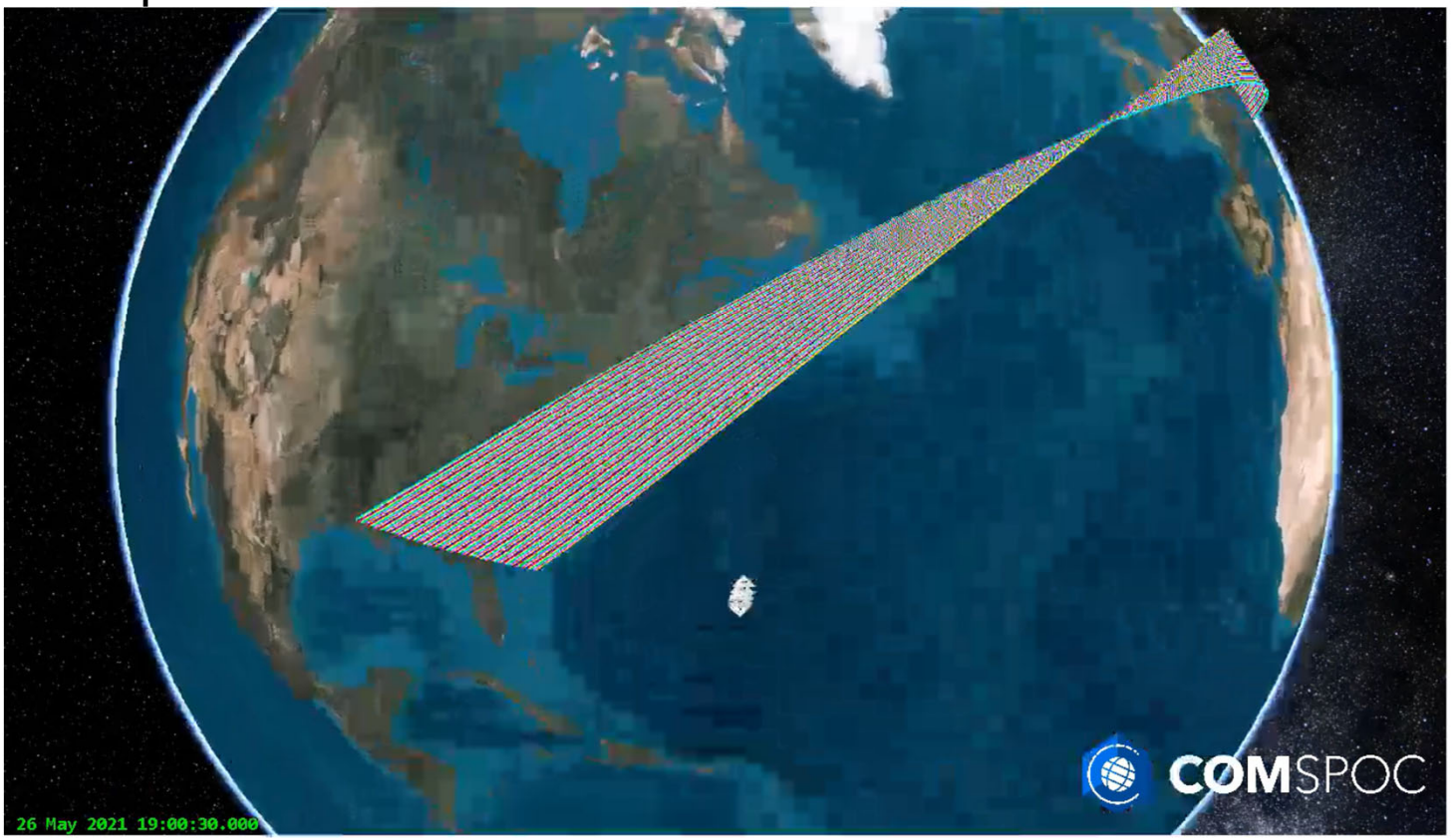
Step size:	60 sec	10 sec	1 sec	0.5 sec
Time (20 min LW)	¼ min	1.5 min	18.6 min	43.4 min
Time (12 hr LW)	0.16 hr	0.96 hr	11.18 hr	26.04 hr

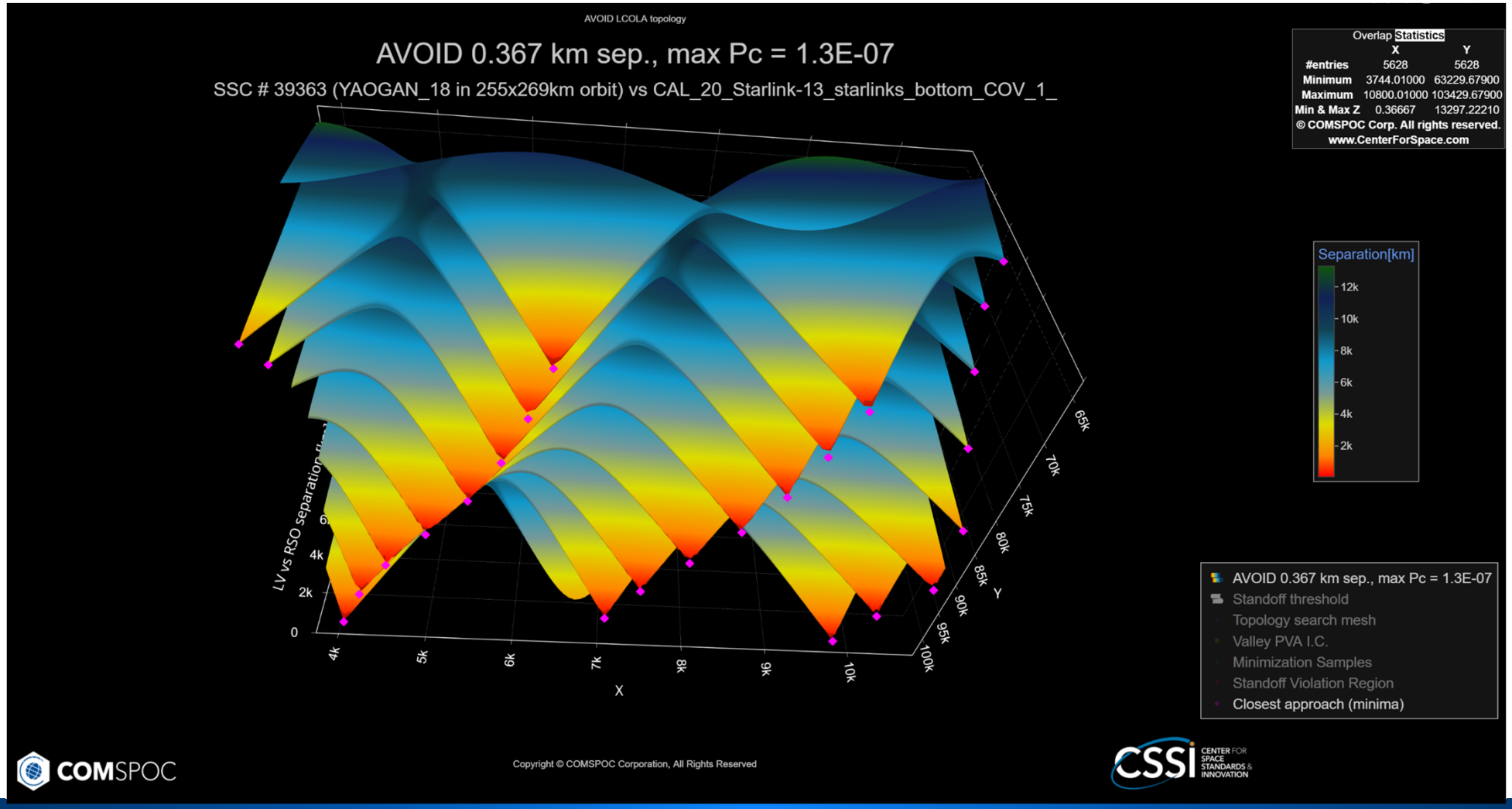
- Assessed 26 May Starlink launch (11 launch trajectories)
  - 850 standoff and 53 Pc violations found (valid for ANY launch time)
  - Run took 20 min for SP Ephem I/O and 7 min for CA screening on standard Dell lapt

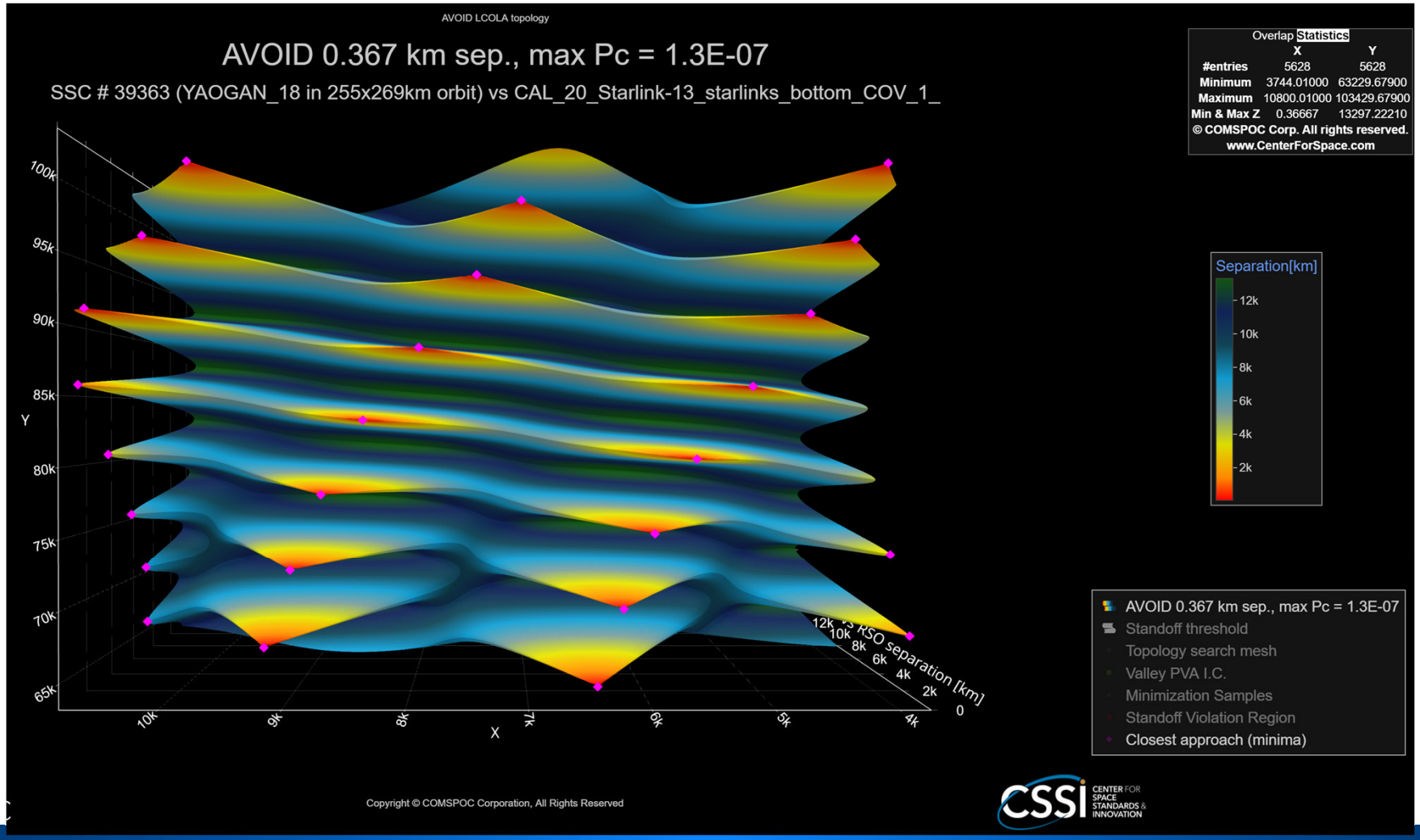


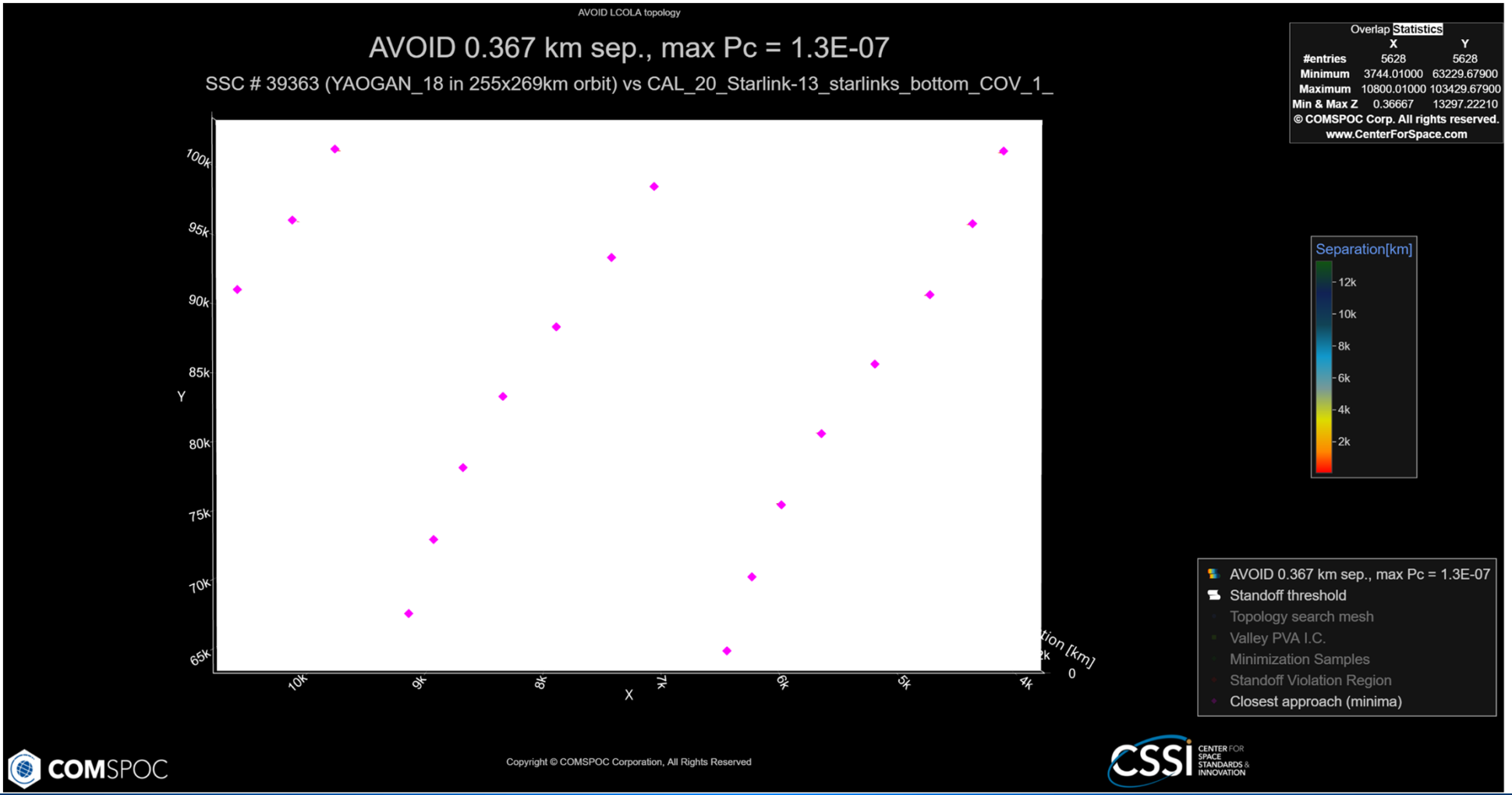
Launch “Fan” discretization approach

- Typical LCOLA tools discretize launch time – yet analyses indicate that a very tiny time step would be required not to miss LCOLA violations.







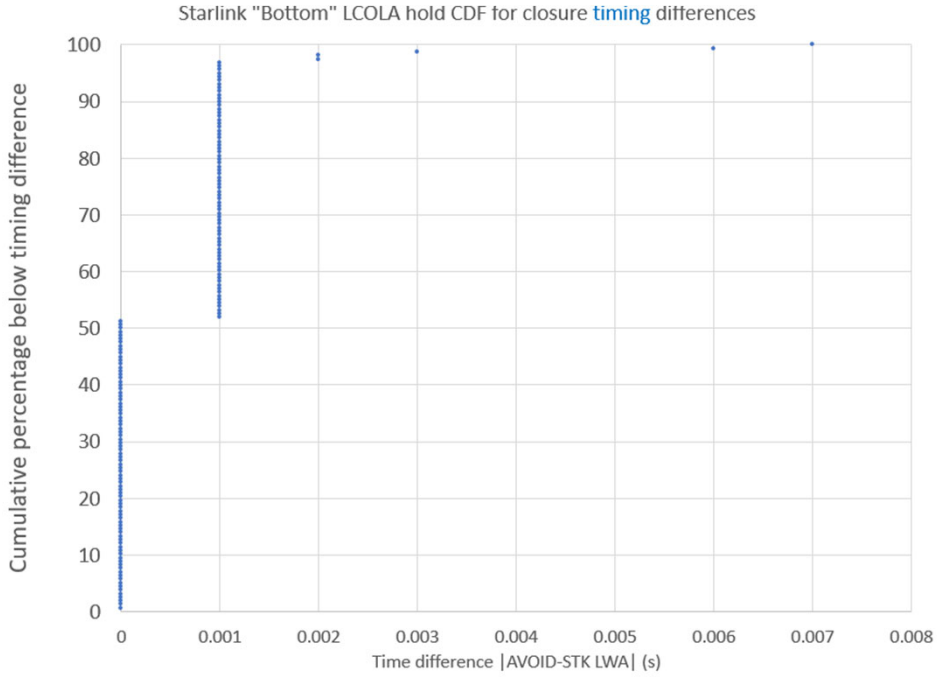


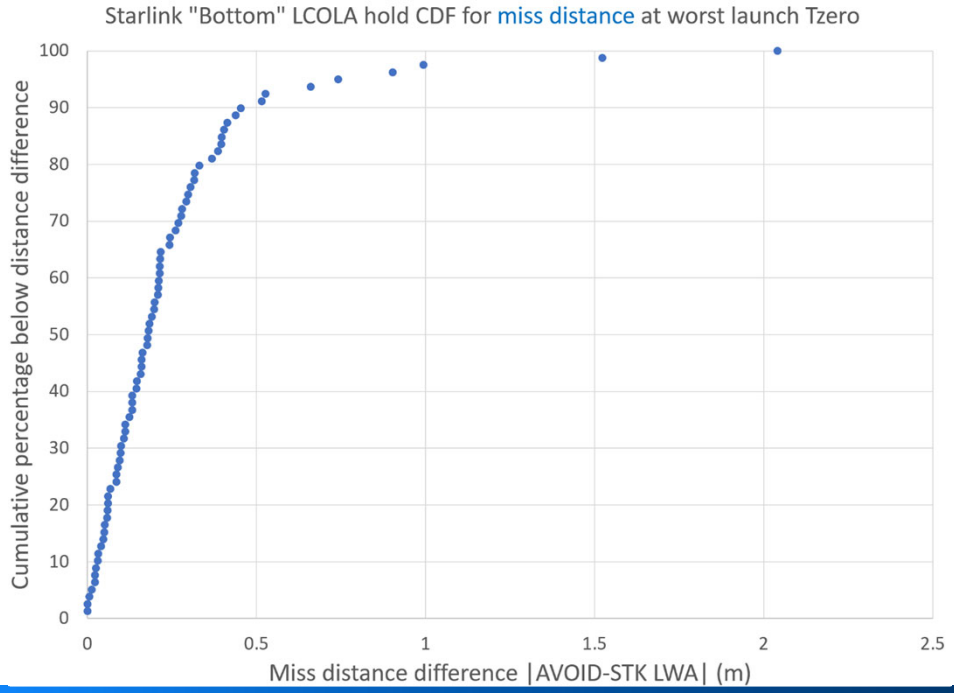
Summary

- Typical LCOLA approaches discretize launch window.
  - Conjunction threats easily missed if step size is not extremely small.
  - Very long analysis runtimes prevent “any time launch.”
- Topology-based LCOLA approach (AVOID) has the following traits:
  - Maximizes launch window availability;
  - Accommodates all deployed objects (can even model ships, air traffic, UAVs, airships, hypersonics);
  - Scalable parallel processing and topologies for rapid assessment;
  - LCOLA screening for miss distance, collision probability or both;
  - Screens entire launch window, unconstrained to “top-of-the-minute” or discretized launch times;
  - Tests covariance for positive-definiteness and remediates if necessary;
  - Post-processing accommodates “top-of-the-minute” or other constraints;
  - Assembles a single set of launch holds for the launch director/team;
  - Verified against both STK LWA and STK AdvCAT.

Comparison with STK Launch Window Analysis (LWA)

- Topology-based LCOLA tool extensively compared with AGI's LWA Tool
  - Window closure times are within ten milliseconds
  - Close approach distances less than a few meters
  - Convergence tolerances are user-configurable in both tools (AVOID + LWA)





Comparison with STK AdvCAT product

- STK AdvCAT heavily verified and used operationally for flight safety and analysis
- Another independent check: Used AdvCAT on launch trajectories epoched to AVOID launch closure times for both distance-based and probability-based thresholds.
- Sample compar
  - AVOID:

MET-CA [s after T-0]	Dist Entry (km)	Dist Closest (km)	Dist Exit (km)	Pc Entry	Pc (worst T-0)	Pc Exit
4941.8	25	.304	25	1.0e-7	3.85e-6	1.0e-7
10298.6	25	.366	25	1.0e-7	2.68e-6	1.0e-7

  - STK AdvCAT:

MET-CA [s after T-0]	Dist Entry (km)	Dist Closest (km)	Dist Exit (km)	Pc Entry	Pc (worst T-0)	Pc Exit
4941.8	25	.304	25	1.04e-7	3.85e-6	9.708e-8
10298.6	25	.366	25	1.01e-7	2.68e-6	1.02e-7

The LCOLA process

- Given:
  - Launch window, e.g., 28 Jan 21 00:00:00 UTC to 28 Jan 21 05 00:00:00 UTC
  - Launch (or “primary”) trajectory(ies)
    - Orbital stages, anticipated failure modes, all deployed objects
    - Expressed in the Earth Fixed frame as function of MET (Mission Elapsed Time)
  - On-orbit (or “secondary”) objects
- Goal:
  - Compute “Launch Closure” or “Hold” within launch window when:
    - Relative range < keepout threshold
    - Collision probability > keepout Pc threshold