CONJUNCTION ASSESSMENT SCREENING VOLUME SIZING AND EVENT FILTERING IN LIGHT OF NATURAL CONJUNCTION EVENT DEVELOPMENT BEHAVIORS

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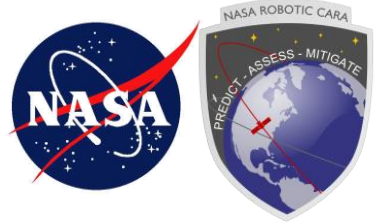


Agenda

- Current screening process
- Screening volume capture goals
- Screening volume capture actionability goals
- Screening volume maneuver planning goals
- Capture performance
- Capture with actionability performance and loading
- Maneuver planning performance and loading
- Overall performance indices
- Conjunction filtering techniques
- Conclusions and future work

Current Screening Procedure

- **Conjunction Screening is a procedure run for a primary object against a catalogue to identify close approaches (conjunctions)**
- **First, orbit-based filters run for primary and rest of catalogue**
  - Identifies object pairs for which conjunction not considered possible (such as large differences in SMA for low-eccentricity orbits)
- **Ephemerides produced for objects that survive filtering, usually 7-10 days into the future**
- **Physical volume defined about primary object**
  - Sized considering orbit maintenance difficulties of particular orbit regime and desired capture performance
- **Volume "flown" along primary ephemeris**
- **Any other satellites that fall within this volume are considered conjunctors**

Screening Volume Capture Goals

- **Certain % of conjunction events that will become "serious"**
  - Owner/operator desire
  - "Serious" usually defined as event with Pc in range of 1 to 5 E-04
- **Earlier studies tried to size for 95% capture of sorts**
  - Looked at component variances from conjunction joint covariances, but examined individually rather than ensemble
  - Did not actually achieve 95% capture but less than that, depending on propagation interval
- **Best way to assess capture performance is with empirical screening data using a large volume**
  - If volumes large enough, will encompass all serious events
  - Capture percentages can then be determined for all smaller volumes, as they are subsets of this large volume

Capture Percentages and Event Actionability

- **Purposes of early capture of serious events (*e.g.*, 7 days to TCA)**
  - Examine OD for improper settings, tracking tagging irregularities, pathologies
  - For poorly tracked-objects, submit sensor tracking increase requests
- **Can perform above tasks on only limited number of objects**
- **Thus need some marker for events likely to become serious**
  - Large number of additional events arising from screening, with no indication of which might become serious, not actually helpful to operations
- **Present rule-of-thumb for potentially serious events: Pc that exceeds 1E-07**
  - Could and should examine possible alternative indices and levels, but present operational practice good place to start

Screening Volume Maneuver Planning Goals

- **If serious conjunction persists, then remediation maneuver planned and perhaps executed**
- **Maneuver sized to bring conjunction risk down to acceptable level**
  - Before execution, proposed maneuver ephemeris sent to JSpOC for screening to ensure that maneuver not create another serious conjunction event
  - Can start worrisome cycle: screen, revise, screen, revise, &c.
- **Larger screening volumes allow most events deriving from planned maneuver to be identified / dealt with by owner/operator initially**
  - Screening results provide information on objects in vicinity of primary
  - These objects not problematic with current trajectory but after a primary maneuver could generate serious events
- **If available to O/O, can be considered in initial maneuver plan**
  - Avoids multiple maneuver screening iterations, wasting time in ops cadence
- **Screening volume should be sized to find significant percentage of post-maneuver potentially serious events**

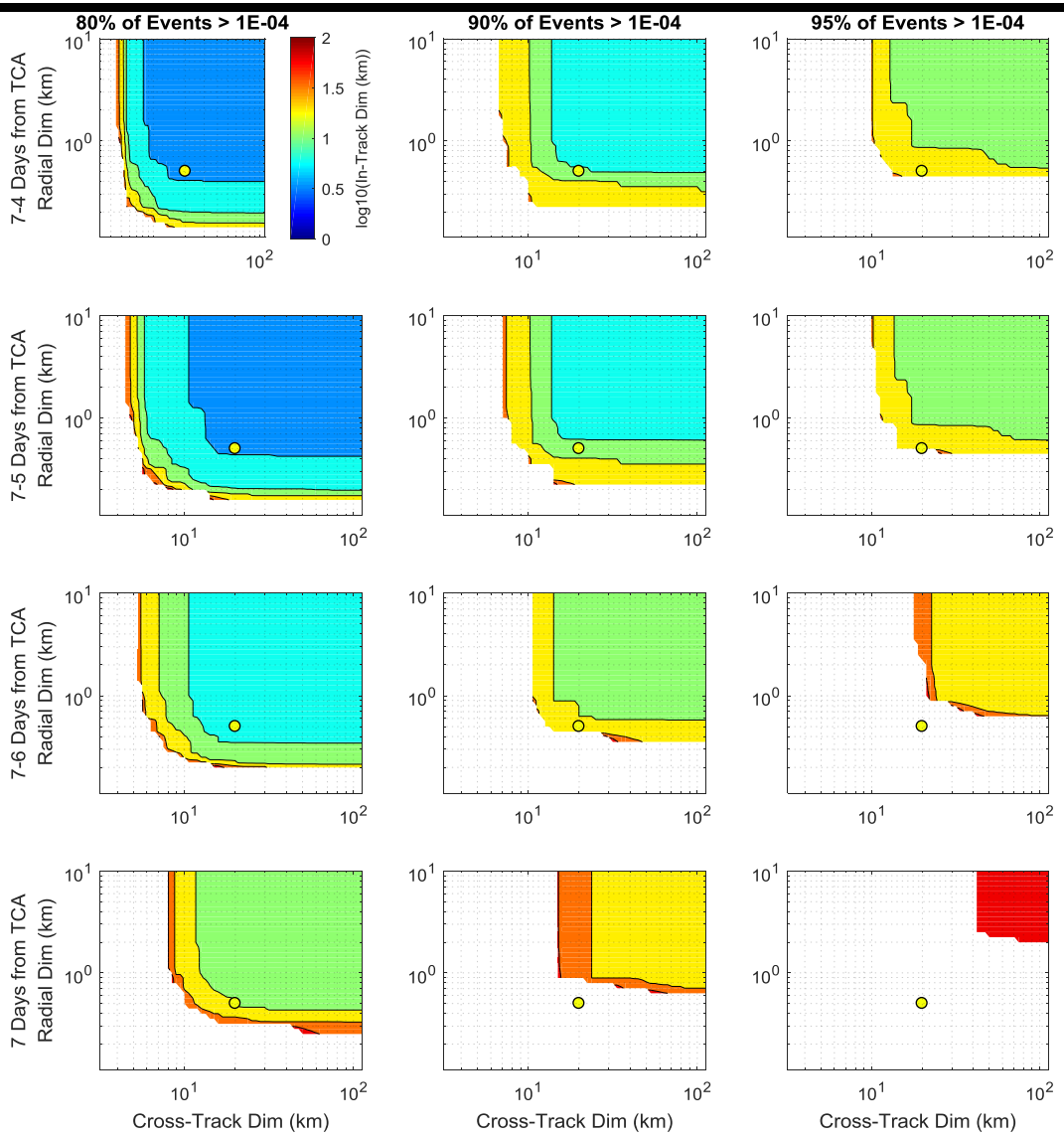
Study Dataset

- **NASA CA performed by NASA personnel on JSpOC floor**
  - Special arrangement between NASA and USAF
  - Can perform certain study activities on non-interference basis with operations
- **Through this arrangement, able to secure special screening dataset**
  - Extremely large screening volume
    - 50km radial x 250 km in-track x 250 km cross-track
  - Six months of such data: 1 OCT 2016 – 31 MAR 2017
- **For present study focus is on one orbit regime**
  - 12 protected payloads in near-circular, 700km orbits
  - Most heavily-populated and important regime for NASA CA
- **Large enough volume and dataset to allow durable conclusions about screening volume sizing**

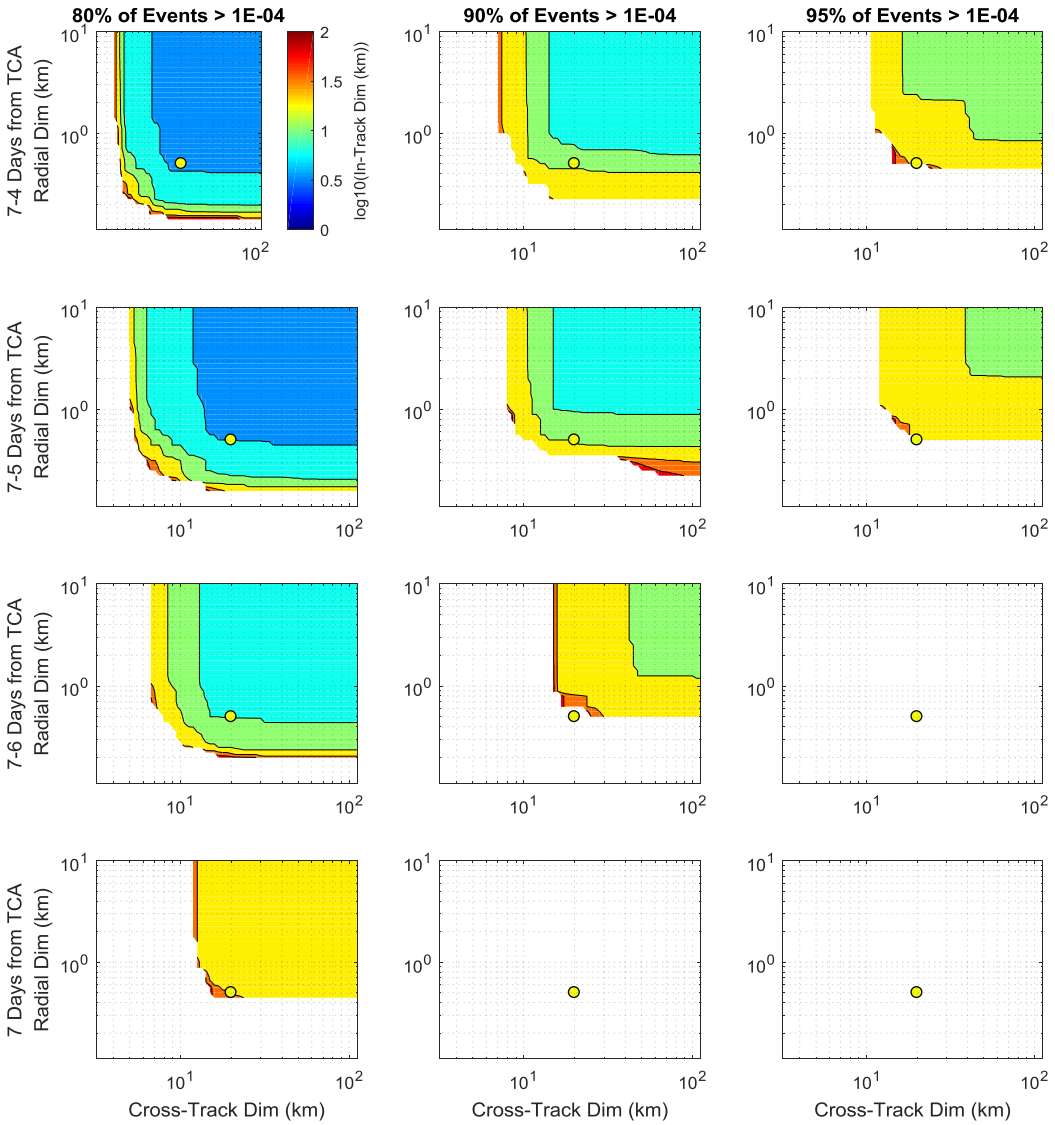
Capture Percentage Plots

- **Examined three capture levels**
  - 80%, 90%, 95%
  - 80% is anchor point; 90% probably minimum operationally acceptable; 95% probably operationally satisfactory
- **Examined three temporal periods**
  - 7 days to TCA, 7-6 days to TCA, 7-5 days to TCA
- **Results examined for following range of screening volume sizes**
  - Radial: 0.1 – 10 km
  - In-track: 1 – 100 km
  - Cross-track: 1 – 100 km
- **How to read plot**
  - X-axis is cross-track range; Y-axis is radial range; color is in-track value
    - Color set to meet capture percentage with associated radial and cross-track values
  - Point is current screening volume size for this orbit regime
    - 0.5 R x 17 I x 20 C

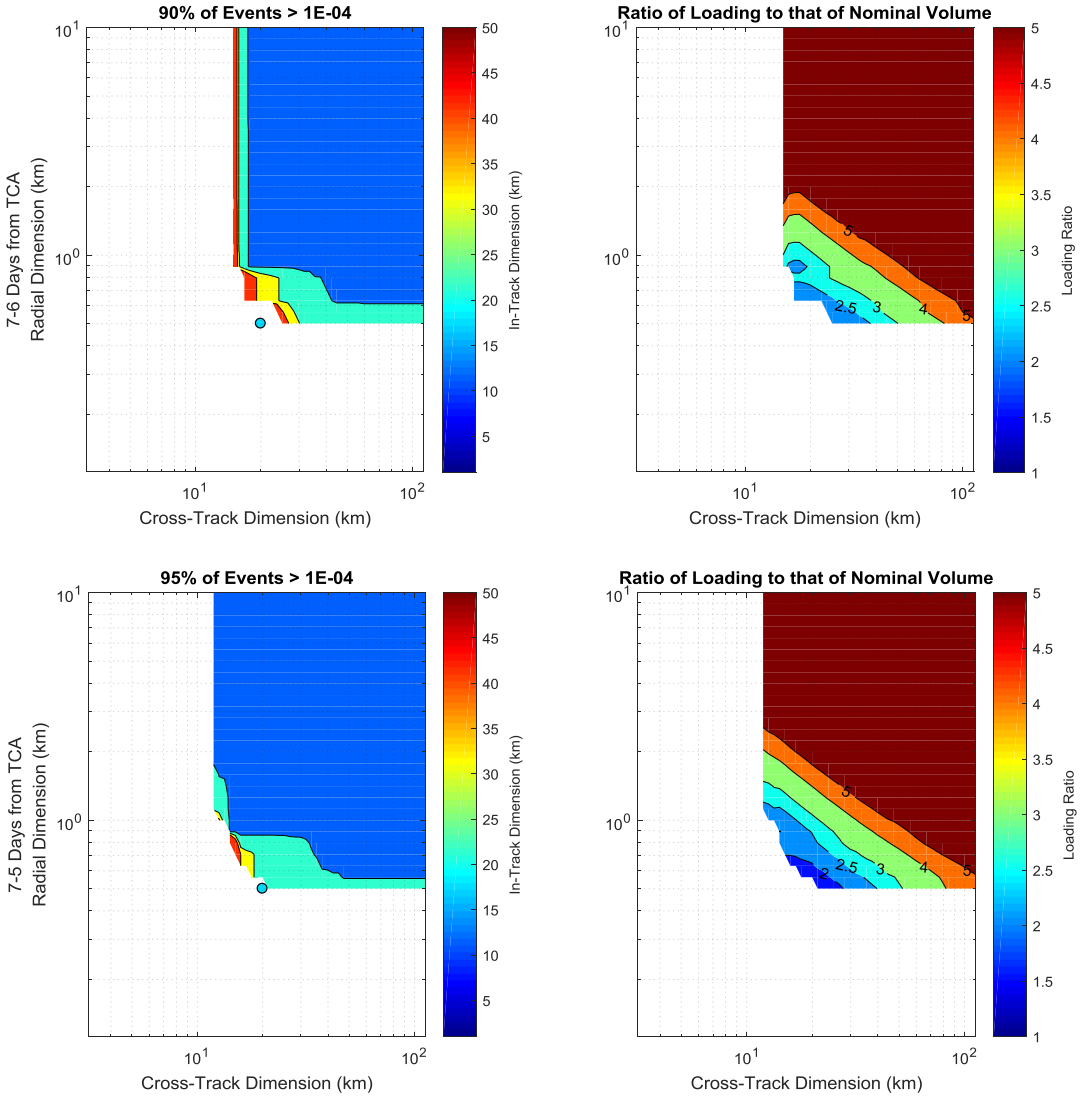
Capture Percentage Results



Capture Percentage Results in which Pc of 1E-07 Required for Significant Event



Loading Charts for 90% and 95% Capture Percentages



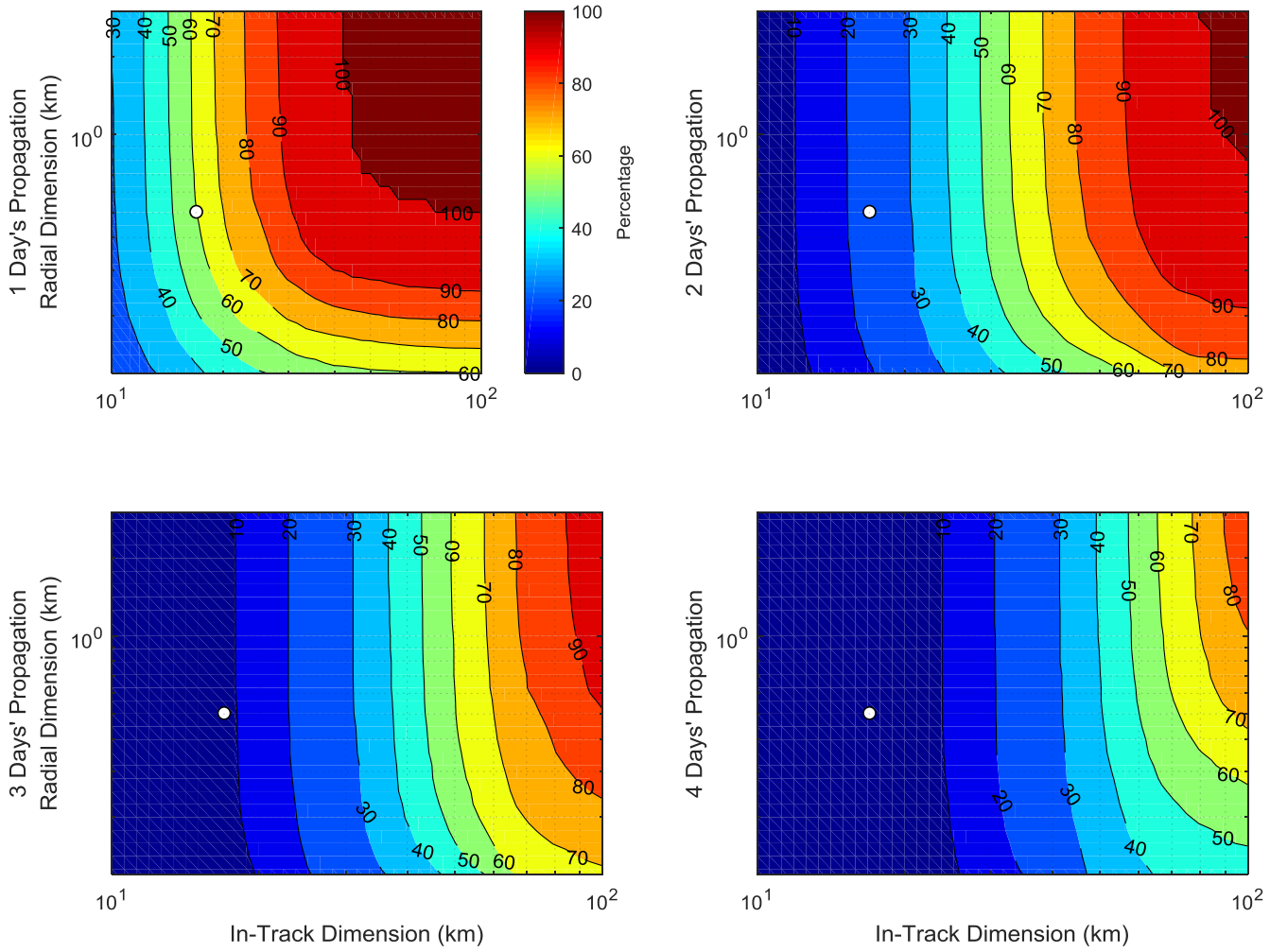
Capture Percentage Results: Takeaways

- **At usual values of serious (1E-04) and potentially serious (1E-07) events, limit to what can be accomplished by geometric screenings**
  - At longer from TCA, not possible to identify potentially serious events by current measuring approaches
  - Continuing to increase screening volume sizes not helpful, as this merely produces more “chaff” events that cannot be singled out for investigation
- **Current screening volume size close to what might be considered reasonable performance levels**
  - ~90% (actual value 85%) at 7-6 days to TCA
  - ~95% (actual value 90%) at 7-5 days to TCA
- **Modest increase in screening volume size can achieve these performance levels with probably tolerable loading increase**
  - 0.5 x 17 x 20 km to 0.6 x 30 x 25 km, will give 90% and 95% performance, with increase in loading by factor of 1.5 to 2

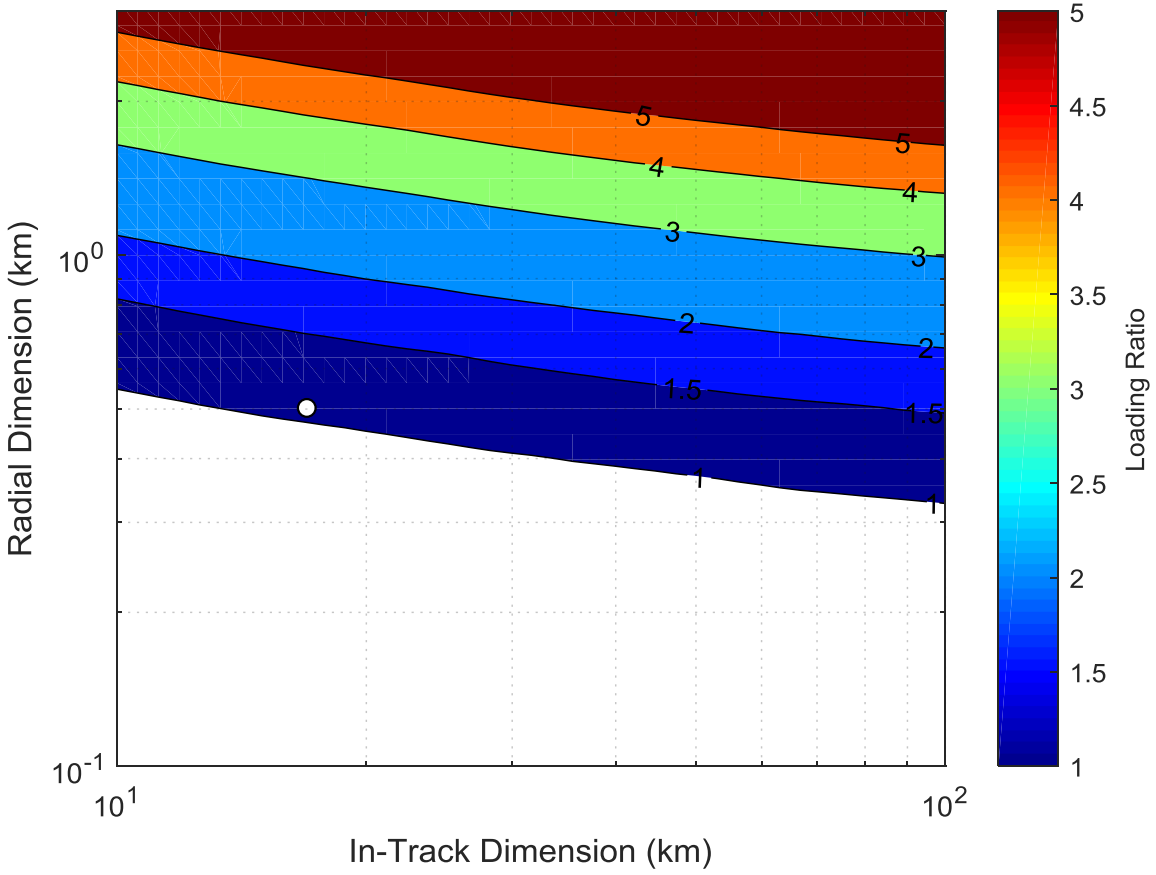
Screening Volume Performance in Support of Maneuver Planning

- **Obtained DMU maneuver history information for three of the 12 spacecraft under analysis (Aqua, Aura, Terra)**
- **Several years' maneuver history; ~125 total DMUs**
  - Most of burn in-track; but other components, especially radial, non-zero
- **For each maneuver, propagated forward both perturbed and unperturbed case and executed comparison**
  - Examined residuals at 1, 2, 3, and four days' propagation
- **Calculated capture percentages of different screening volume sizes for the maneuver residuals**
  - Gives indication of screening volumes' abilities to identify conjunctions that could become significant after a maneuver
- **Not a perfect characterization; maneuver sizes dependent on space weather, satellite placement strategy within control box, &c.**
- **However, adequate to give general characterization of capture**

Maneuver Capture Percentage Results



Maneuver Capture Loading Results



Summary Table of Results

- **Smallish changes in current volume allow full 90% / 95% compliance**
- **Increasing in-track component of screening volume quite effective in capturing large % of DMUs with relatively small loading penalty**
  - Increase to 100km achieves ~70% capture of maneuvers at loading increase factor of 1.5
- **Performing both achieves both performance goals at additional loading factor of slightly over 2**

R (km)	I (km)	C (km)	% Capture at 7-6 Days	% Capture at 7-5 Days	Loading Scale Factor	Comment
0.5	17	20	85	90	1.00	Nominal volume size
0.6	30	25	90	95	1.65	Small change to meet reqt
0.5	100	20	88	94	1.48	Change I to 100km only
0.6	100	25	90	96	2.14	Both small changes (row two) and I set to 100km

Filtering Techniques to Reduce "Chaff"

- **Alfano—maximum Pc construct**
  - At particular miss distance, determines covariance to produce maximum Pc
    - Either absolutely (degenerate) or within bounds from profiled catalogues
    - Objects with Max Pc less than serious threshold can be discarded
  - Not helpful if trying to preserve conjunctions useful for maneuver planning
    - Present large miss distances will become small miss distances after maneuvers
- **George and Chan**
  - Interesting procedure of setting miss distance to 0, combining primary and secondary covariances in maximal way, and computing Pc
    - If Pc below threshold, can discard since covariances should only shrink with time
    - Not quite true for maneuver situation, as tracking and maneuver execution error can increase covariance; but still reasonable proposal
  - However, calculated Pc so "maximal" that few events removed
    - At serious threshold of 1E-04, only *ca.* 5% eliminated, at propagation times from seven to four days to TCA
- **Neither approach particularly useful here, given the situation**

Conclusions

- **If actionable screening results desired, then intrinsic limit to what can be provided by volumetric screenings**
- **For orbit regime analyzed, slight increase to volume allows reasonable requirements compliance**
  - 90% at 7-6 days to TCA; 95% at 7-5 days, at modest loading increase
  - 1 out of 20 serious events will be a < 5 day “surprise”; not much to be done about this
- **Volumes can be extended quite a bit in in-track direction with relatively small loading penalty**
  - Capture > 70% of maneuver-induced serious events (at 4 days’ propagation)
  - Loading increases by factor of only 1.5 to 2, depending on whether volume dimension alterations were made

Future Work

- **Apply analysis to other orbit regimes**
- **Perform additional sensitivity analysis around thresholds**
  - Potentially superior results can be achieved with relatively small changes to the two governing “serious” and “potentially serious” Pc thresholds
- **Perform analysis against Space Fence simulation datasets to determine if performance and loading factors appear similar**
- **Investigate the Mahalanobis distance as potential additional discernment parameter**
  - Informal evaluation by authors produced unpromising results, but analysis should be formalized and published