CARA Risk Assessment Thresholds

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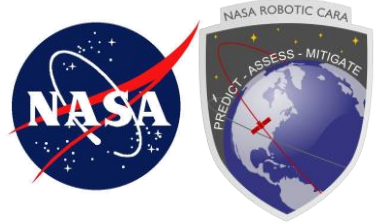
MAY 2016

CARA Threshold Types

- **Warning / remediation threshold ("Red" threshold)**
  - Pc level at which warnings are issued, and active remediation considered and usually executed
- **Analysis threshold ("Green to Yellow" threshold)**
  - Pc level at which analysis of event is indicated, including seeking additional information if warranted
- **Post-remediation threshold**
  - Pc level to which remediation maneuvers are sized in order to achieve event remediation and obviate any need for immediate follow-up maneuvers
- **Maneuver screening threshold**
  - Pc compliance level for routine maneuver screenings (more demanding than regular Red threshold due to additional maneuver uncertainty)

CARA Thresholds Development Status

- **Red and Green-to-Yellow thresholds established**
  - Type 1 and Type 2 error analysis
  - Imputed workload analysis
- **Post-remediation threshold methodology in work**
  - Rule-of-thumb in place presently
  - Analysis avenues for more robust approach
- **Approach envisioned for post-remediation threshold can also be applied to maneuver screening threshold**



RED AND YELLOW-GREEN THRESHOLD DETERMINATION

The CARA "Worktier" System Defined

- **System for determining how much induced work a given event commanded**
  - Worktier 1: e-mail contact and follow-up with O/O
  - Worktier 2: HIE package produced and briefing delivered
  - Worktier 3: RMM planning conducted
  - Worktier 4: RMM executed
- **Worktier level a good proxy for seriousness of event**
- **Worktier level thus used as "truth" criterion to choose red and green Pc thresholds**
  - Worktier 2+ recommended as particular level to use, meaning high-risk event set defined as those with a worktier level of 2 or higher
  - Plots will, however, show performance at all four worktier levels (1+, 2+, 3+, and 4)

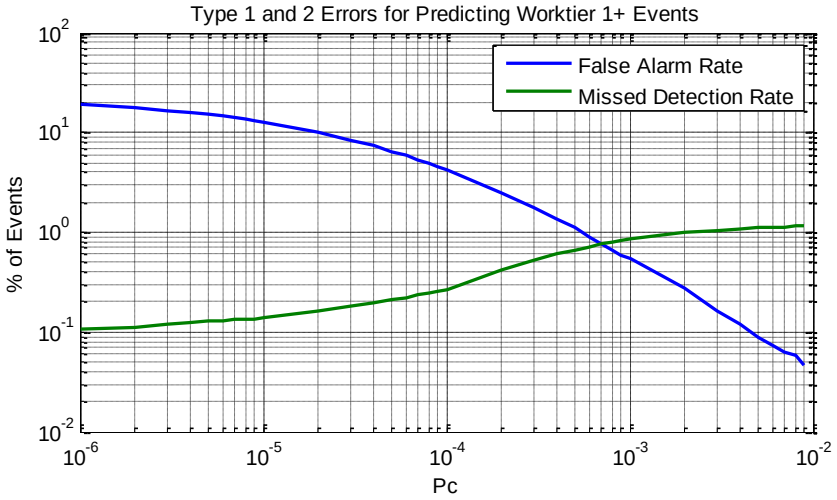
Worktiers and Pc Threshold Circularity

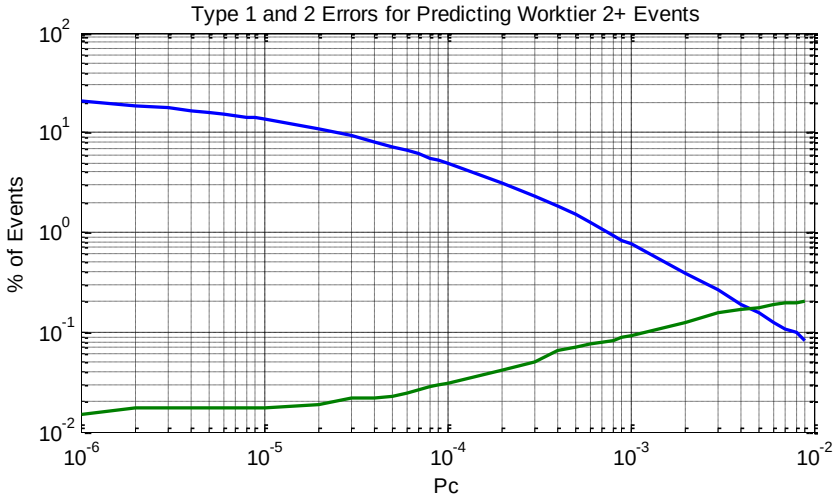
- **Worktiers reasonable proxy for seriousness of event**
- **However, Pc levels presently used to establish seriousness**
  - Thus, must be careful in using historical worktier data to set Pc levels—easy to devolve into circular argumentation
- **Original examination used dataset from period before Pc thresholds established and in place**
  - Thus legitimate dataset from which to establish threshold set
- **For this reason, updates to original values no longer easily achievable through data mining**

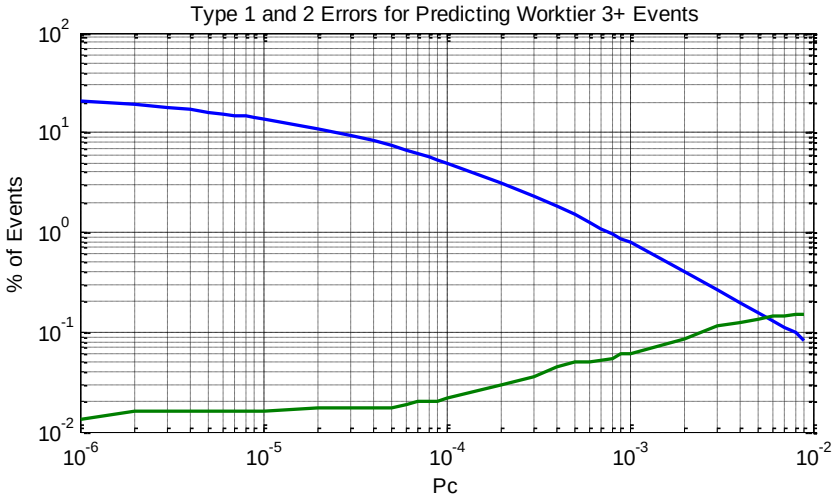
Exploratory Analysis: Event Maximum Pc as Predictor of Worktier

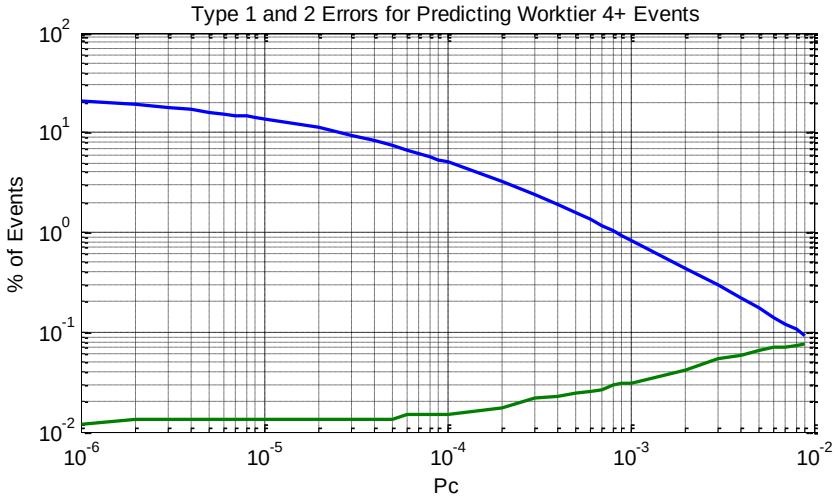
- **How good a predictor of the eventual work tier assignment is the maximum Pc during the event?**
- **Examined all events in 2011-2013**
- **One graph for each work tier**
  - Quad-chart format shows results for each cumulative worktier level
- **False alarm rate (blue line): % of cases in which the Pc indicated a serious event but the event was actually not high-risk**
  - Also called a “type 1” error, and is a nuisance factor
- **Missed detection rate (green line): % of cases in which the Pc indicated a non-high-risk situation but the event actually was high risk**
  - Also called a “type 2” error, and is the more serious error type

Event Maximum Pc as Predictor of Worktier: Results









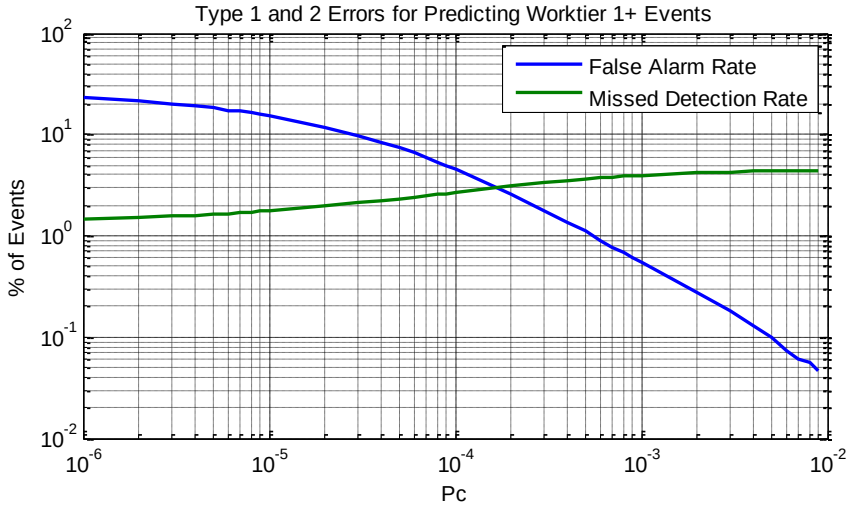
Event Maximum Pc as Predictor of Worktier: Interpretation of Results

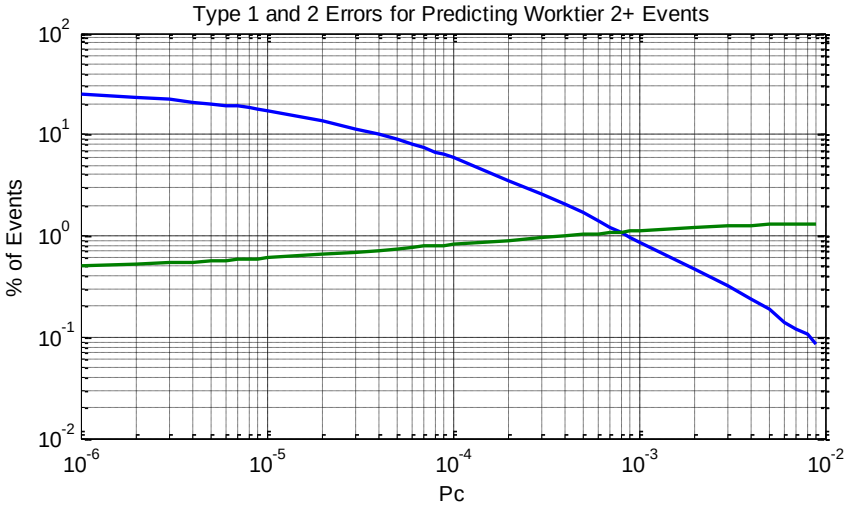
- **Interpretive questions center on tolerable levels for the type 1 and type 2 errors**
- **Type 2 error rates**
  - 0.01% to 0.1% for a 1E-05 to 1E-03 Pc threshold range—quite small
  - Events that are just below the red threshold can be promoted manually red and thus be processed as HIEs
- **Type 1 error rates**
  - Range from 10% to 0.5%--again, not very large and seemingly tolerable
- **Overall construct thus looks promising**

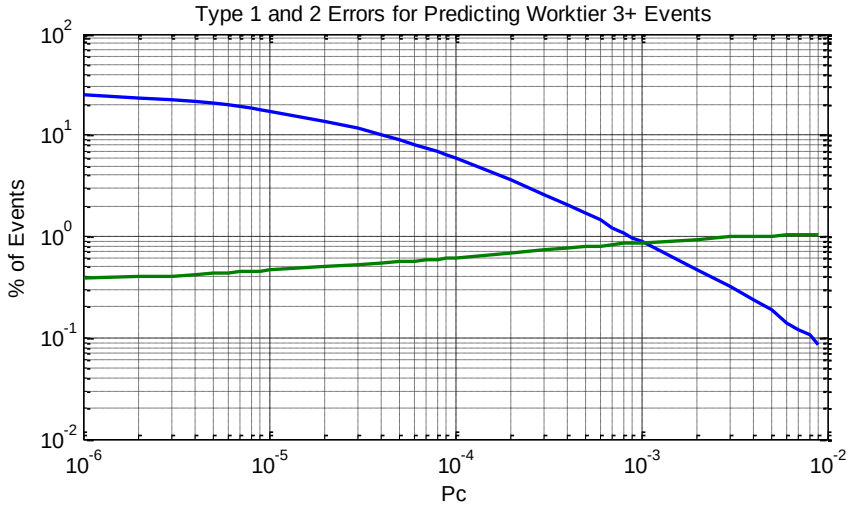
Individual Event CDMs as Predictor of Worktier

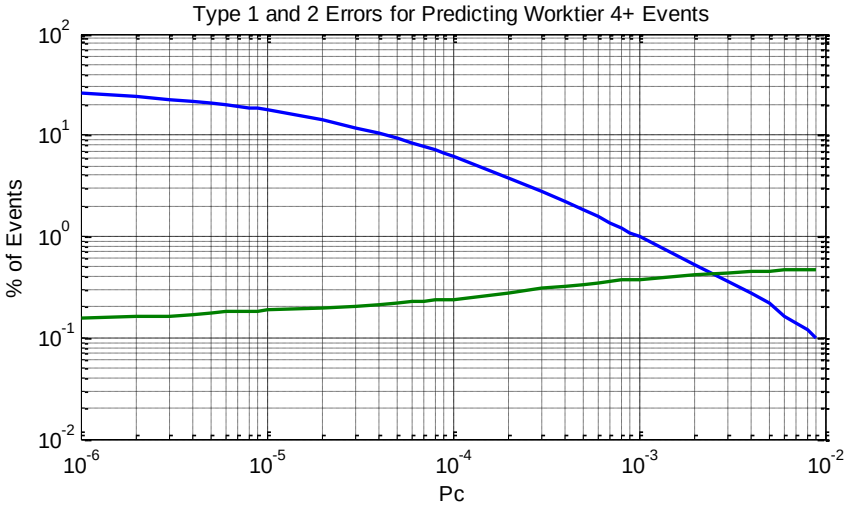
- **A typical event consists of a chain of CDMs from 7 days to 1-2 days from TCA**
- **These usually begin with a smallish Pc value and increase to a maximum, then decrease somewhat rapidly**
- **Question now is how well each pre-max Pc value will predict the eventual worktier level of the event**
  - This is the way CONOPS will actually operate
- **Certain to perform worse than using only the max Pc value as a predictor**
  - But may still perform quite adequately for CONOPS purposes

Individual Event OCMs as Predictor of Worktier: Results









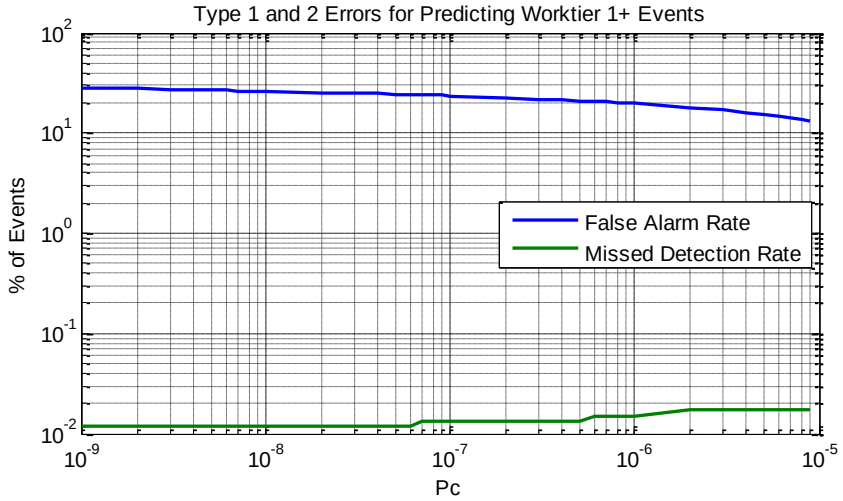
Individual Event OCMs as Predictor of Worktier: Interpretation

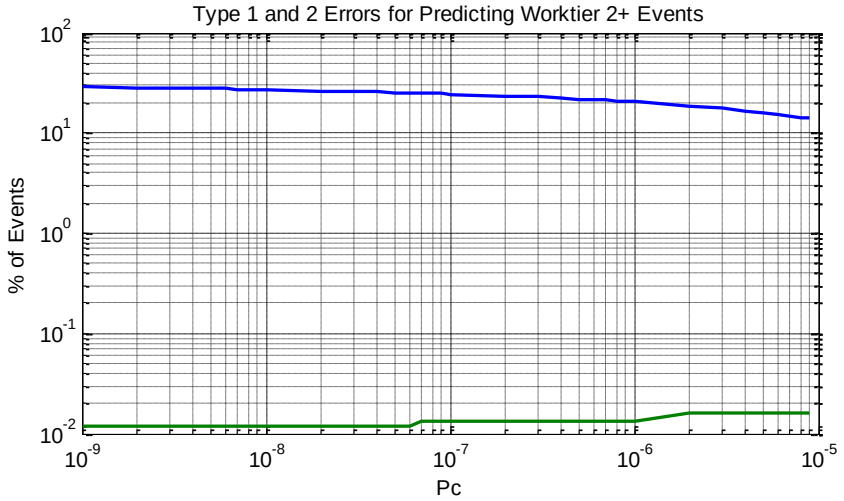
- **As expected, performance is worse with this arrangement**
- **Type 2 error rates higher**
  - These are between 0.5% and 1% for the 1E-05 to 1E-03 range
  - Not blissfully low, but not particularly surprising or disturbing given what is being attempted
    - Initial relatively low Pc values in an event not readily predictive of event destiny
    - Consequence is not a missed event, only that event will not be caught as early
  - Curve relatively flat, especially below 1E-04
    - Very little marginal gain from choosing a lower threshold (*e.g.,* 1E-05)
- **Type 1 error rates not very different from previous**
  - Not surprising, given typically lower Pc values at the beginning of events
    - Rare that early-event Pc would exceed red threshold, not be the maximum Pc, and then drop sufficiently quickly that event would not remain an HIE

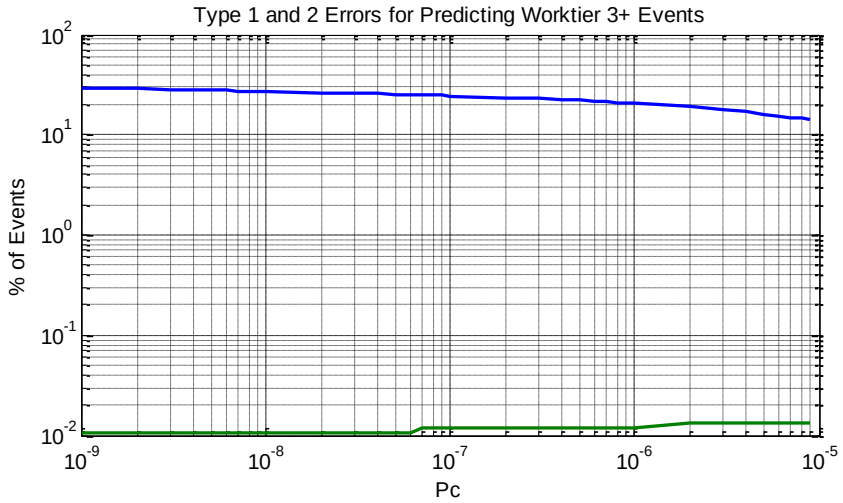
Green-To-Yellow Threshold

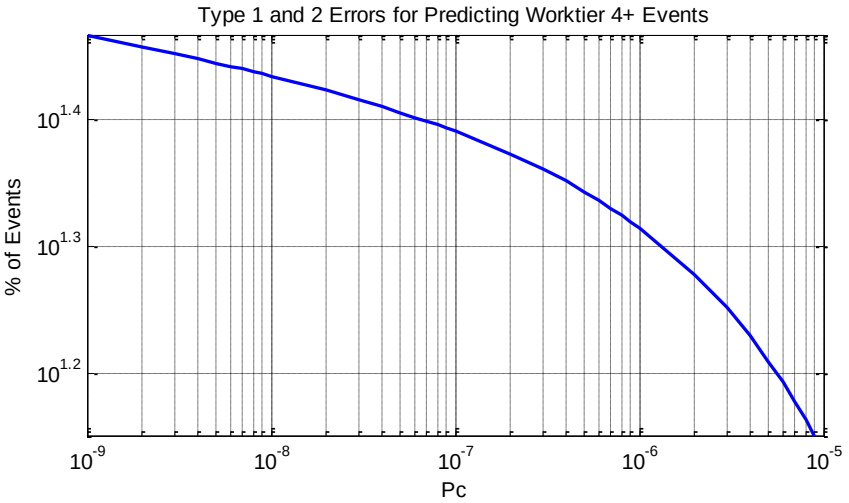
- **Idea is to set a lower bound on Pc so that events with a Pc below this threshold will almost never become high-risk events**
- **Type 1 error: Pc is above this threshold but never becomes high risk**
  - Not really a false alarm, as it is expected that the great majority of non-green Pc values will remain yellow and never become high risk events
  - However, to maintain parallelism with construct used for setting red threshold, appropriate to label it a Type 1 error
- **Type 2 error: Pc is below this threshold but becomes high risk**
  - Even here, the problem is not particularly serious: events are not missed but just have their true severity discovered somewhat later
- **Investigate against all pre-max-Pc OCMs in each event**

Green Threshold Performance: Pre-max-OCMs in each Event









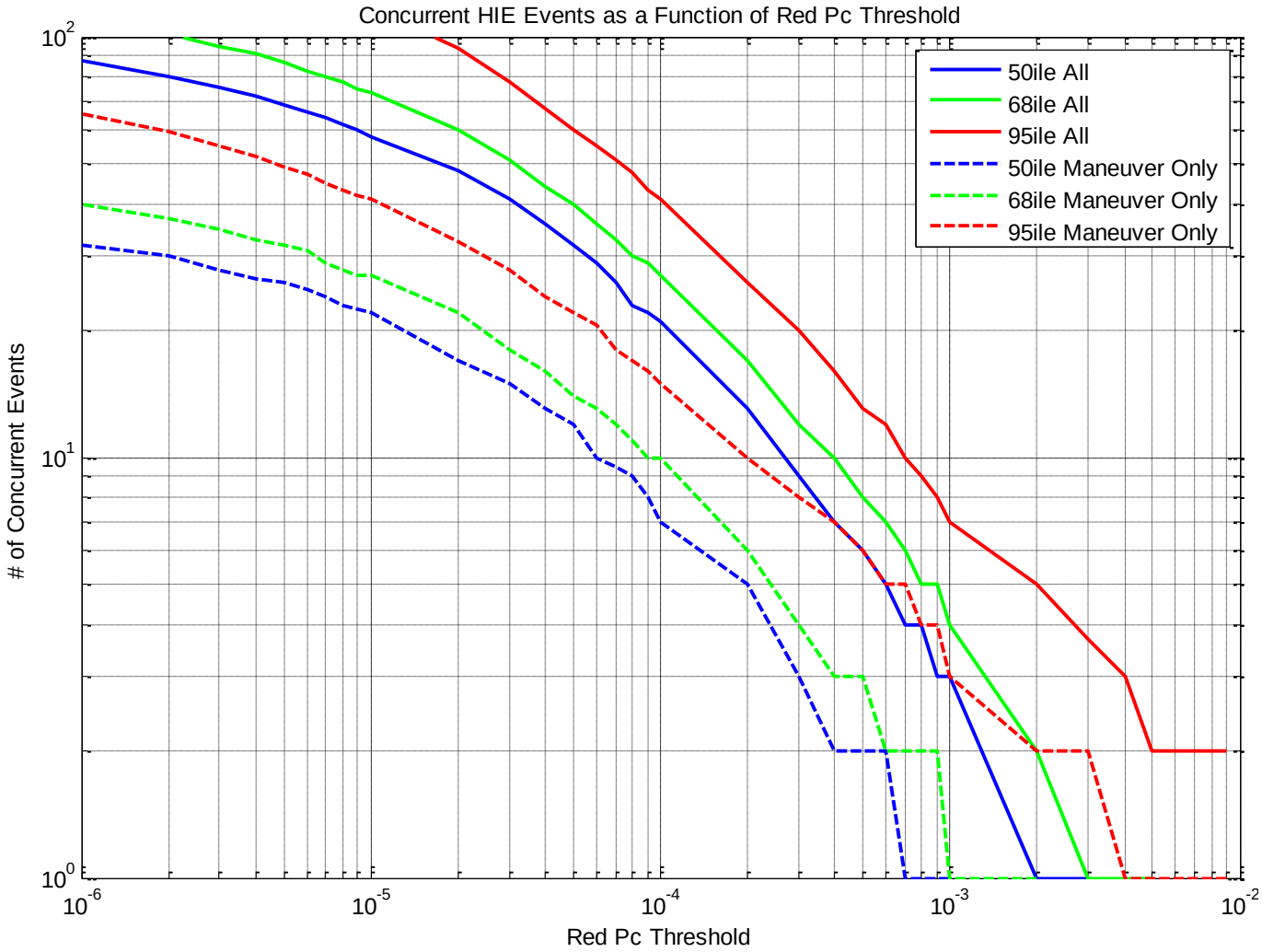
Green Threshold Performance: Interpretation

- **Type 2 error performance**
  - Stable at 0.015% for 1E-08 to 1E-06
  - Numbers quite low
- **Type 1 error performance**
  - Ranges from 30% to 20%
  - Numbers seem high, but actually have little significance
    - Essentially # of yellow events that never become red—this is expected

Concurrent Events

- **If an event's Pc exceeds the red threshold, it becomes an HIE**
  - Usual dynamics is for the event to remain at this level until TCA
- **Can thus determine the number of concurrent HIEs implied by a particular red threshold**
  - # of concurrent HIEs per day over the 2011-2013 period
  - Summarized by 50th, 68th, and 95th percentiles
  - Separate lines for all satellites and maneuvrable satellites only
- **Graph on next slide**

Concurrent Events Plot



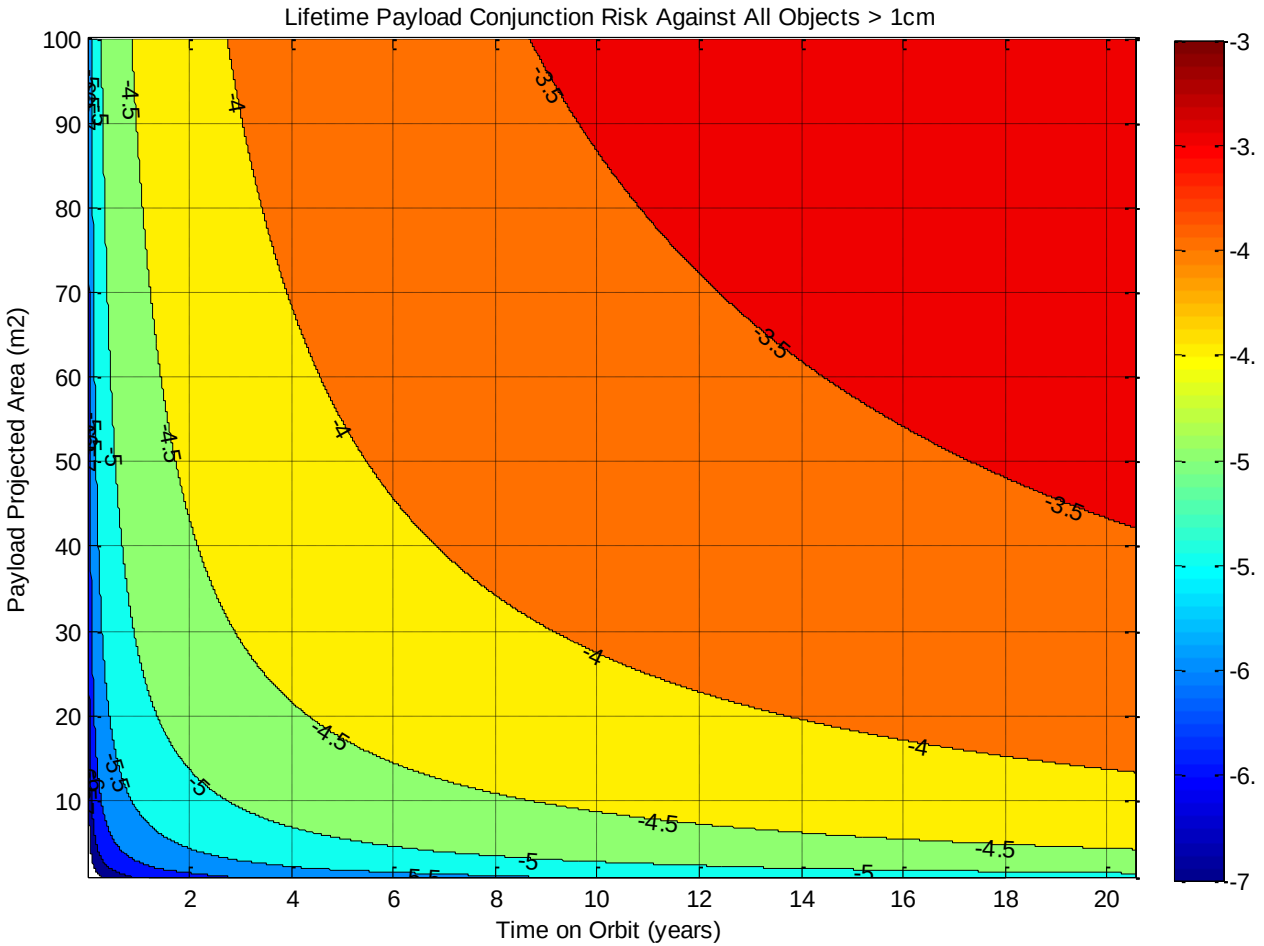
Concurrent Events: Interpretation

- **Workload becomes problematic around 5E-04 with current staffing**
- **Must also consider imputed workload on missions with more frequent HIEs**

Satellite Lifetime Conjunction Risk

- **Aerospace study developed factor for satellite lifetime conjunction risk calculation**
  - 1E-08 per 10 m^2 of spacecraft projected area per day
  - Based on older version of ORDEM and not orbit regime dependent, so a durable result would require re-execution of the study
  - However, factor can be used to produce results to provide orientation
- **Contour plot gives composite satellite conjunction risk as a function of spacecraft size and years on orbit**
  - Colors represent log10(Pc)

Lifetime Conjunction Risk Contour Plot



Satellite Lifetime Conjunction Risk: Interpretation

- **Satellites with a reasonable lifetime on orbit (~10 years) and a non-trivial size (~4m^2) have a lifetime conjunction risk of ~3E-04**
- **Does not make sense to remediate conjunctions with a risk much smaller than this**

Overall Summary

- **Analysis does not point to single value for red or green threshold**
- **However**
  - Region between 1E-04 and 5E-04 seems to be a reasonable choice for red threshold
    - Type 2 error rates OK (0.05% or so)
    - Type 1 error rates OK also (~5%)
  - Not much improvement in situation in choosing a smaller threshold
    - Type 2 error curves relatively flat
  - Workload, however, does increase substantially when smaller threshold chosen
  - Smaller thresholds begin to approach lifetime conjunction risk values, most of which is due to untrackable small debris
- **CARA ~4E-04 choice, while not made inevitable by this analysis, is reasonably supported by it**

POST-MANEUVER THRESHOLD DETERMINATIONS

CARA Post-Remediation Threshold

- **Current recommendation is to choose maneuver to reduce cumulative Pc to 1E-10**
  - Rule of thumb that has arisen over the years
  - Intent is essentially to eliminate need for follow-up maneuver because original maneuver inadequately sized
- **Many missions now push back against this conservative value**
  - Can put missions outside of control box
  - Even if executable, can consume large amount of fuel
  - No rigorous justification at present for value
- **Sketch of expected approach to resolution to follow**

Pc Uncertainty and Post-Maneuver Remediation

- **Pc Uncertainty construct pursued by CARA for years; briefed recently at AAS (paper 16-241)**
- **Considers all of the uncertainties in the input parameters to generate a PDF of Pc values, rather than a single value**
- **Can use to determine likelihood of obtaining a Pc of a certain value or higher at a given percentile point**
  - E.g., 5% or lower chance that the Pc will exceed 1E-04
- **Can incorporate into Maneuver Trade-Space functionality**
  - Function presently produces contour plot of Pc as a function of maneuver size and maneuver execution time (phasing)
  - Pc uncertainty can be used instead to give the likelihood of the post-maneuver Pc exceeding a specified threshold
    - Perhaps 4.4E-04 or 1E-05 (red and maneuver planning thresholds)
    - Graph could show likelihood of Pc exceeding 1E-05; perhaps choose 2% or less
  - Frames output in terms of likelihood of post-maneuver high risk
  - Works best if maneuver execution error incorporated into construct

CARA Maneuver Screening Threshold

- **Same approach as for RMM sizing can be used**
- **Both canonical threshold and percentile point could be different**
- **Setting of percentile points can be informed by regular operational practice**
  - i.e., percentile point to be used when evaluating red threshold under regular conditions