National Aeronautics and Space Administration

The Effects of Space Weather on Space Situational Awareness

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PREDICT—ASSESS—MITIGATE

NASA ROBOTIC CARA

www.nasa.gov

Background: Space Weather Impacts on Satellites

- Particle bombardment
  - Electrical charging
  - Ionization events
- Satellite disorientation
- Communication loss
- Increased atmospheric drag
  - Satellite position
  - Covariance size
- Ionospheric effects
  - Incomplete/inadequate ionospheric correction will impact range performance of SSN ground-based radar tracking
  - Could impact OD

Important to Orbital debris profiling and CA

Atmospheric Density Effects on SSA

- Historically, space surveillance networks have relied on two principal parameters to modify atmospheric models for solar activity variations.
  - F10.7: The solar 10.7 cm radio flux is indicative of the average level of radiation over the full solar disk
  - A_p: The geomagnetic index is strongly influenced by solar flares
- Changes in atmospheric drag will cause a satellite to penetrate a sensor's coverage volume at a time other than that expected.
  - Correlation of the object with its true identity might be delayed or not possible
  - Uncorrelated observations increase data processing requirements and can lead to less frequent updates of orbital elements and to "lost" satellites
- A decrease in the accuracy of satellite orbital parameters will also degrade the quality of conjunction assessments needed for collision avoidance decisions
- Unreliable predictions of atmospheric density will affect projections of debris populations for different orbital regimes

Lost Satellites

- A “lost satellite” is one for which reliable orbital elements are more than 30 days old
  - Satellites with orbits older than 5 days are typically placed on an attention list
  - Conjunction assessments conducted with data older than 5 days are of limited value
- The number of lost satellites typically grows during periods of high solar activity, due to difficulties in predicting neutral atmospheric density
  - The problem was well-documented during Solar Cycles 21 and 22
- In July 2012, approximately solar max, the lost list for the U.S. Space Surveillance Network reached a record high
  - Many factors contribute to lost list size, but atmospheric density mis-modeling plays a role

Other SSA Considerations

- The satellite catalog today consists of a much greater number of very small objects with moderate or high area-to-mass ratios. Orbit maintenance for such objects is more challenging, in part, because only one or a few sensors can track them
- Increased orbital decay rates can result in more objects passing through a given orbital regime, increasing the need for conjunction assessments
  - The International Space Station has experienced a marked increase in close approaches as more objects fall through its orbital regime
  - Prediction of debris densities, and therefore prediction of future debris environments and shielding requirements, also affected adversely
- Changes in atmospheric ionization can adversely affect the performance of radar sensors, the primary means of monitoring objects in low Earth orbits
  - Range errors can increase
  - Low elevation passes might need to be restricted, leading to shorter observation times or missed opportunities

Potential SSA Countermeasures

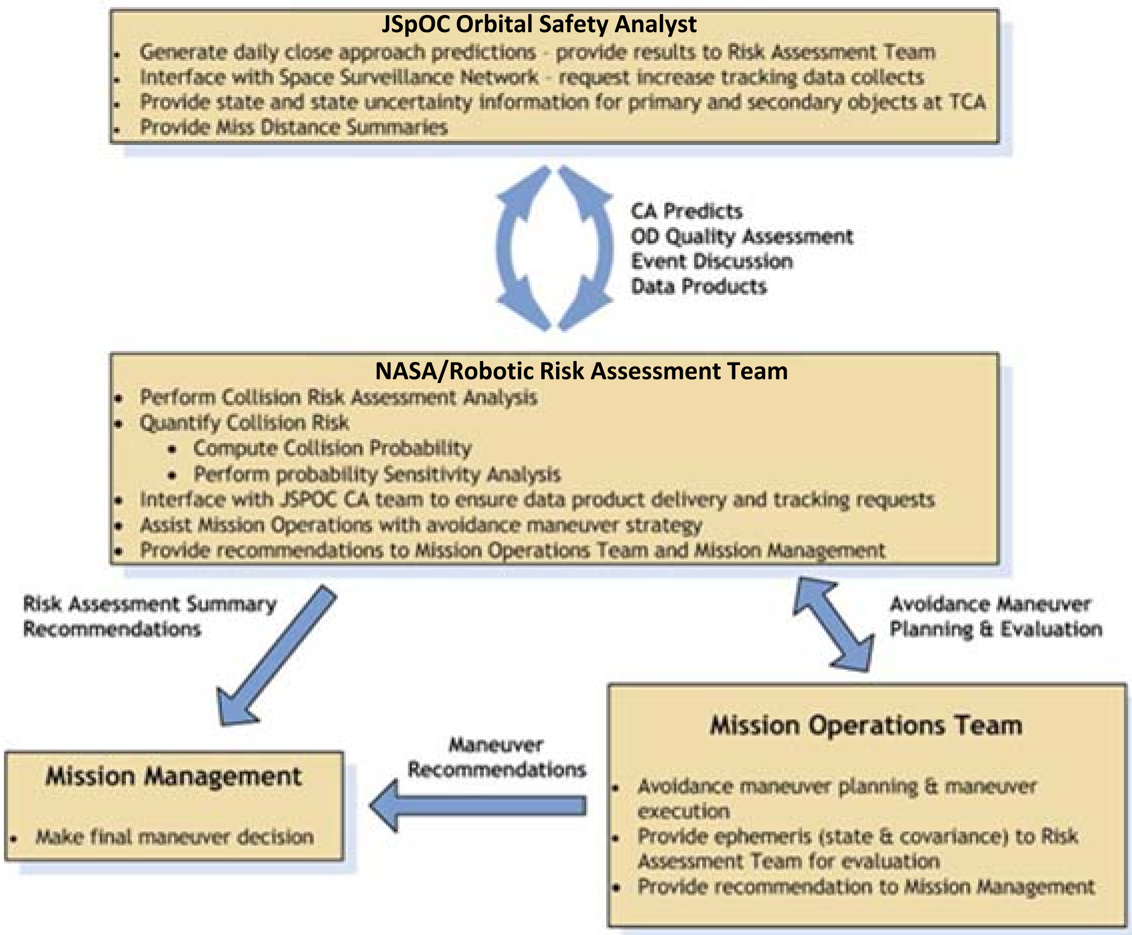
- Increase in tracking frequency for many satellites
  - Places greater loads on both sensors and processing centers
- Increase in frequency of satellite orbital element updates
  - Orbital elements are often not updated after each new observation
- Increase in the use of full differential correction in orbital element updates
  - Often only partial differential corrections are performed
- Increase in the frequency and quality of updates of solar indices
- Improvement of atmospheric models
  - High accuracy satellite drag model (HASDM) in development in U.S. since 2001; improved HASDM to be operational in 2013
  - However, still empirical rather than physics-based model; will be limited in predictive capabilities
- Modification of collision avoidance processes and procedures to take into account the increased uncertainty (covariance) in conjunction assessments
  - Nonetheless, will increase both type 1 and type 2 errors

NASA Robotic Conjunction Assessment Risk Assessment Process

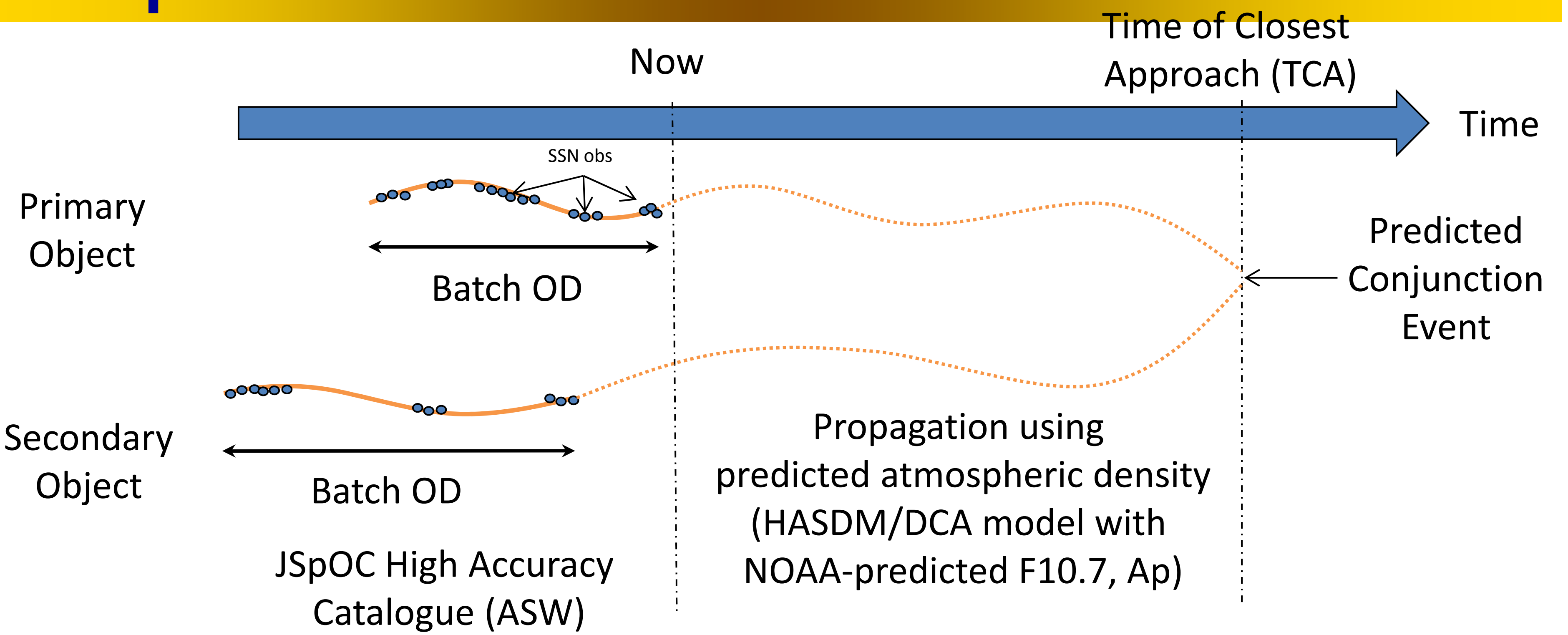
Air Force (JSpOC)

NASA Robotic CARA

End User (O/O)

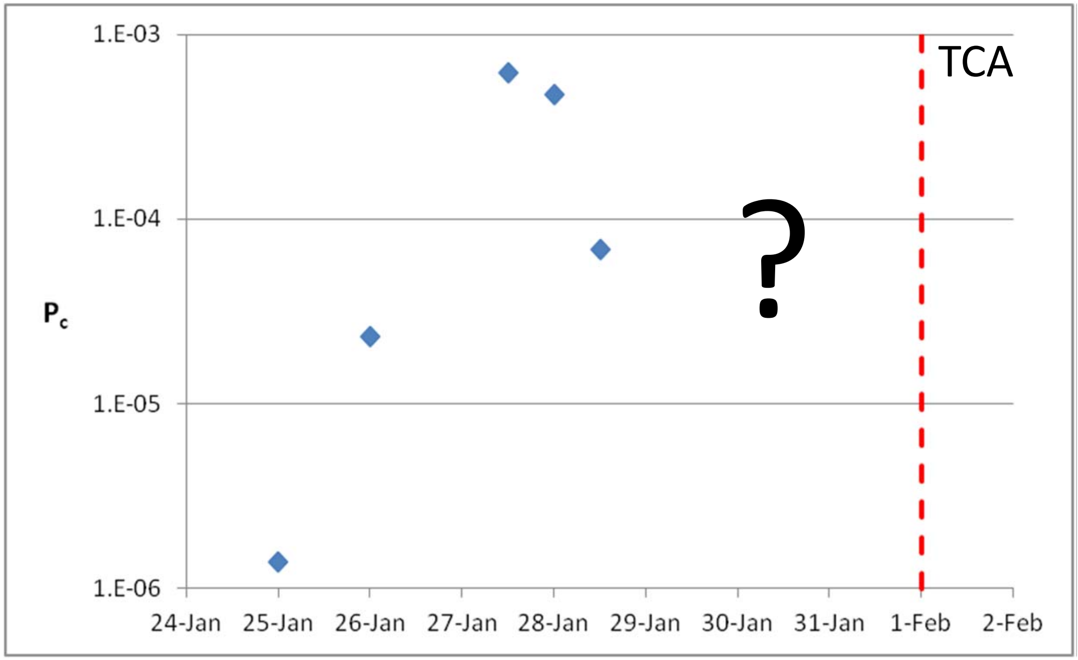


Conjunction Assessment: JSpOC Process and Products



- Orbital Conjunction Message (OCM) provided for each screening:
  - Includes both objects' state vector and position covariance at TCA
    - Allows computation of probability of collision (P_c)
  - Higher drag in the *past* (during OD) leads to larger covariance size in *future* (TCA)

Space Weather and Conjunction Assessment: A Notional Event



25 Jan: first identification of possible conjunction on 1 Feb

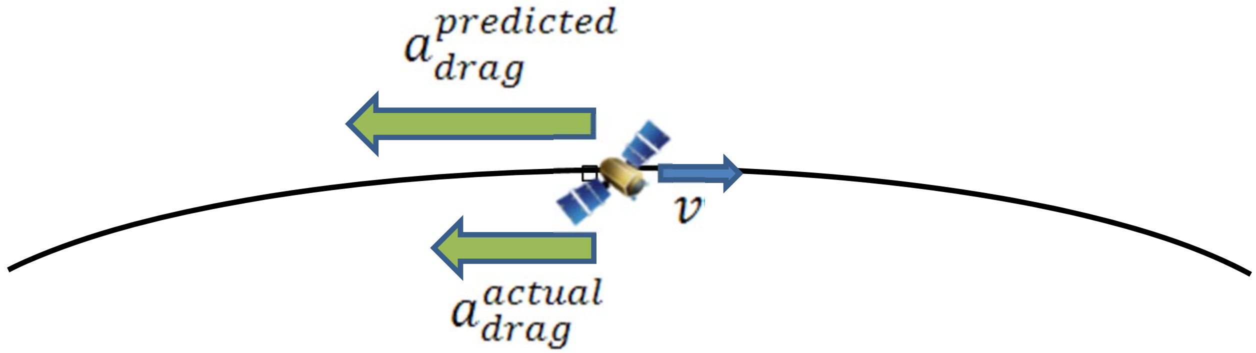
27-28 Jan: P_c first increases to level of concern before starting to fall (looking safer)

29 Jan: Alert of a Coronal Mass Ejection (CME) heading for Earth on 31 Jan

Spacecraft O/O wants to know if (and how) CME will impact conjunction event

- Does the new space weather prediction make this event safer or riskier?
- Might performing a maneuver make the conjunction event worse?

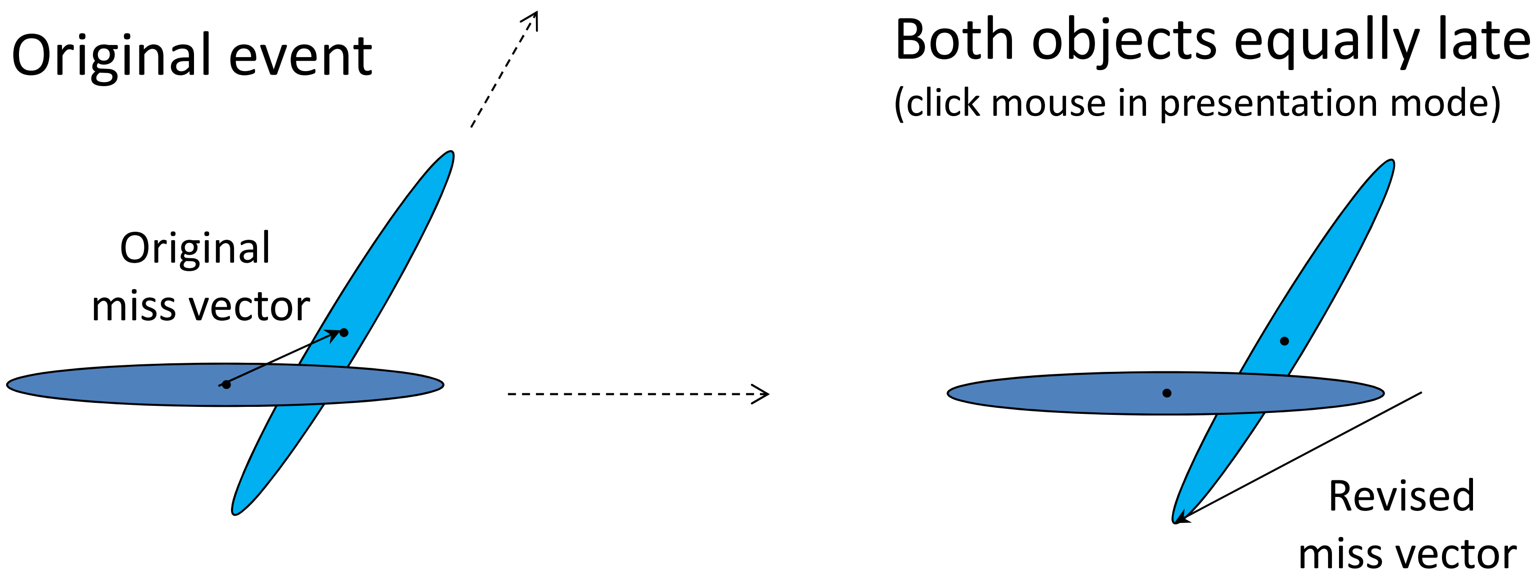
Background: Atmospheric Drag and Predicted Satellite Position



- Satellite will be at a different position if $a_{drag}^{actual} \neq a_{drag}^{predicted}$
  - Uncertainty in predicted atmospheric density not currently incorporated into propagation results
  - Uncertainty in ballistic coefficient incorporated in covariance
- Drag acceleration ~counter to satellite velocity
  - Change to drag primarily results in offset in along-track position
  - Equivalently can be represented as an early/late offset time

Qualitative Impact of Time Offsets

"Non-head-on" event with different offset times:

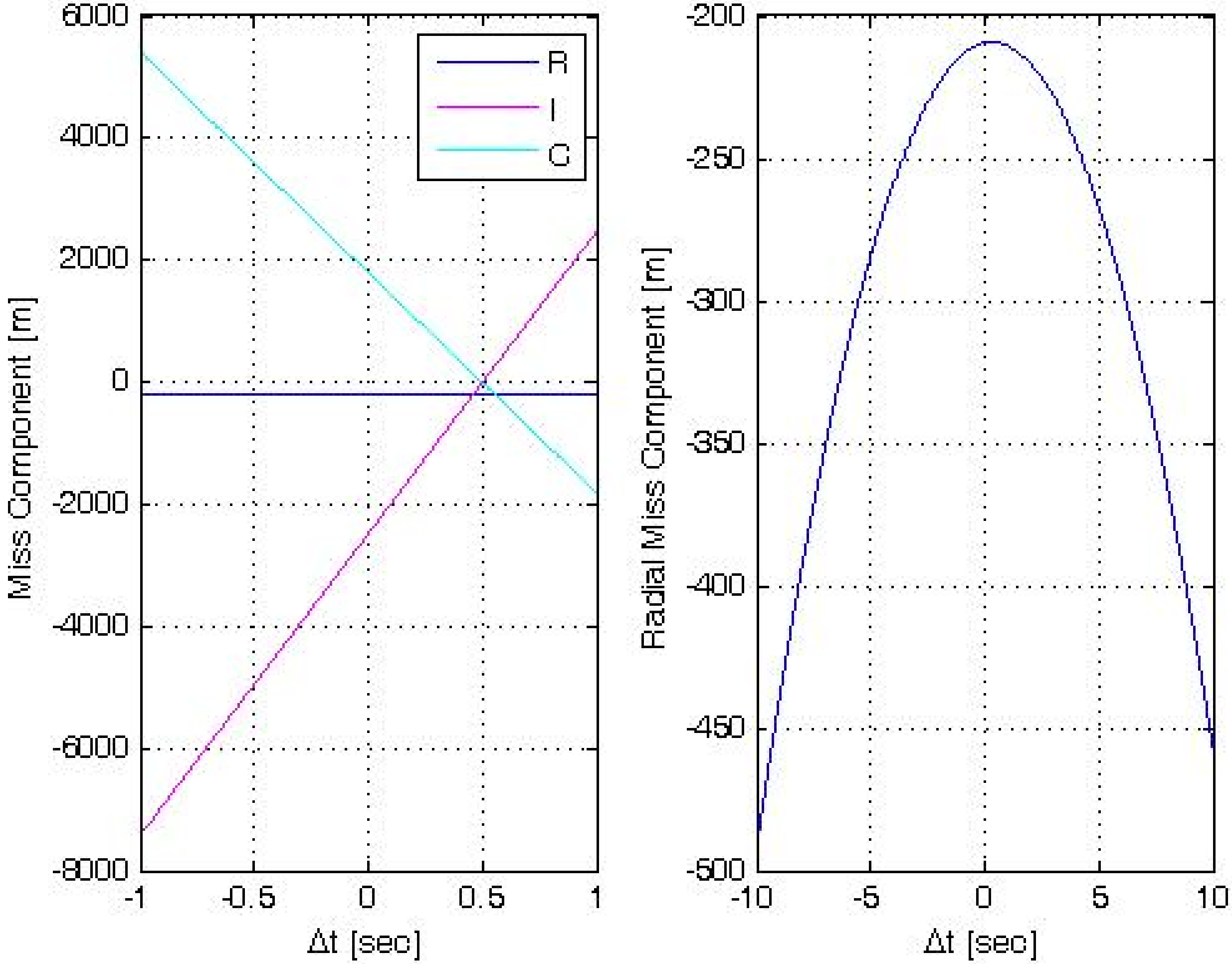


Results: TCA shifts, and conjunction event looks different at new TCA

How to Enhance Risk Assessment

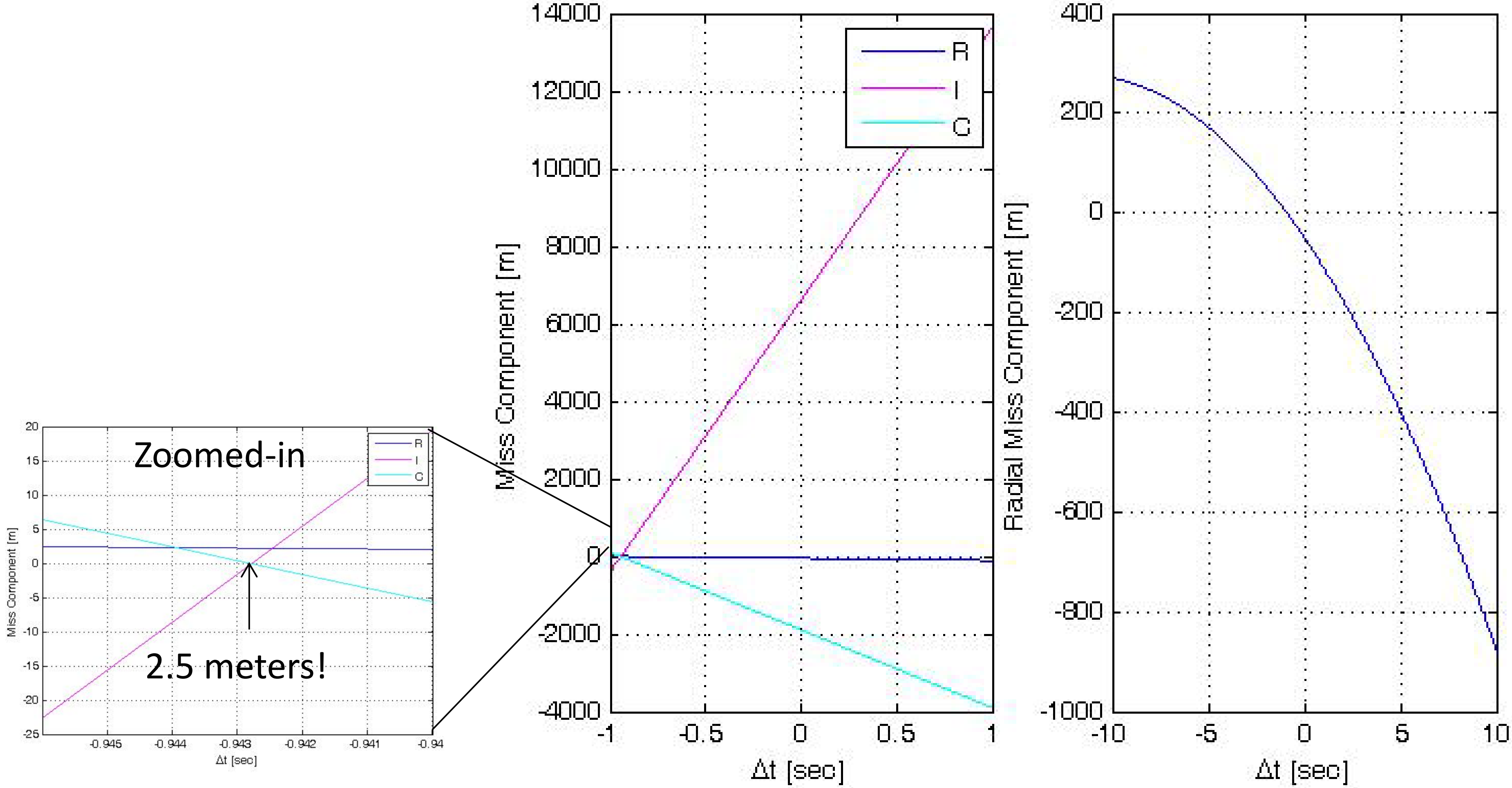
- Cannot at present determine actual effect of CME on atmospheric density
  - Atmospheric density will increase, and thus drag will increase; but cannot say by how much
- However, one can explore drag increases to determine if conjunction likely to become riskier
  - Increase in drag maps to time offset in objects' closest approach
  - Can profile situation for a variety of delta-t values and compute conjunction parameters
  - Can determine increased drag situation presents possible riskier scenarios than the nominal solution

Quantitative Impact of Time Offsets: No increase in risk



No risky scenario in negative half-plane

Quantitative Impact of Time Offsets: Potential Increase in Risk



There exists a negative-half-plane time offset that is extremely dangerous!

More Robust Approaches: Space Weather Predictions

- Because satellite maneuver commit times occur ~2-3 days before TCA, conjunction risk is always determined using predicted data
- Non-trivial space weather predictions thus required
  - Three-day forward-predict of F10 and Ap available from USAF/NOAA
  - Predictions not particularly accurate
  - Propagations longer than three days lack full space weather predictions
- Present atmospheric model (J70MOD) is empirical model
  - Upgrading to JBH09 in next month—should bring 15-25% improvement depending on orbit altitude and propagation time
  - Will use eleven solar indices rather than two
  - Still an empirical model, however

More Robust Approaches: Physics-based Atmospheric Models

- Empirical models quite effective at modeling atmospheric density in the past
  - Useful for orbit determination
- Such models weaker in prediction, due to their nature
- Physics-based modeling a promising paradigm for prediction use, especially beyond 72 hours
- Also better suited for trying to model effects of discrete space weather events, such as coronal mass ejections (CMEs)
- However, probably 5-10 years before such a model developed, vetted, and available to operations

CARA Way Forward

- Deploy heuristic tool that determines whether increases in drag increase or decrease the risk of a particular conjunction event
  - Consider whether some maneuver planning rules can be developed for cases in which risk increased by CME &c.
- Await completion/deployment of more robust atmospheric models and predictive space weather indices
  - Bounds on Δt would be helpful, even though incomplete solution
  - General predictive improvements (*e.g.,* longer than 72 hours) would be implemented by the JSpOC; probably no direct CARA implementation
  - Density effects of CMEs could be modeled directly by CARA for individual high-interest events