

Techniques for assessing space object cataloguing performance during design of surveillance systems

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- Europe builds up surveillance capabilities → requires analysis of sensor design
- Typically detection performance is assessed during design but **not** the cataloguing performance

Cataloguing tasks: combine observations to improve the orbital states (e.g. for collision avoidance)

- Determine initial orbits from observations
- Associate observations
- Improve states and determine accuracy

Develop a simulation framework for all individual steps and assess sensor cataloguing performance

A large, complex geometric dome structure composed of interconnected lines, resembling a geodesic dome or a mesh simulation. The lines are light gray and form a series of triangles and polygons. A blue rectangular box is overlaid on the left side of the dome, containing the word 'SIMULATION' in white capital letters.

SIMULATION

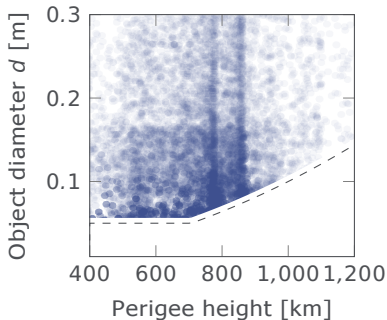
1. Propagate subset of MASTER reference population with SGP4
2. Subset selected with object size / perigee height envelope
3. Radar setup: south pointing and 60° elevation, $100^\circ \times 30^\circ$ field-of-regard in deflection angles
4. Create track whenever object passes field-of-regard and is detectable

Assure minimum
signal-to-noise ratio

$$\frac{d^2}{\rho^4} \geq \frac{d_{\min}^2}{\rho_{\text{ref}}^4} \propto \text{SNR}_{\min}$$

Generate random errors

$$\sigma_{\rho}^2 \propto \frac{1}{\text{SNR}} \quad \text{and} \quad \sigma_{\alpha,\beta}^2 \propto \frac{1}{\text{SNR}}.$$



Parameter	ρ_{ref}	d_{\min}	$\sigma_{\rho,\max}$	$\sigma_{\alpha,\beta,\max}$
Value	1000 km	10 cm	5 m	0.2°

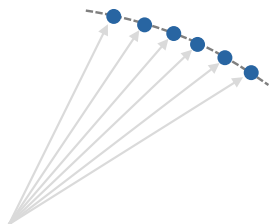
A diagram showing two overlapping white elliptical orbits on a gray background. A small white circle marks the intersection point of the two orbits. A blue horizontal bar is overlaid on the diagram, containing the title text.

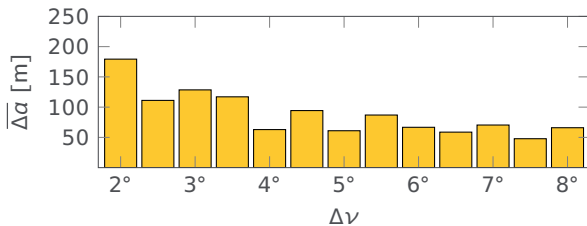
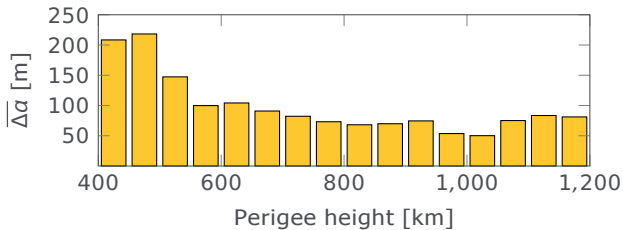
INITIAL ORBIT DETERMINATION

Stable fixed-point iterations to get a state \mathbf{y}

$$\mathbf{y}^{(i+1)} = \mathbf{H}(\mathbf{y}^{(i)}) \mathbf{z}$$

with observations \mathbf{z} and update-matrix \mathbf{H} from series expansion around $\mathbf{y}^{(i)}$
(adapted from the GTDS ranges and angles method)

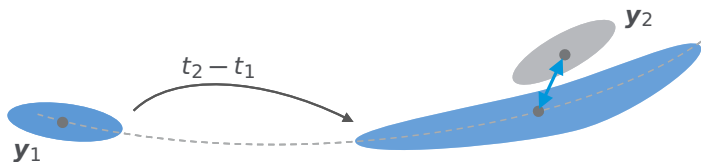


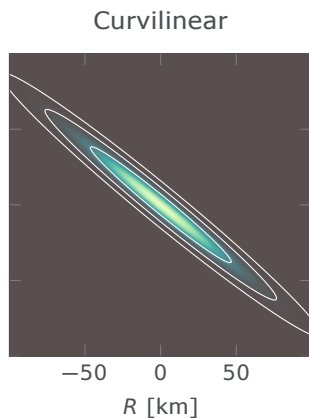
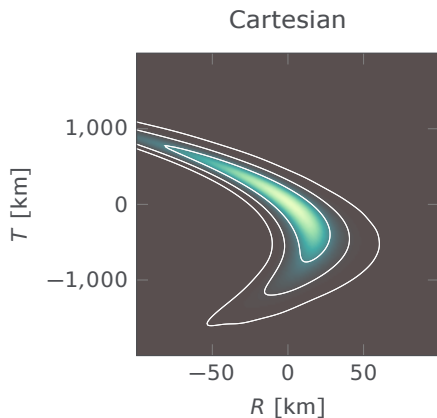


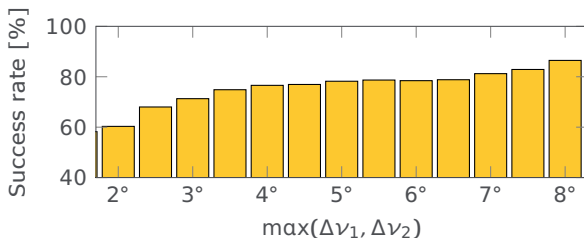
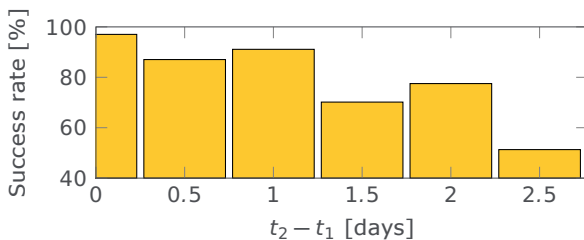
A decorative graphic of white curved lines on a grey background, forming a large, abstract shape that resembles a stylized 'e' or a partial circle. A small white circle is located at the intersection of two of the lines on the right side.

ASSOCIATION

- Test two consecutive tracks \rightarrow estimate if they belong to the same object
- Propagate to a common epoch
- Covariance-based association: accept if distance measure below threshold







Three large, thin white arcs are drawn across the slide, overlapping each other and the text box. One arc is a large semi-circle at the top, another is a smaller arc below it, and a third is a vertical arc on the right side that intersects the other two.

ACHIEVABLE ACCURACY

Model insufficiencies cause uncertainty: e.g. density variations in atmosphere, bias terms and other error sources

→ account erroneous model in covariance estimation

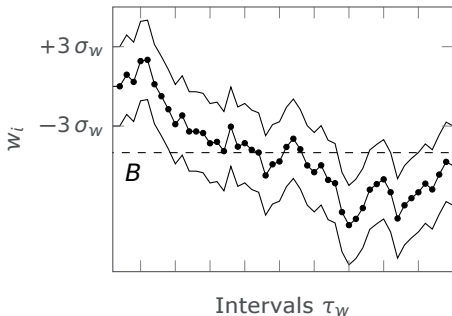
Most dominant error source is the unknown atmospheric variation

Augment drag acceleration
with correction w

$$\mathbf{a}_D(\mathbf{y}, t, B)(1 + w(t))$$

Model w as a random walk
using discrete steps w_i
with $E(w_i) = 0$ and the
covariance

$$E(w_i w_j) = \sigma_w^2 \exp\{-|i-j| \tau_w\}$$

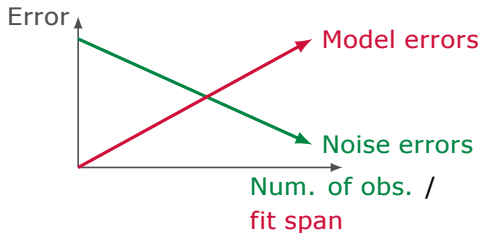


Trade-off between information gain and model capabilities

- More measurements → better accuracy
- Larger time span → model cannot be adjusted

Difficult to simulate

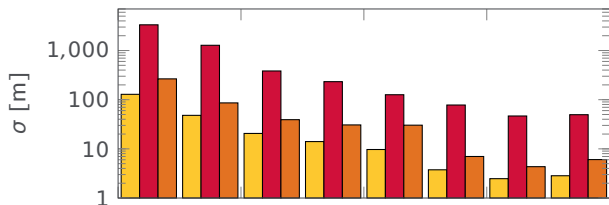
Use a fit span depending on energy-dissipation-rate (ranging from few days to two weeks)



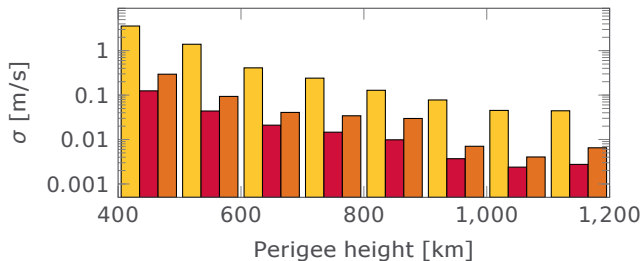
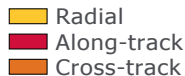
Achievable accuracy (*preliminary*)



Position



Velocity



- Simulation of a surveillance radar
- Initial orbit determination using fixed-point iterations
- Covariance-based measurement association
- Preliminary study on achievable accuracies

Open tasks

- Incorporate more elaborate detection model
- Special treatment of short radar tracks
- Use framework for the design: analyse influence of location, field-of-regard, pointing, and other design parameters

ANY

QUESTIONS ?

