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

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Introduction

- 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

SIMULATION

Simulation (1)

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° × 30° field-of-regard in deflection angles
4. Create track whenever object passes field-of-regard and is detectable

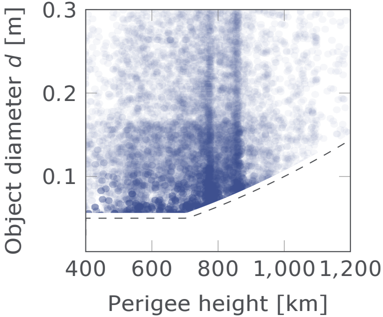
Simulation (2)

Assure minimum signal-to-noise ratio

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

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}	$\sigma_{\rho,\text{max}}$	$\sigma_{\alpha,\beta,\text{max}}$
Value	1000 km	10 cm	5 m	0.2°

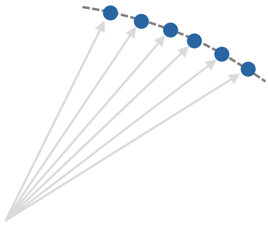
INITIAL ORBIT DETERMINATION

Initial orbit determination

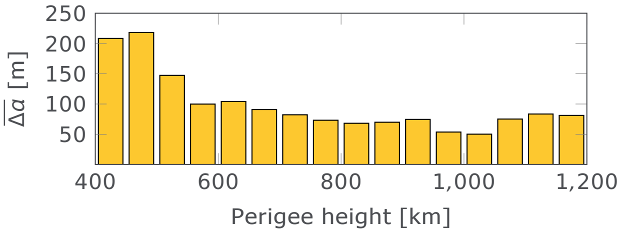
Stable fixed-point iterations to get a state $\boldsymbol{y}$

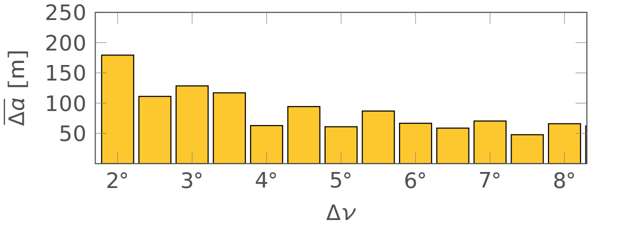
$$\boldsymbol{y}^{(i+1)} = \boldsymbol{H}(\boldsymbol{y}^{(i)})\,\boldsymbol{z}$$

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



Initial orbit accuracy

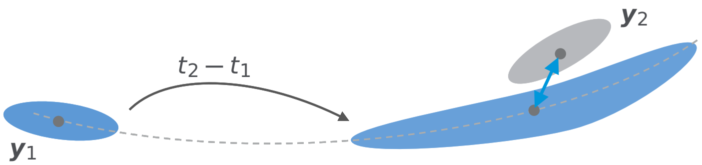




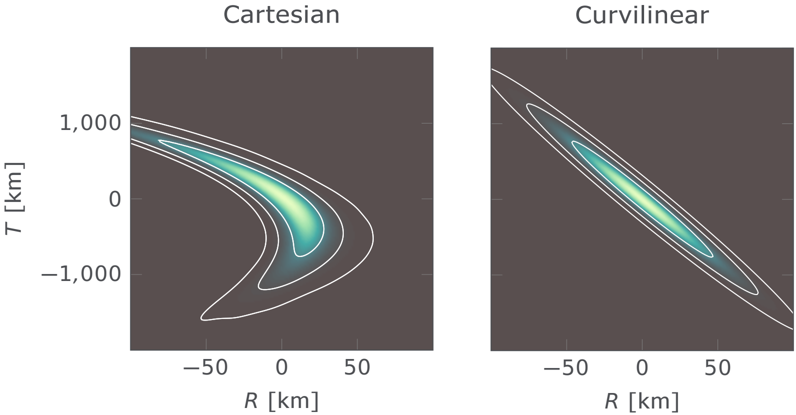
ASSOCIATION

Association test

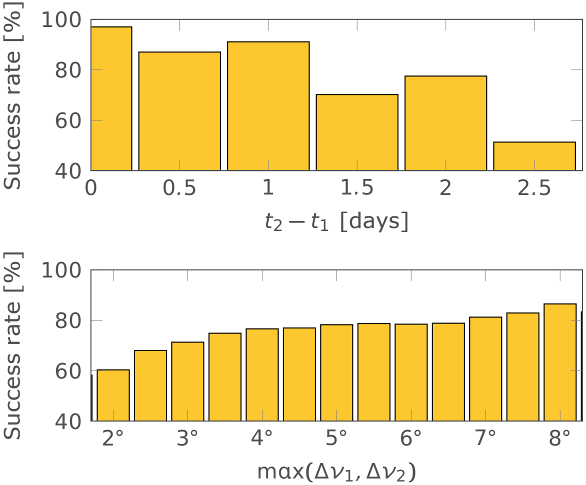
- Test two consecutive tracks → estimate if they belong to the same object
- Propagate to a common epoch
- Covariance-based association: accept if distance measure below threshold



Uncertainty transformation



Association performance



ACHIEVABLE ACCURACY

Consider covariance analysis

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

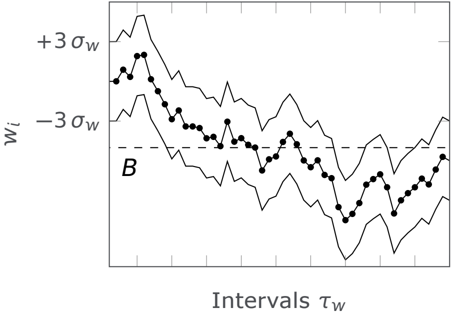
Consider parameter

Augment drag acceleration with correction w

$$\boldsymbol{a}_{\mathrm{D}}(\boldsymbol{y}, t, B)(1 + w(t))$$

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

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



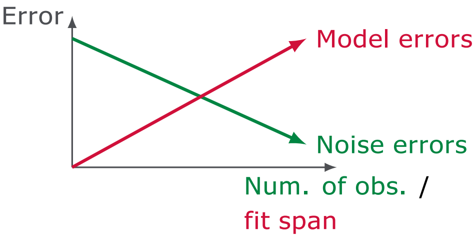
Fit span selection

Trade-off between information gain and model capabilities

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

Difficult to simulate

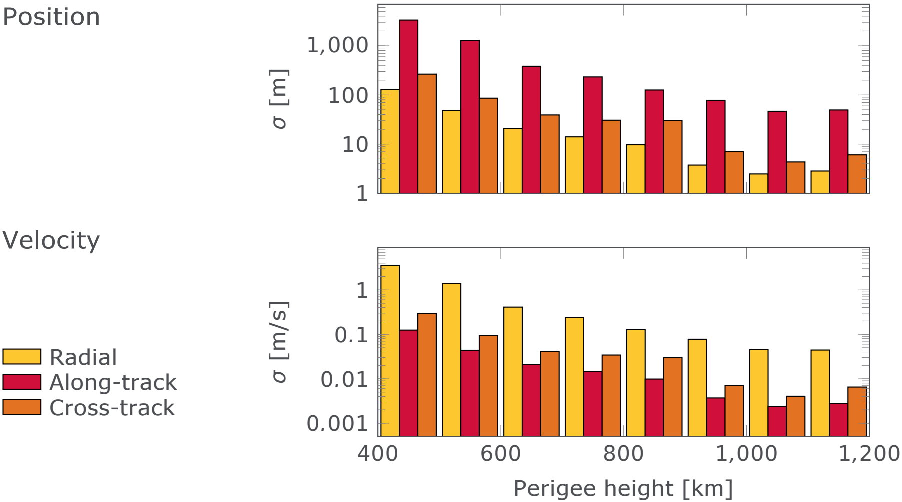
Use a fit span depending on energy-dissipation-rate (ranging from few days to two weeks)



Achievable accuracy (*preliminary*)

Position

Velocity



Summary and conclusion

- 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 ?