Orbit design for L-band satellite swarm-based aperture synthesis radiometers for super-resolution Earth-observation in Low-Earth Orbit

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A satellite swarm-based aperture synthesis radiometer could increase the spatial resolution of L-band radiometers…

Why do we need better spatial resolution?

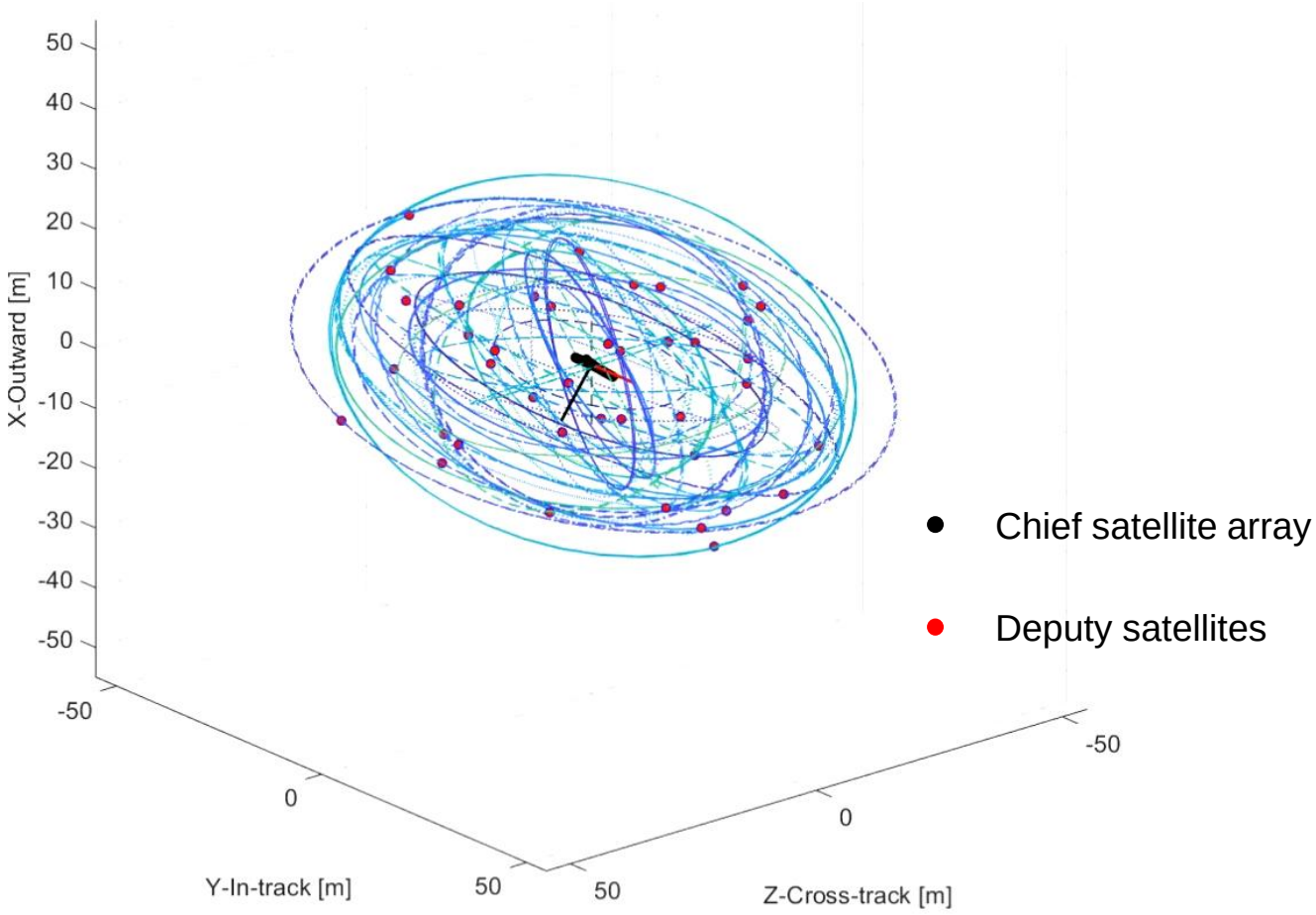
- To **improve existing applications,** e.g**.**
  - Sea ice localisation / ship routing
  - Higher resolution permafrost maps
  - Improved drought and flood mapping
  - Higher resolution soil moisture maps for regional hydrology

Fundamental system concept:

- Centre „**Chief**“ satellite **carries a Y-correlator**
- Small nanosatellites „**Deputies**“ (20 cm cubes) carry individual antennas **extending the Chief‘s Y-correlator**
- System placed on 750 km SSO in **LEO**

Artist‘s view

Main challenge: How can the relative orbit elements of the deputies be defined to ensure system feasibility and imaging performance?



Chief Orbit: Sun-Synchronous at 750 km

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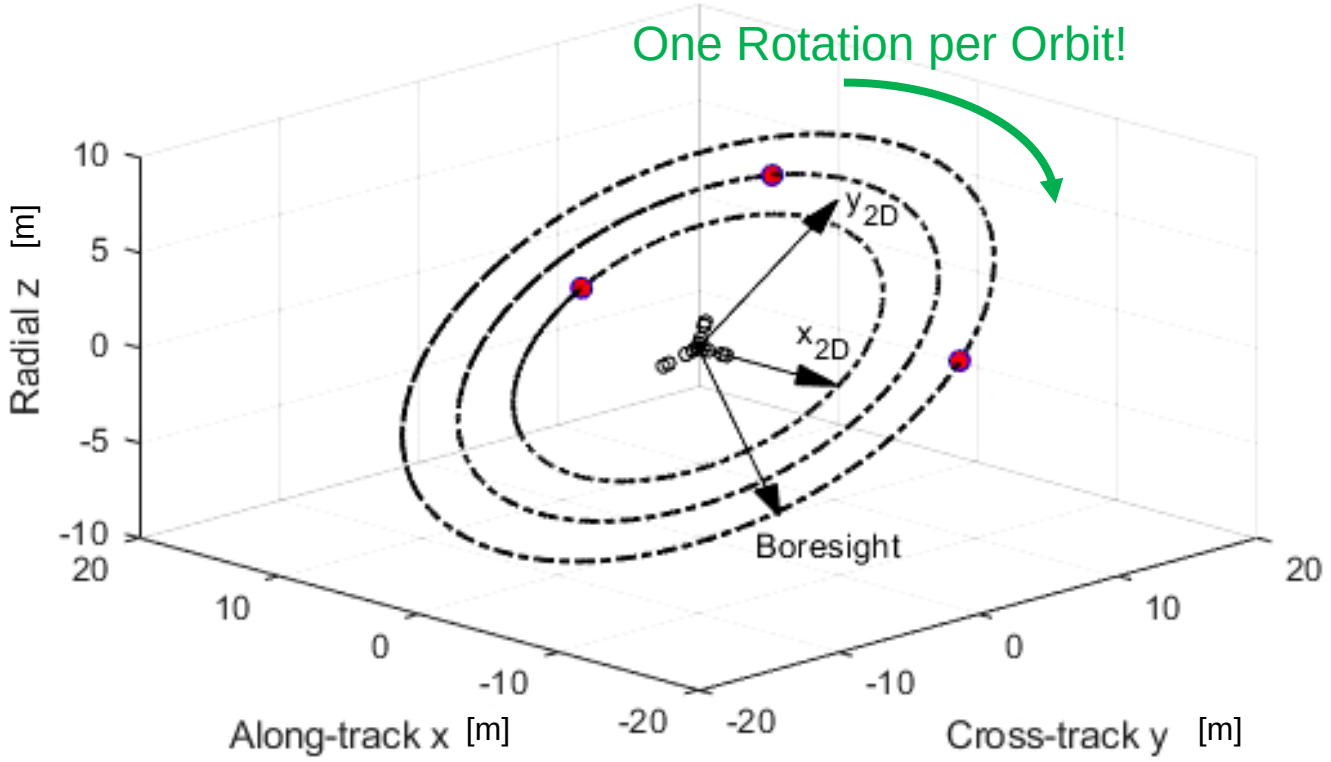


Optimization of deputy positions on the relative orbital plane is conducted by an evaluation of the spatial frequency coverage

Main goals of optimization:

1. Radial distribution of samples is Gaussian with a small variance
2. Homogenous distribution of samples in azimuth

Objective function:

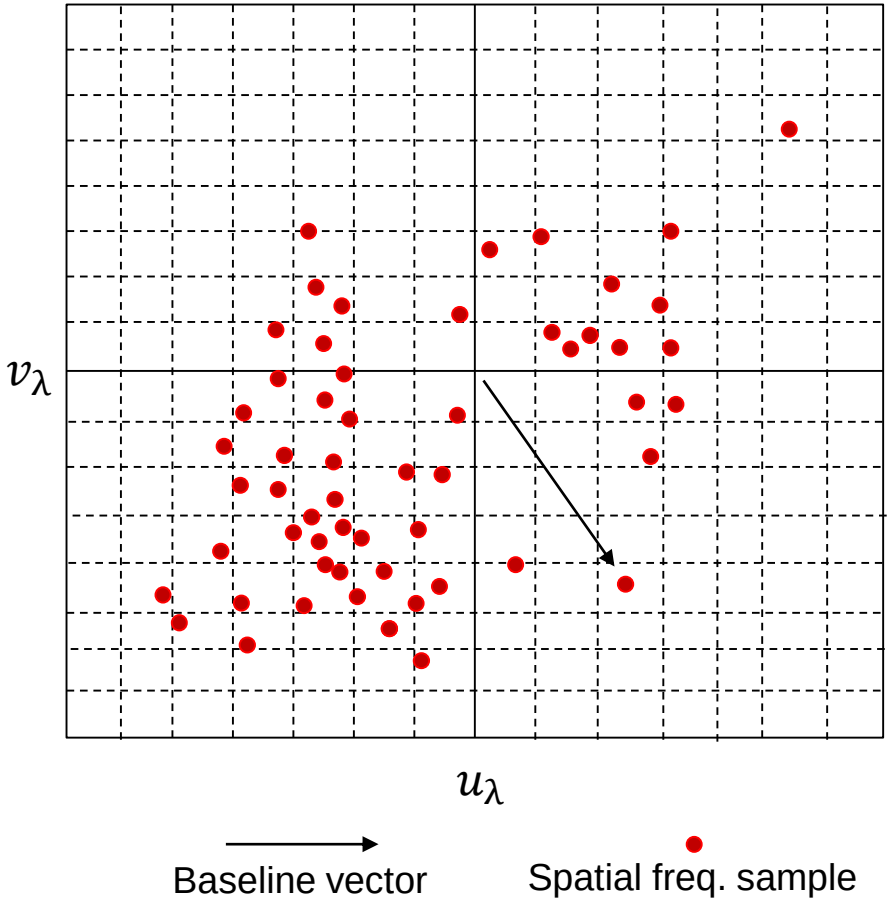
$$f(x) = -\sum_{j=1}^{N_R} \underbrace{N_{cell}(j)^{-1}}_{\text{Density}} \cdot \underbrace{e^{-\frac{1}{2}\cdot\left(\frac{|Distance|}{\sigma_{Gauss}}\right)^2}}_{\text{Distance}}$$

$$\underset{x}{\text{minimize}} \quad f(x)$$

subject to

Min. Distance to Chief
Min. Distance to other deputies

Initial spatial frequency coverage:



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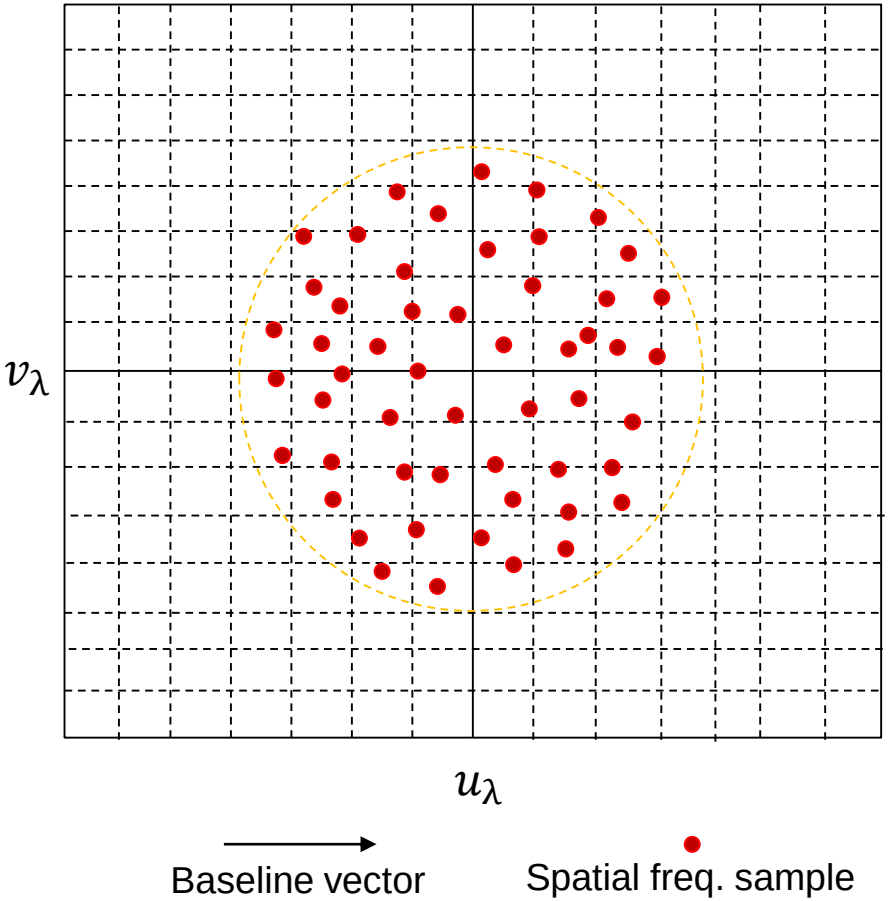
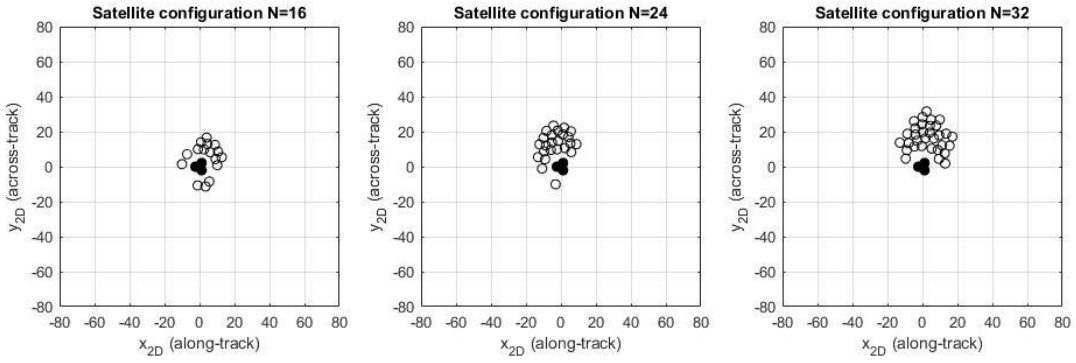
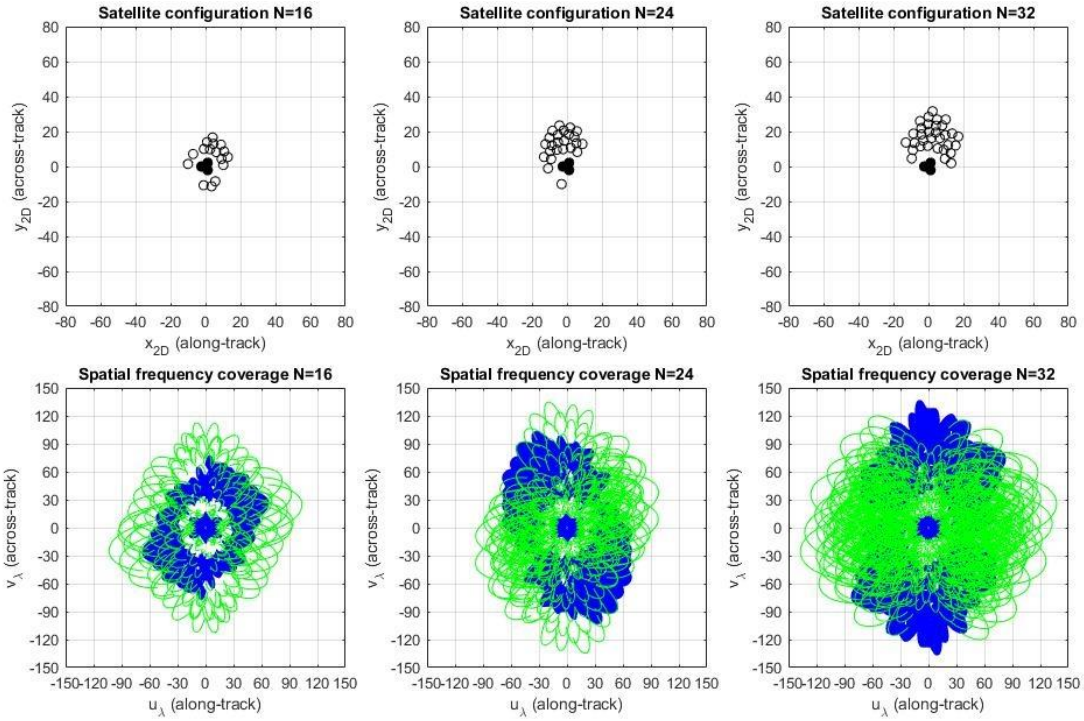
Optimized spatial frequency coverage:



Satellite configurations from optimization with 16 - 32 deputies



Spatial frequency coverage from optimization with 16 - 32 deputies



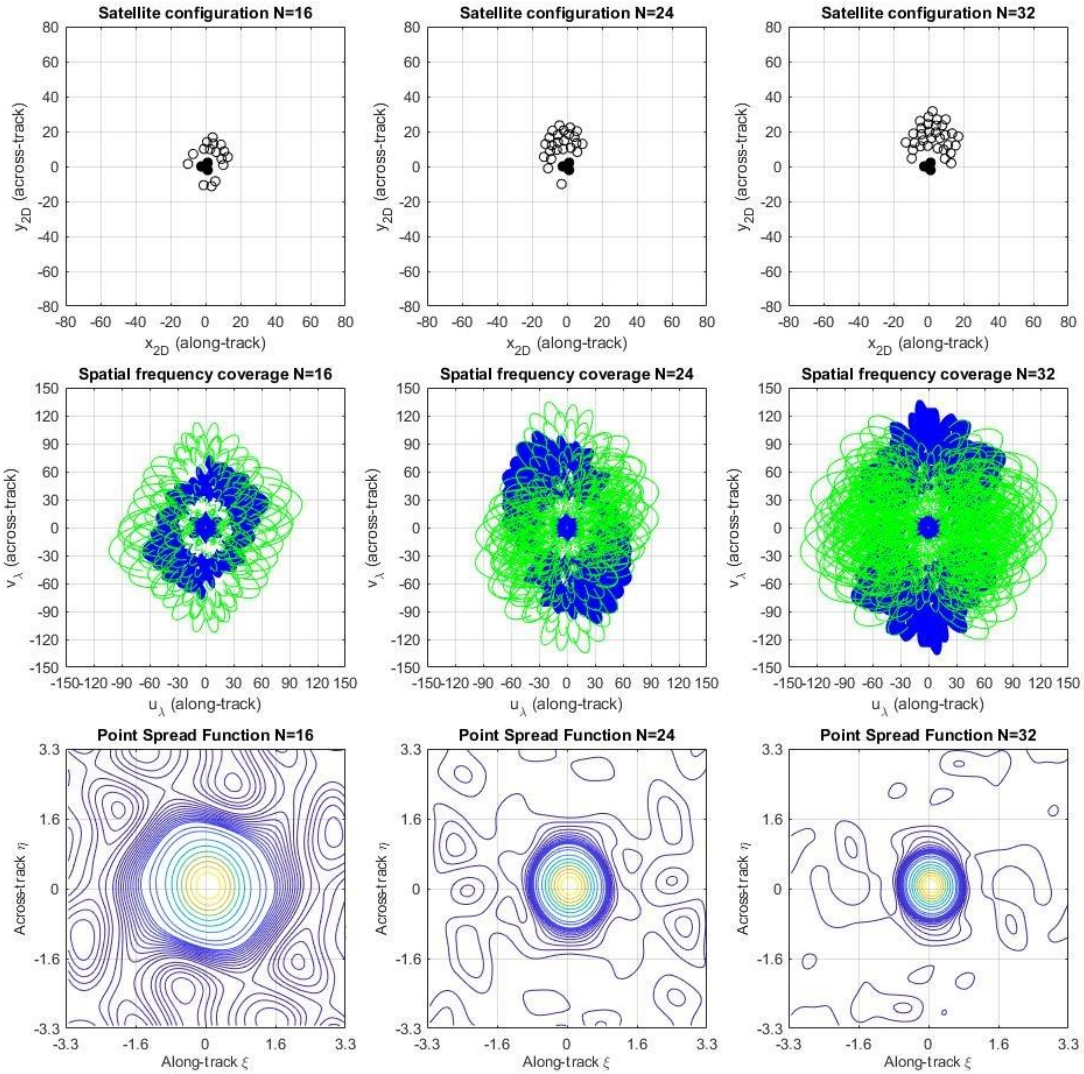
Deputy/Chief baselines

Deputy/Deputy baselines

Antenna Parameters	**Values**
Central antenna array dimensions	Uniform Y-Shaped array
Number of antennas per arm	N_{arm} =13
Centre frequency	$f_c = 1.4\ G\mathrm{Hz}$
Receiver noise bandwidth	$B = 7\ M\mathrm{Hz}$
Half-power beamwidth of individual antenna	$BW_{El} = 62°$
Chief antenna tilt angle	Θ=30°

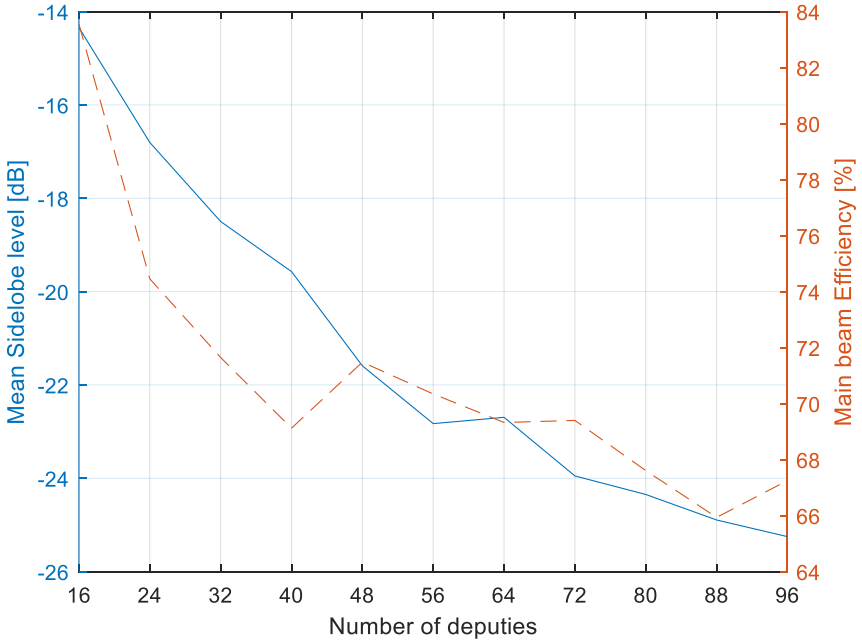
Point Spread Function (PSF) from optimization with 16 - 32 deputies

NUFFT

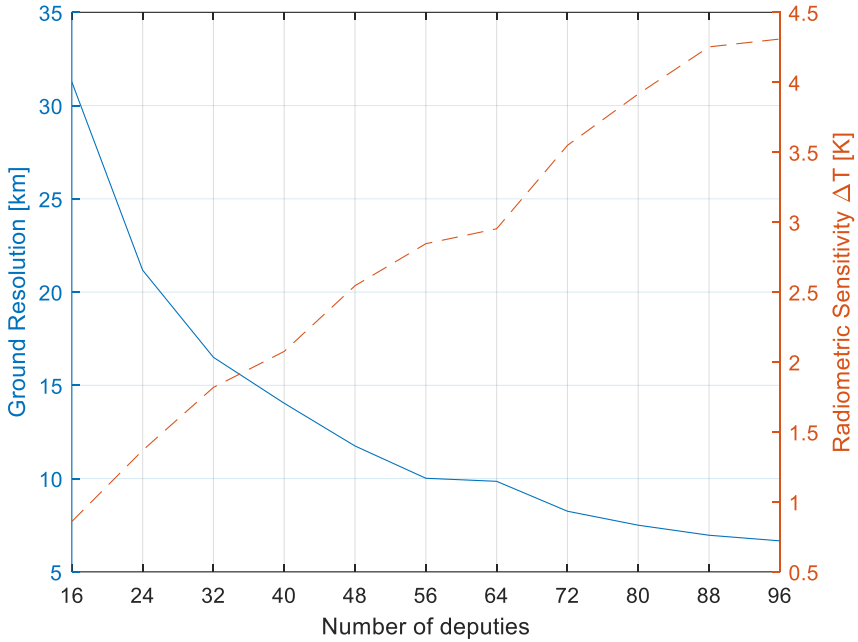


More satellites lead to an improvement of spatial resolution but a degradation in radiometric resolution!

Sidelobe level supression



Imaging Performance



Summary & first conclusions

Summary:

- The **system feasibility** and the **imaging performance** of a satellite swarm-based aperture synthesis radiometer concept **was investigated** by numerical simulations.

- A **methodology** based on numerical optimization **was proposed for the orbit design** of a swarm-based radiometer system.

Conclusions:

- It is **reasonable a fractionated L-Band radiometer can be designed** based on a satelite swarm with a significantly improved spatial resolution.

- There will likely be a **trade-off with the radiometric resolution** as a higher spatial resolution is automatically detrimental for radiometric resolution.

- **More research** on the other aspects of this system (synchronisation, inter-satellite communication, etc.) and customizations for applications **needs to be done**