# Genetic Algorithm Optimization of GNSS Ground Tracking Networks for Orbit Determination

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IGS 2026 WORKSHOP
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## INTRODUCTION

**Background and Motivation**

Precise orbit determination (POD) for GNSS satellites relies on a globally distributed ground tracking network. At NGS, all stations from the most recent instance of the IGS network (IGb20: 343 total, ~291 active on any given day) have historically been used. Because NGS uses double-difference processing, baselines scale quadratically with station count, resulting in significant excess computational cost.

**The Station Selection Problem**

Selecting a near-optimal station subset is inherently multi-objective (spatial coverage vs. data quality vs. efficiency), combinatorially explosive ($2^{343} \approx 10^{103}$ possible configurations), and subject to operational constraints (IGS Core region representation, co-location avoidance).

**Contributions**

We present a framework for dynamically assembling a GPS POD network at runtime based on actual data availability. Station selection is formulated as a constrained multi-objective optimization using spherical Voronoi geometry, observation completeness, and time series length, solved with NSGA-II. A 16-week test (extracted from an ongoing 1-year test run) within the operational NGS pipeline demonstrates ~38% wall-clock runtime reduction with only ~1 mm additional 3D RMS degradation relative to legacy products compared against IGS final orbits.

## METHODS

**Pipeline Overview**

For each processing day: (1) download RINEX data from all IGb20 stations; (2) apply quality control screening using TEQC; (3) select a near-optimal station network via NSGA-II multi-objective optimization; (4) process the selected network through the NGS POD pipeline (PAGES -> GPSCOM).

**Optimization Formulation**

$f_1$ (minimize): Coefficient of variation of spherical Voronoi cell areas; $f_1 = \sigma(A)/\mu(A)$; with $A_i$ the area of the spherical Voronoi cell generated by the $i$th station

$f_2$ (maximize): Sum of observation completeness; $f_2 = \sum p_i$; with $p_i$ the fraction of observations present in the $i$th selected station's RINEX file.

$f_3$ (maximize): Median time series length; $f_3 = \tilde{t}$; with $\tilde{t}$ the median lifetime observation time series length across selected stations.

**Constraints**

$C_1$: At least one station from each of the 55 IGb20 Core regions must be included.

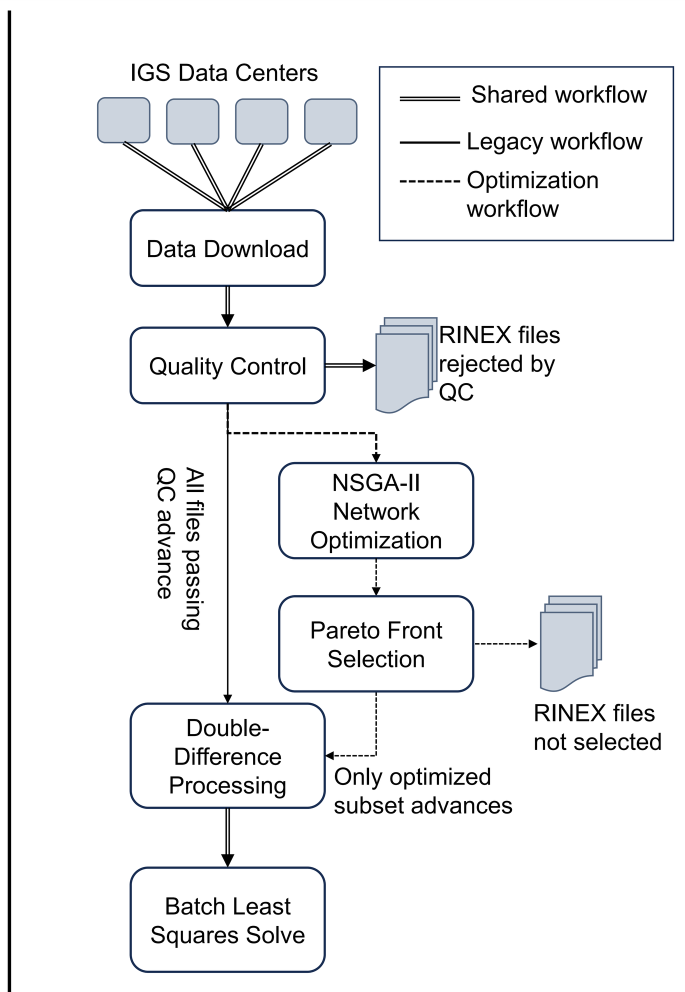
$C_2$: No more than 2% of selected stations may have angular separation $< 10^{-6}$ radians (~6.5 m) from any other selected station.

**Selection**

Network selection from the final Pareto front uses a compromise programming approach. Each objective function value is normalized to [0,1] across the front. The selected network is the individual whose normalized objective vector has minimum Euclidean distance to the origin.

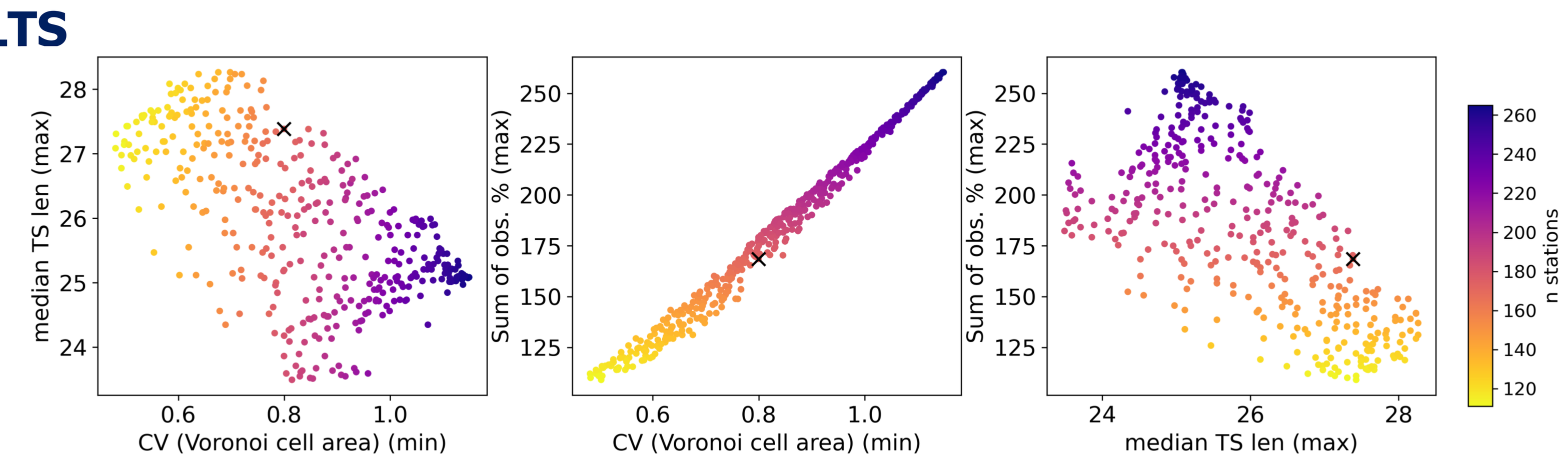
**Experimental Setup**

A 16-week test period (112 daily solutions) was processed twice: once using the legacy static network (all available IGb20 stations) and once using the dynamic NSGA-II-selected network. Both used identical processing parameters (e.g. same QC thresholds from TEQC, PAGES double difference baselines, GPSCOM batch global adjustment). Resulting orbits were compared against IGS final products using per-satellite and constellation-wide 3D RMS.

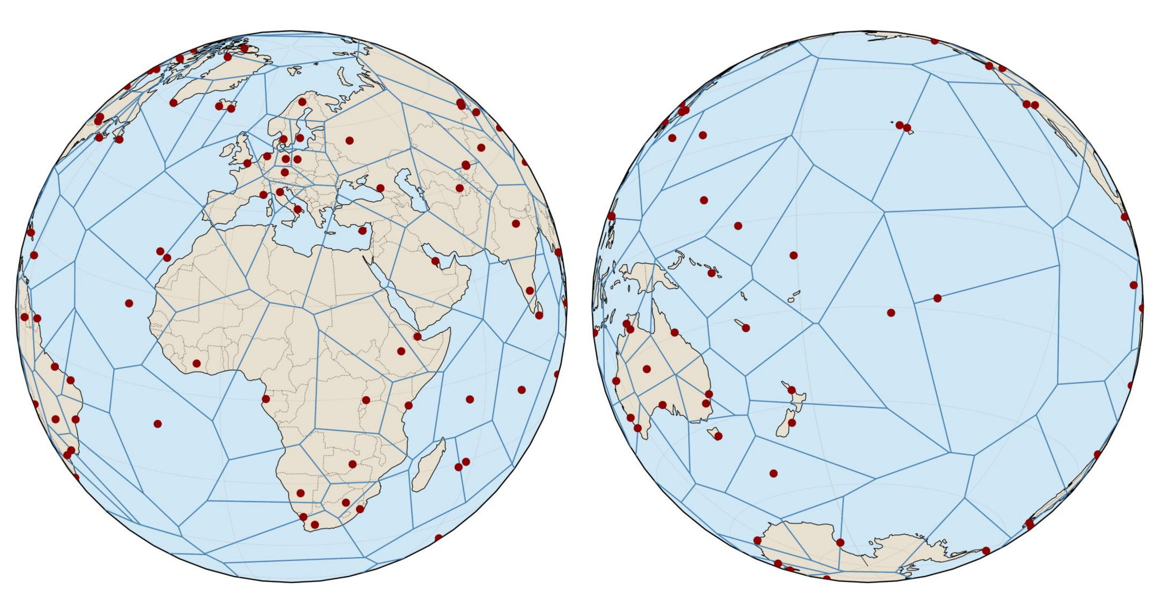



*NGS POD processing pipeline with and without network optimization*

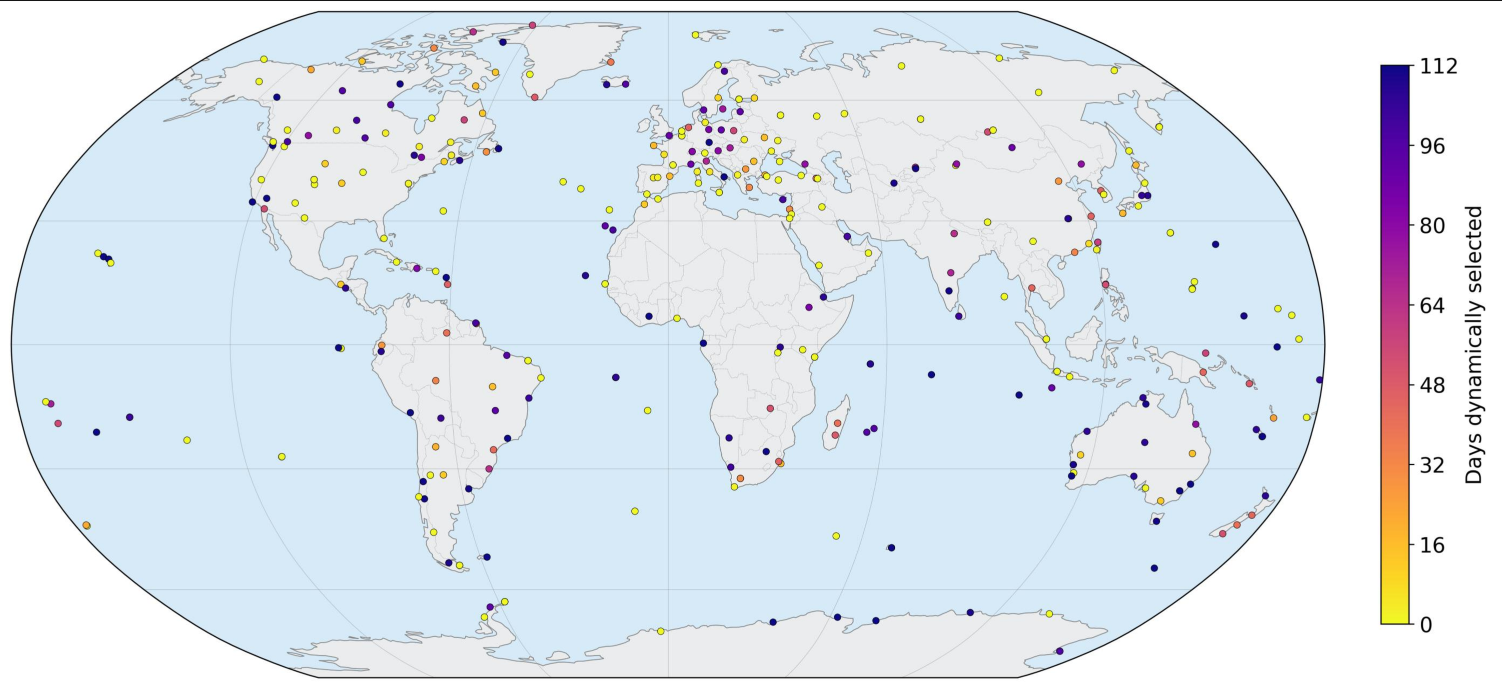
## RESULTS



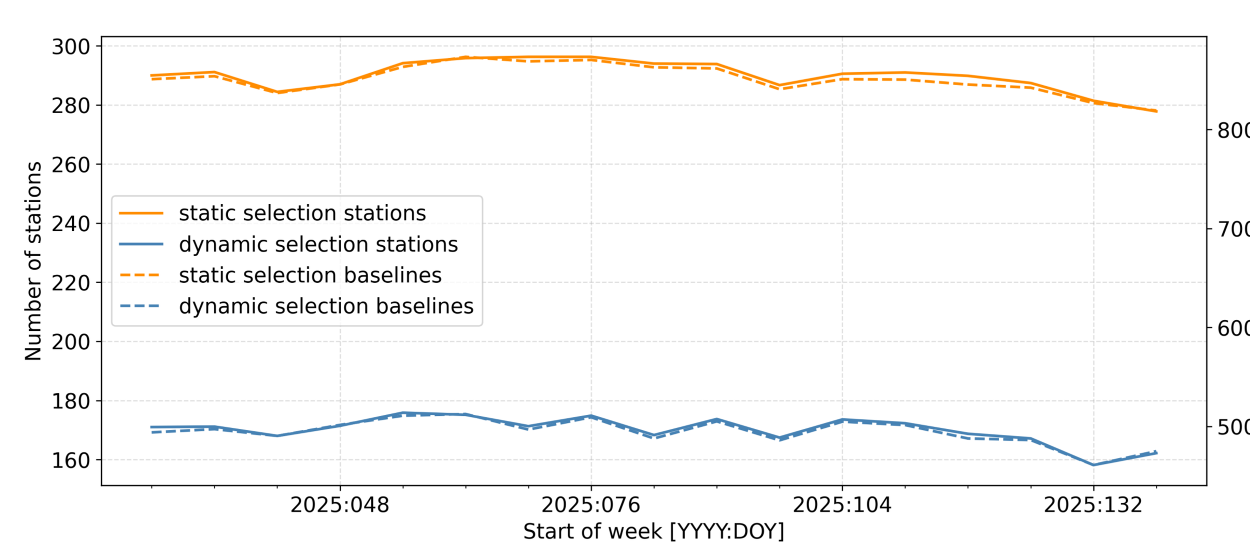

*Representative 2D plots for day 2025:032 showing the objective function tradeoffs for all individuals in the final Pareto front color coded by the number of stations per individual. The selected network is marked with an "X".*



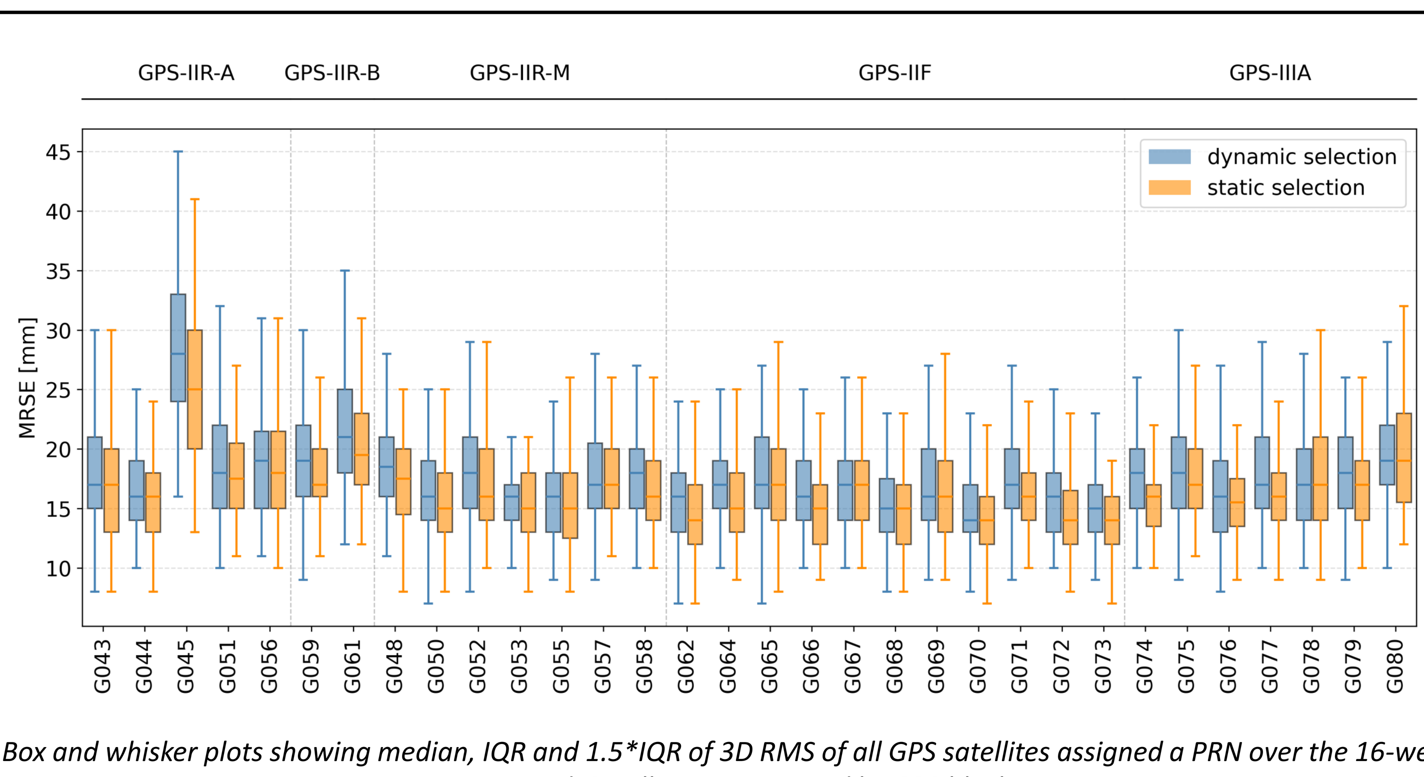
*Representative spherical Voronoi diagram from day 2025:033 showing the Voronoi cell area for each generator (i.e. selected station).*



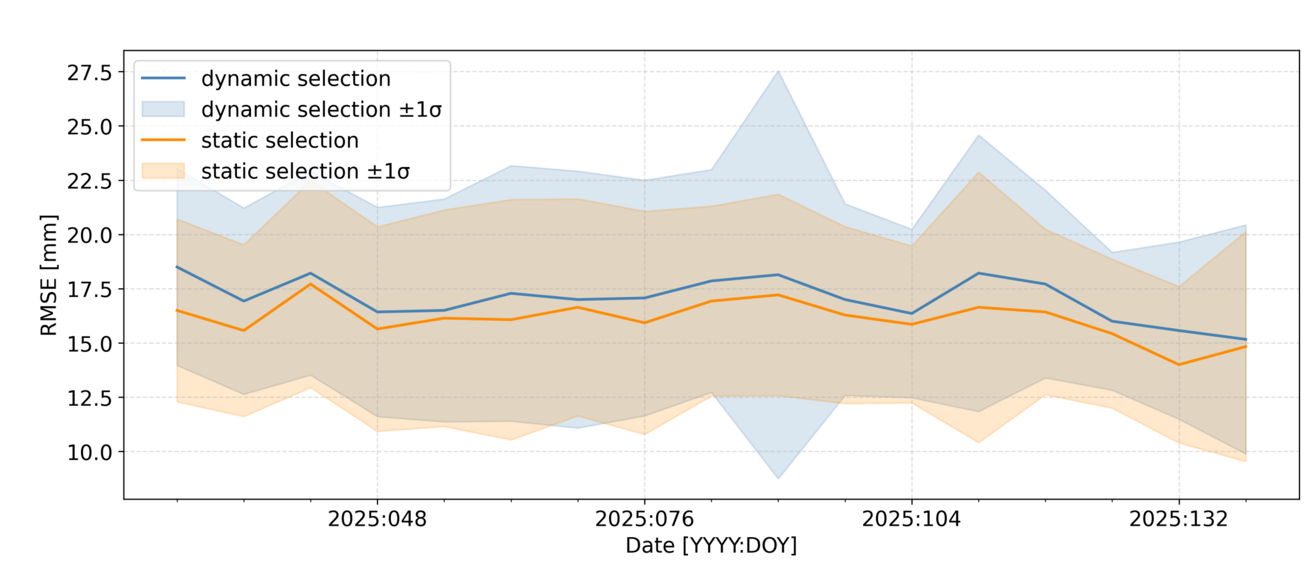

*Map showing the locations and selection frequency of all 343 IGb20 stations over the 16-week test period.*




*Time series showing the 1-week average of network size (solid) along with the 1-week average of number of double-difference baselines computed for the sessions in that week (dashed).*




*Box and whisker plots showing median, IQR and 1.5*IQR of 3D RMS of all GPS satellites assigned a PRN over the 16-week test period. Satellites are grouped by GPS block.*




*Weekly average constellation-wide 3D RMS time series over 16-week test period (solid lines) and $\pm 1\sigma$ region (shaded).*

## CONCLUSIONS

- NSGA-II multi-objective optimization of the GPS ground tracking network reduces wall-clock POD processing time by ~38% over the 16-week test period while maintaining orbit quality within ~1 mm 3D MRSE of legacy products compared against IGS final orbits. Additionally, we see a 4x tighter runtime distribution, increasing runtime predictability for operational use.
- The optimized network median $\pm 1\sigma$ size is 161-179 stations from the 285–297 available on a given day, reducing the number of double-difference baselines from 851 to 495. Orbit accuracy remains consistent across all 32 GPS satellites, with no individual satellite showing pronounced degradation.
- As a complementary coverage metric, the 95th–percentile of spherical covering radius — the maximum great-circle distance from any point on Earth to the nearest selected station — is 2726 km for the optimized network versus 2630 km for the legacy network, confirming that spatial coverage is preserved despite the reduction in station count.
- The framework runs at the start of each daily POD session, adapting station selection to actual data availability rather than relying on a static network definition. This makes the pipeline robust to station outages without manual intervention.
- Future work will investigate alternative objective formulations, including covering radius minimization and mean observation completeness (rather than sum), to reduce implicit coupling between objective values and network size along the Pareto front.

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