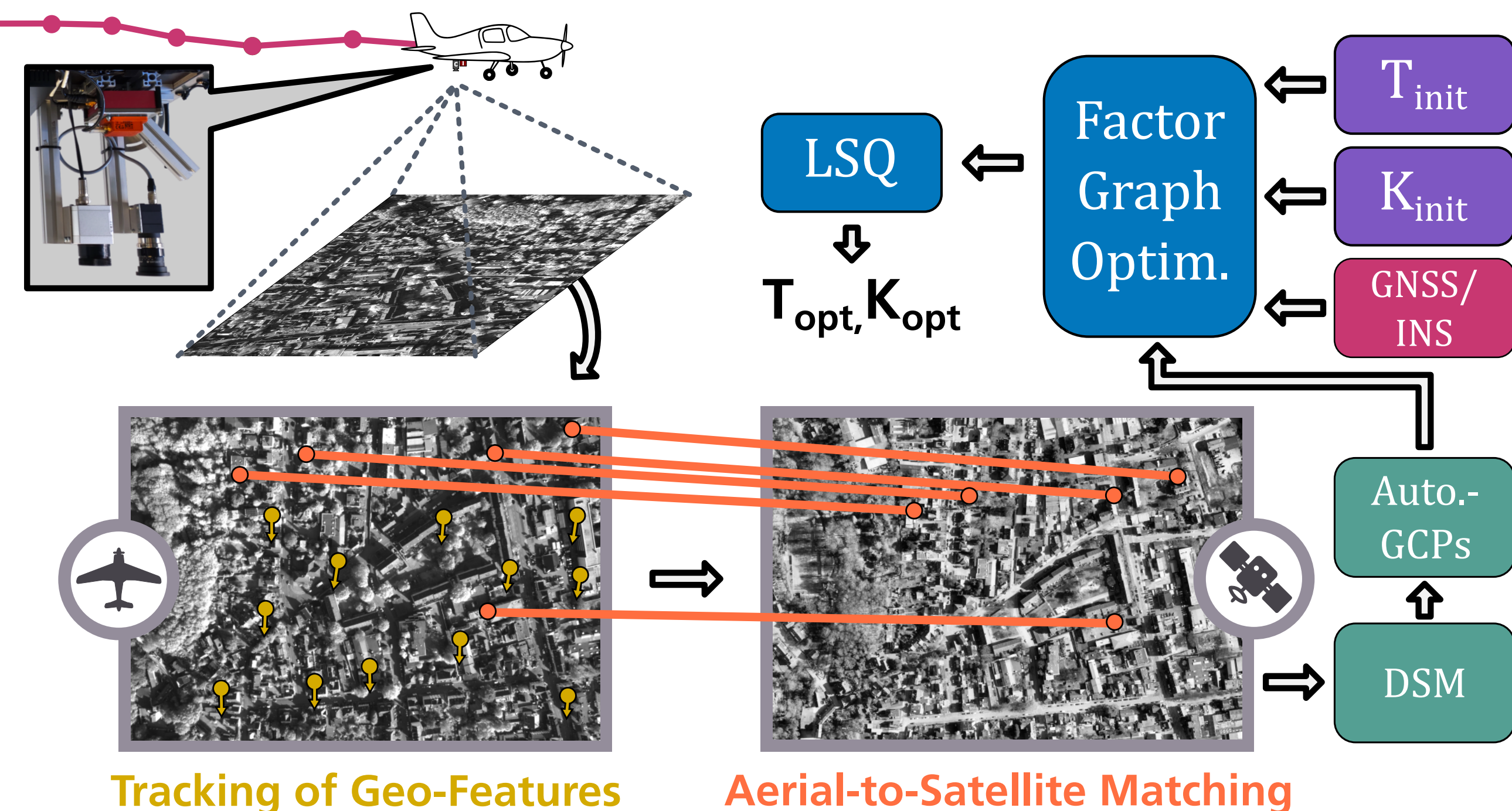


1. Why and Setting

- Calibration misalignments hurt visual-inertial localization in GNSS-denied scenarios
- Manual target calibration does not scale to repeated deployments, especially at high altitudes
- Key idea: Use satellite imagery + DSMs as georeferenced anchors for inflight calibration refinement
- No calibration target, dedicated maneuver, or manual ground control points required

Pipeline overview



2. Approach

- Create 2D-3D anchors from aerial-to-satellite matching
- Fuse anchors with GNSS/INS pose priors in a factor graph

Core Objective

$$\min_{\{C\}, \{X\}, K} \sum_t \underbrace{\|r_t^{cam}\|_{\Sigma_t^{cam}}^2}_{\text{pose priors}} + \sum_j \underbrace{\|r_j^{anc}\|_{\Sigma_j^{anc}}^2}_{\text{3D anchors}} + \sum_{t,j} \underbrace{\|r_{j,t}^{rep}\|_{\Sigma_{rep}}^2}_{\text{2D-3D repr.}}$$

Staged optimization schedule

1. Optimize $R_{cam,t}^W$

2. Optimize $p_{cam,t}^W$

3. Opt. X_j in XY

4. Opt. intrinsics

5. Joint refinement

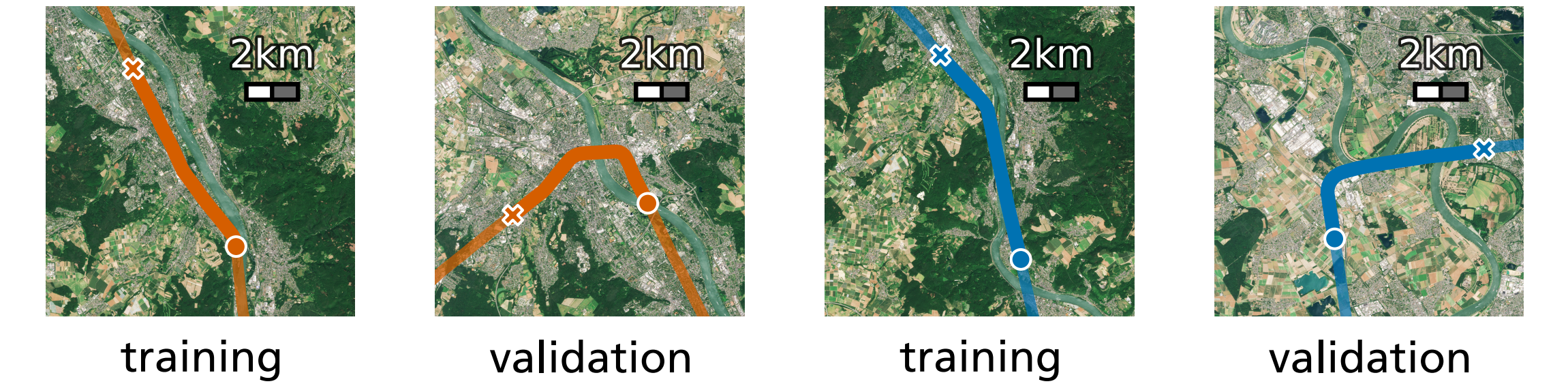
6. Recover extrinsics

Extrinsics refinement

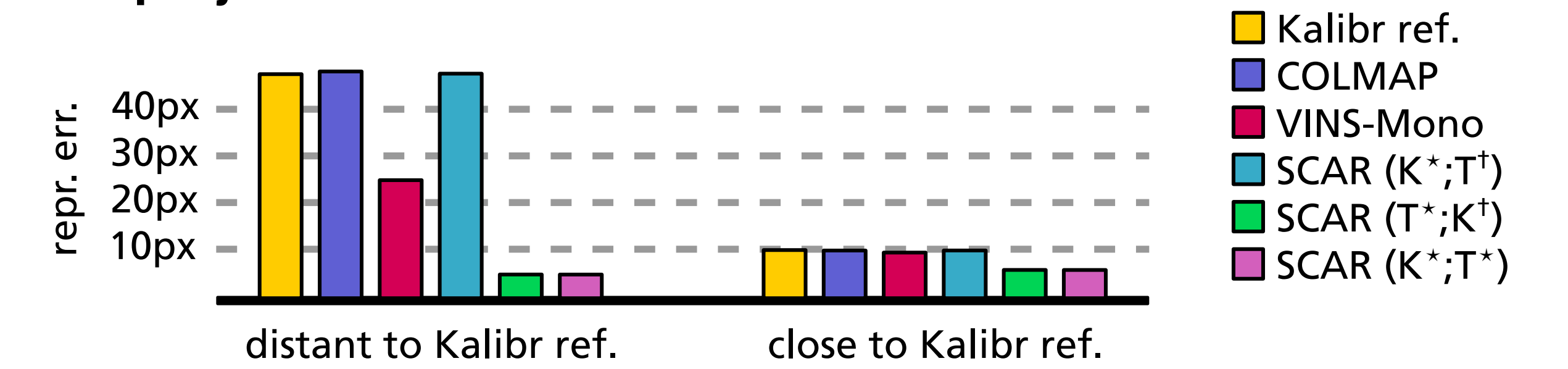
$$T_{opt}^{INS \rightarrow CAM} = \underset{T \in SE(3)}{\operatorname{argmin}} \sum_t \rho(\| \operatorname{Log}[(C_t^*)^{-1} (P_{INS,t}^W T)] \|^2)$$

3. Experiments and Results

- Evaluation on 6 long-term aerial campaigns (2022 - 2024)
- Two routes flown three times each; define shared splits:



Reprojection validation



- SCAR outperforms baselines for in- and extrinsic refinement
- In task-based evaluation for visual localization, SCAR reduces median rotation errors from 2-3° to <1°

Image matching ablation

- Learned feature detectors outperform classical ones

