Converting Relative InSAR Heights to Absolute Elevations: A Guide for SAOCOM L-band Data

InSAR measurements are inherently relative due to the fundamental physics of phase measurement—specifically, the 2π wrapping constraint and integer ambiguity that cannot be resolved without external reference data. ScienceDirect +4 **Your SAOCOM time-series heights require calibration to a known reference datum**, accomplished through either ground control points or statistical comparison with reference DEMs like Copernicus GLO-30 or TINITALY. For L-band data specifically, ionospheric correction is essential and should be applied before height referencing to achieve accuracies of 2-5 meters for DEM generation or 3-6 mm/year for deformation monitoring. Wikipedia

The core challenge is that phase unwrapping requires an arbitrary reference point where phase equals zero, making all subsequent measurements relative to that point. Wikipedia +2 This technical limitation means **absolute elevation cannot be determined from InSAR alone**—external calibration data is mandatory for establishing absolute heights compatible with geodetic reference frames.

Why InSAR produces relative heights: The fundamental problem

InSAR phase measurements operate within a $-\pi$ to $+\pi$ radian range due to wavelength constraints. NASA Earthdata ScienceDirect The interferometric phase relates to slant range difference through $\Delta\varphi = (4\pi/\lambda) \times \Delta R$, but this equation contains an unknown integer ambiguity representing complete wavelength cycles. Wikipedia alaska Without external information, determining the absolute number of wavelengths traveled is impossible. Stack Exchange

Phase unwrapping algorithms resolve relative phase differences between adjacent pixels but require setting a reference point to zero phase. Alaska **All other measurements are calculated relative to this arbitrary reference**, creating the relative height problem. As documented in Alaska Satellite Facility processing guides, "phase shifts are only resolvable relative to other points in the interferogram" and "SAR interferometry measures the relative height of a surface with the difference in phase between two SAR images." Alaska NASA Earthdata

For your SAOCOM CSV data containing negative height values, these values are perfectly valid within a relative reference frame. The negative values simply indicate positions below your current reference point. The challenge is transforming this entire dataset to match the absolute elevation datum of Copernicus GLO-30 or TINITALY.

Standard methodologies for establishing absolute heights

The process of converting relative InSAR heights to absolute elevations follows a hierarchical approach with increasing accuracy levels. Understanding which method suits your application requirements is critical.

Reference DEM statistical calibration (5-10m accuracy)

This method provides the most straightforward approach when high-precision ground control points aren't available. The workflow involves extracting 50-100 co-located sample points from both your InSAR heights and the reference DEM (Copernicus GLO-30 or TINITALY), creating a scatter plot of InSAR elevation versus reference DEM elevation, and performing linear regression analysis.

If the correlation coefficient R^2 exceeds 0.6, you can derive a correction equation: elevation_corrected = a × InSAR_elevation + b. This can be simplified to a constant offset (elevation_corrected = InSAR_elevation + offset) when the relationship is linear with slope near 1.0. esa Apply this correction via band math operations to your entire dataset.

For your case, this would involve loading your SAOCOM CSV heights and the corresponding Copernicus GLO-30/TINITALY elevations at the same geographic coordinates, calculating the regression parameters, and applying the transformation. This approach is suitable for DEM generation and large-scale mapping but achieves only moderate accuracy due to inherent uncertainties in reference DEMs.

Ground control point calibration (0.5-2m accuracy)

When higher precision is required, use surveyed ground control points with known absolute elevations measured via differential GPS or leveling equipment. ResearchGate ScienceDirect The rigorous approach involves least-squares adjustment using 3-5 well-distributed GCPs across your study area. ScienceDirect Each GCP should be located on stable features with high temporal coherence (>0.8) to ensure reliable measurements.

Modern approaches employ an "Auto-PS-GCP" method that automatically selects persistent scatterers as ground control points based on coherence thresholds and amplitude stability indices. MDPI Points meeting criteria of temporal coherence ≥0.8 and amplitude dispersion index ≥0.7 are candidates. The selection algorithm considers point density, spatial distribution, and terrain conditions to optimize GCP coverage. Taylor & Francis Online

GNSS network integration (sub-meter to mm-level accuracy)

For the highest precision applications—particularly when assessing deformation rates—integrate with continuous GNSS stations across your study area. SpringerOpen This method accounts for spatially varying corrections including tropospheric delays, orbital errors, and residual topographic effects. MDPI Multiple GNSS stations enable estimation of spatial correction gradients rather than simple constant offsets.

The projection from GNSS measurements to InSAR line-of-sight requires careful geometric transformation: LOS_velocity = VE × sin(θ) × cos(α) + VN × sin(θ) × sin(α) + VU × cos(θ), where θ is incidence angle, α is azimuth angle, and VE, VN, VU are east, north, and up velocity components from GNSS. Google Groups

Selecting reference points and areas: Practical strategies

Reference point selection critically impacts the quality of your absolute height calibration. The selection process balances multiple competing factors to identify optimal locations.

Automated vs manual selection approaches

Operational processing systems like Alaska Satellite Facility's HyP3 use automated algorithms that examine coherence maps to find maximum coherence values, identify all pixels with maximum coherence, perform 9-pixel window analysis around each candidate, and select the pixel with highest sum within the window. alaska If ties exist, the pixel closest to the scene origin is selected. Alaska

However, manual selection is strongly recommended for your SAOCOM data. Automated selection may choose locations affected by ionospheric artifacts or subtle deformation signals. Manual selection allows incorporation of prior knowledge about terrain stability, infrastructure locations, and potential deformation sources.

Ideal reference point characteristics

Your reference point should exhibit high temporal coherence (≥0.8 for PSI analysis), be located in a stable region beyond documented deformation zones, have minimal vegetation to avoid temporal decorrelation, sit on exposed bedrock or stable infrastructure, and occupy flat or gently sloping terrain to minimize geometric effects. ScienceDirect MDPI

Physical target examples include exposed bedrock in non-deforming areas, stable infrastructure like building foundations or roofs with documented temporal coherence values above 0.9, and areas with minimal vegetation that would cause seasonal decorrelation. For volcanic monitoring studies, researchers typically select reference points 1.5+ km from the deformation source over stable geological formations. MDPI

Critical for L-band SAOCOM data: Avoid areas showing ionospheric streaks or anomalies in your interferograms. L-band is 16 times more sensitive to ionospheric effects than C-band, ScienceDirect Wikipedia making ionosphere-affected reference points particularly problematic.

Reference area vs single point strategies

For large study areas exceeding 25 km², employ multiple reference points in different subareas rather than relying on a single point. Process each subarea with its own reference point and ensure 30% overlap between subareas for consistency checking. MDPI This approach mitigates spatially varying atmospheric effects and orbital uncertainties that would compromise single-point referencing over large extents.

For your SAOCOM time-series, examine the spatial distribution of your measurement points. If they span significant elevation ranges (>1000m) or large horizontal distances (>50 km), consider multi-reference processing to account for tropospheric stratification effects.

Fattahi & Amelung (2013): What it does and doesn't do for your problem

The Fattahi & Amelung (2013) paper published in IEEE Transactions on Geoscience and Remote Sensing (DOI: 10.1109/TGRS.2012.2227761) addresses a related but distinct problem from establishing absolute heights. Readthedocs +3 Understanding this distinction is crucial for your workflow.

The paper's actual focus: DEM error correction

The method corrects phase-to-height conversion errors caused by inaccuracies in the input DEM used during InSAR processing, not conversion of relative to absolute heights. (IEEE Xplore) (Elsevier) It addresses contamination in displacement time series where DEM errors introduce systematic phase errors that corrupt ground displacement measurements. (R Discovery) (Elsevier)

The mathematical innovation operates in the time domain after network inversion for displacement time series, contrasting with earlier methods operating in the interferogram domain before inversion. (IEEE Xplore) (Elsevier) The method estimates DEM error by analyzing phase components that correlate with perpendicular baseline history, then removes these contributions from the time series. (Elsevier)

Critical distinction: As stated in MintPy implementation documentation, "InSAR measures relative range change, so does this step. Thus, this estimated DEM residual is with respect to the reference pixel, which has zero DEM residual." (GitHub) The method produces relative corrections—all corrections remain relative to the chosen reference pixel.

Relevance to your workflow

The Fattahi & Amelung method is relevant but not sufficient for establishing absolute heights. It improves relative displacement accuracy and removes systematic errors from DEM inaccuracies, providing a better foundation for subsequent absolute calibration. However, it does not provide absolute elevation values, does not remove the inherent relative nature of InSAR measurements, and cannot enable direct comparison with GPS absolute heights without additional calibration.

You should apply this method as part of your processing chain to improve the quality of your relative SAOCOM heights, but you must subsequently perform additional calibration steps using reference DEMs or GNSS to establish absolute heights. The typical workflow sequence places DEM error correction between network inversion and final calibration: invert network → correct DEM error (Fattahi & Amelung) → correct troposphere → correct orbital errors → calibrate to absolute reference frame. (Readthedocs +2)

SAOCOM and L-band specific considerations

L-band InSAR from SAOCOM presents unique advantages and challenges compared to C-band systems like Sentinel-1. Understanding these distinctions is essential for successful height referencing.

SAOCOM mission characteristics and processing

SAOCOM-1A (launched 2018) and SAOCOM-1B (launched 2020) operate at L-band frequency of 1.275 GHz with 23.5 cm wavelength. (USGS) The constellation provides 8-day repeat coverage with Stripmap mode (10m resolution, 20-40 km swath) and TOPSAR mode (30-100m resolution, up to 350 km swath). (eoPortal)

Critical limitation: Unlike Sentinel-1, SAOCOM lacks controlled orbital tube management, resulting in highly variable perpendicular baselines MDPI ranging from near-zero to several kilometers. usgs Recent USGS validation studies (2024) comparing SAOCOM-1 with ALOS-2, Sentinel-1, and TerraSAR-X showed 1:1 ± 3% correlation in line-of-sight velocity with minimum detectable deformation of 4 ± 0.6 cm in individual interferograms. USGS +2

Software support includes ISCE with full SAOCOM support and split-spectrum ionospheric correction capabilities, Up-rs-esp SNAP with limited support primarily for Stripmap mode, and GAMMA with proper calibration parameters. For your workflow, ISCE is recommended given the need for ionospheric correction.

L-band advantages for height measurements

L-band's 23.5 cm wavelength provides fundamental advantages over C-band's 5.6 cm wavelength. springeropen +2 **Superior coherence maintenance** in vegetation—SAOCOM maintains coherence >0.6 in forested areas with 16-day temporal baselines where Sentinel-1 degrades to <0.3. ResearchGate +2 Deeper penetration (1-2m in vegetation or sand) MDPI enables measurements in challenging environments. SpringerOpen The larger critical baseline (~10-15 km versus 5-6 km for C-band) ScienceDirect provides more tolerance for baseline variations. Alaska

Fewer fringes simplify phase unwrapping in high-relief terrain—the larger wavelength means fewer 2π cycles for equivalent height differences, reducing unwrapping complexity. ScienceDirect For your SAOCOM data, this translates to more reliable height measurements in mountainous regions compared to C-band alternatives.

The ionospheric challenge: L-band's critical weakness

Ionospheric phase delays represent the most significant challenge for L-band height referencing. The ionosphere causes dispersive phase delay proportional to Total Electron Content (TEC), with effects inversely proportional to frequency squared. ScienceDirect ScienceDirect **L-band suffers 16 times greater ionospheric effects than C-band**. Wikipedia

Typical ionospheric phase contributions range from 1-20 cm equivalent displacement under normal conditions, but extreme cases in equatorial regions during high solar activity can reach 2 meters equivalent displacement. ScienceDirect ScienceDirect These effects manifest as both long-wavelength patterns spanning hundreds of kilometers and short-wavelength streaks from ionospheric scintillation.

For your SAOCOM data processing, ionospheric correction is mandatory unless you're working in high latitudes during solar minimum with very small study areas. Without correction, your height measurements will contain systematic errors that cannot be removed through standard reference point calibration.

Split-spectrum method: The gold standard for L-band ionospheric correction

The split-spectrum method exploits the dispersive nature of ionospheric delays. Readthedocs The approach splits SAR bandwidth into lower and higher frequency sub-bands, where ionospheric effects differ (dispersive) but non-dispersive effects like topography and deformation affect both equally. SpringerOpen +3 Separating these components enables isolation of ionospheric contamination.

The mathematical implementation: $\varphi_{ionosphere} = (f_{low}^2 \times f_{high}^2)/(f_{low}^2 - f_{high}^2) \times (\varphi_{low}/f_{low}^2 - \varphi_{high}/f_{high}^2)$. Performance studies show 8-28× reduction in ionospheric noise (latitude dependent) MDPI with achievable accuracy of 3-6 mm/year for time-series analysis validated against GNSS. ScienceDirect

Implementation considerations: The method requires full-bandwidth data and reduces effective resolution due to sub-band filtering. ISCE includes split-spectrum implementation for SAOCOM data. Up-rs-esp Recent Earth, Planets and Space research (2025) provides optimized processing parameters: 4-10 looks in range, 20-40 in azimuth, Gaussian filtering with 500-1500m radius depending on signal wavelength. SpringerOpen

Alternative methods include Faraday rotation using polarimetric data (requires full-pol or quad-pol acquisitions), range-azimuth offset methods for single-pol data with lower accuracy, and external GPS TEC maps from Global Ionosphere Maps. However, GIM temporal resolution (2-hour) and spatial resolution (~300 km) are generally too coarse for local effects—best used for initial correction combined with split-spectrum refinement.

Regional considerations for ionospheric effects

Equatorial regions (±20° magnetic latitude) experience strongest effects with TEC variations up to 100 TECU. NASA Airborne Science Program Diurnal peaks occur around 14:00 local time with maximum seasonal activity during equinox months. Split-spectrum correction is essential for all equatorial SAOCOM processing.

Mid-latitudes (20-60°) show moderate effects generally <50 TECU with 3-5× variation between solar minimum and maximum. Split-spectrum is recommended, though simple plane-fit corrections may suffice for some applications with relaxed accuracy requirements.

High latitudes (>60°) experience aurora-related scintillation causing rapid, less predictable phase variations. Science.gov Geomagnetic substorm events create artifacts difficult to correct. Avoid processing data acquired during geomagnetic storms (Kp>5) when possible.

Identify your study area's magnetic latitude and solar activity period when acquiring SAOCOM data to assess ionospheric correction requirements and expected accuracy.

Practical implementation: Step-by-step workflow

The complete workflow for converting your relative SAOCOM heights to absolute elevations compatible with Copernicus GLO-30 or TINITALY datums involves multiple coordinated steps.

Data preparation and quality assessment

Begin by loading your SAOCOM CSV time-series data and examining the distribution of height values. Identify whether your data includes coherence metrics, temporal information, and geographic coordinates. Load your reference DEM (Copernicus GLO-30 or TINITALY) ensuring it covers your entire study area.

Assess data quality by examining temporal coherence distributions—values above 0.7 indicate reliable measurements. ScienceDirect Check for spatial patterns suggesting ionospheric contamination, particularly long-wavelength ramps or directional streaks. If present, these must be corrected before proceeding with height referencing.

Reference point identification

Manually identify stable reference point candidates by overlaying your SAOCOM measurements on the reference DEM and examining topography. Potential reference locations include exposed bedrock at high elevations away from valleys where moisture accumulates, stable infrastructure with documented construction dates predating your SAOCOM time-series, and areas outside documented deformation zones.

For each candidate, extract temporal coherence and amplitude stability metrics. Select the point with highest coherence (>0.85 preferred) in the most stable terrain. Record the exact geographic coordinates and reference DEM elevation at this point.

Offset calculation methods

Method 1: Simple constant offset. For study areas <50 km with uniform atmospheric conditions, calculate the mean difference between SAOCOM heights and reference DEM heights across 20-50 stable points (high coherence, low deformation). This mean difference represents your systematic offset. Apply uniformly: elevation_absolute = SAOCOM_height + mean_offset.

Method 2: Linear regression. When systematic relationships exist between relative and absolute heights (common when reference frame differences dominate), extract SAOCOM and reference DEM values at 100+ well-distributed points. Perform linear regression: DEM_elevation = a + b × SAOCOM_height. Apply the inverse transformation: elevation_absolute = (SAOCOM_height - a) / b.

Method 3: Spatially varying correction. For large areas (>100 km²) or significant topographic relief (>1000m), fit a 2D polynomial surface to height differences between SAOCOM and reference DEM. Typical models include planar (3 parameters: a + bx + cy) or bilinear (4 parameters: a + bx + cy + dxy). Fit the polynomial to stable areas only (mask deforming regions), then apply spatially varying correction across entire dataset.

Python implementation example

python

```python
import numpy as np
import pandas as pd
from scipy import stats
from scipy.interpolate import griddata

# Load SAOCOM CSV data
saocom_data = pd.read_csv('saocom_timeseries.csv')
# Assumes columns: 'lat', 'lon', 'height', 'coherence'

# Load reference DEM (example for Copernicus GLO-30)
from osgeo import gdal
ds = gdal.Open('copernicus_glo30.tif')
reference_dem = ds.ReadAsArray()
geotransform = ds.GetGeoTransform()

# Function to extract DEM value at lat/lon
def get_dem_value(lat, lon, dem, geotransform):
    x_pixel = int((lon - geotransform[0]) / geotransform[1])
    y_pixel = int((lat - geotransform[3]) / geotransform[5])
    return dem[y_pixel, x_pixel]

# Extract reference DEM values at SAOCOM points
saocom_data['dem_reference'] = saocom_data.apply(
    lambda row: get_dem_value(row['lat'], row['lon'],
                              reference_dem, geotransform),
    axis=1
)

# Filter stable points (high coherence, exclude outliers)
stable_mask = (saocom_data['coherence'] > 0.8) & \
              (np.abs(saocom_data['height']) < 100)  # Adjust threshold
stable_points = saocom_data[stable_mask]

# Method 1: Constant offset
height_diff = stable_points['dem_reference'] - stable_points['height']
constant_offset = np.median(height_diff)  # Use median for robustness
print(f"Constant offset: {constant_offset:.3f} m")

saocom_data['height_absolute_v1'] = saocom_data['height'] + constant_offset

# Method 2: Linear regression
slope, intercept, r_value, p_value, std_err = stats.linregress(
    stable_points['height'],
    stable_points['dem_reference']
)
```

```
)
print(f"Linear fit: DEM = {intercept:.3f} + {slope:.3f} × SAOCOM")
print(f"R² = {r_value**2:.3f}")

saocom_data['height_absolute_v2'] = \
    intercept + slope * saocom_data['height']

# Method 3: Spatially varying (2D polynomial)
from sklearn.preprocessing import PolynomialFeatures
from sklearn.linear_model import LinearRegression

# Prepare spatial features
X = stable_points[['lon', 'lat']].values
y = stable_points['dem_reference'].values - stable_points['height'].values

# Fit bilinear model
poly = PolynomialFeatures(degree=2, include_bias=True)
X_poly = poly.fit_transform(X)
model = LinearRegression()
model.fit(X_poly, y)

# Apply to all points
X_all = saocom_data[['lon', 'lat']].values
X_all_poly = poly.transform(X_all)
spatial_correction = model.predict(X_all_poly)

saocom_data['height_absolute_v3'] = \
    saocom_data['height'] + spatial_correction

# Validation: Calculate RMSE at stable points
rmse_v1 = np.sqrt(np.mean(
    (stable_points['dem_reference'] -
     (stable_points['height'] + constant_offset))**2
))
rmse_v2 = np.sqrt(np.mean(
    (stable_points['dem_reference'] -
     (intercept + slope * stable_points['height']))**2
))
print(f"RMSE Method 1: {rmse_v1:.3f} m")
print(f"RMSE Method 2: {rmse_v2:.3f} m")

# Save results
saocom_data.to_csv('saocom_absolute_heights.csv', index=False)
```

Geoid correction considerations

Your reference DEMs may be referenced to either ellipsoidal heights (geometric height above reference ellipsoid) or orthometric heights (height above geoid/mean sea level). Copernicus GLO-30 provides heights relative to the EGM2008 geoid. Alaska alaska TINITALY typically uses orthometric heights referenced to the Italian vertical datum.

If your SAOCOM processing used ellipsoidal heights but your reference DEM uses orthometric heights, apply geoid correction: height_orthometric = height_ellipsoidal - geoid_undulation. The EGM2008 geoid model provides undulation values globally. For Italy, geoid undulations range from approximately +45m to +52m.

Python implementation using pyproj:

```python
from pyproj import Transformer

# Create transformer for geoid conversion
transformer = Transformer.from_crs(
    "EPSG:4326",  # WGS84 geographic
    "EPSG:4326+5773",  # WGS84 + EGM2008 geoid
    always_xy=True
)

# Apply geoid correction
for idx, row in saocom_data.iterrows():
    lon, lat, h_ellipsoid = row['lon'], row['lat'], row['height_absolute_v1']
    x, y, h_orthometric = transformer.transform(lon, lat, h_ellipsoid)
    saocom_data.at[idx, 'height_orthometric'] = h_orthometric
```

Quality control and validation

After applying height corrections, perform rigorous validation. Calculate residuals between corrected SAOCOM heights and reference DEM at stable points. The residual distribution should be approximately normal with mean near zero. Standard deviation provides accuracy estimate—values <5m indicate acceptable quality for most applications, <2m indicates high quality.

Examine spatial patterns in residuals. Systematic gradients suggest unmodeled effects like orbital errors or tropospheric stratification requiring additional correction. Random spatial distribution indicates successful calibration.

If independent validation data exists (GNSS, leveling surveys, lidar), compare corrected SAOCOM heights at these locations. This provides unbiased accuracy assessment since validation points weren't used in calibration.

Spatial considerations: When corrections vary

The decision between constant offset and spatially varying corrections depends on study area characteristics and accuracy requirements.

Constant offset is appropriate when

Small study areas (<100 km²) minimize spatial variations in atmospheric and orbital effects. Low topographic relief (<500m) reduces elevation-dependent tropospheric delays. Modern satellites with precise orbits (though SAOCOM orbital accuracy is lower than Sentinel-1) limit systematic trends. Short temporal baselines minimize temporal atmospheric variations.

For your SAOCOM data, if measurements span limited spatial extent with uniform terrain, constant offset provides acceptable accuracy with minimal computational complexity.

Spatially varying corrections required when

Large study areas (>100 km²) experience differential atmospheric delays and orbital geometry variations. Significant topographic variation (>1000m relief) creates elevation-dependent tropospheric delays—water vapor concentration decreases exponentially with altitude, causing phase delays correlating with topography. ScienceDirect Wikipedia Long temporal baselines or time-series analysis accumulate atmospheric variations requiring sophisticated modeling.

Tropospheric stratification effects represent the primary driver of spatially varying corrections. The stratified tropospheric component correlates with topography and can mimic deformation signals in volcanic or mountainous terrain. ScienceDirect +2 Correction methods include phase-elevation regression fitting linear or power-law models ($\varphi(h) = \varphi_0 \times (h/h_0)^\alpha$ where α typically ranges 2-4), weather model integration using ERA-5 or ECMWF reanalysis data, and adaptive approaches like quadtree segmentation achieving 50% reduction in phase standard deviation. Wiley Online Library Wiley Online Library

Magnitude of spatial variations: 20% variation in relative humidity can produce 10-14 cm measurement errors. Seasonal tropospheric variations reach up to 10 cm stratified delay in mountainous regions. Wikipedia ScienceDirect In areas with 1000+ meter elevation ranges, tropospheric correlation with topography significantly impacts height accuracy.

For your SAOCOM data processing, examine whether measurement points span significant elevation ranges. If elevation differences exceed 500m across your study area, implement elevation-dependent corrections using phase-elevation regression or weather model integration.

Integrating with MintPy for automated workflows

MintPy (Miami InSAR Time-series software in Python) provides comprehensive tools for InSAR time-series analysis including height referencing capabilities. GitHub +6 Understanding MintPy's workflow enables efficient processing of your SAOCOM data.

MintPy processing sequence

The standard MintPy workflow proceeds through: load_data (ingest interferograms), modify_network (optimize interferogram network), reference_point (set spatial reference), invert_network (generate raw time-series), correct_troposphere (remove atmospheric delays), deramp (remove orbital ramps if needed), correct_topography (Fattahi & Amelung DEM error correction), and velocity (estimate deformation rates). Readthedocs +5

Configuration occurs through template files (smallbaselineApp.cfg) specifying processing parameters. Critical parameters for your workflow include reference point selection, DEM error correction enabling, and tropospheric correction method.

Reference point configuration

Manual reference point specification is strongly recommended:

```python
# In smallbaselineApp.cfg
mintpy.reference.lalo = 43.850,11.234  # Latitude, longitude
mintpy.reference.minCoherence = 0.85   # Coherence threshold
```

If you have GPS/GNSS station in stable terrain, use its coordinates as reference. This directly ties your InSAR measurements to absolute geodetic reference frame.

DEM error correction setup

Enable Fattahi & Amelung topographic residual correction:

```python
mintpy.topographicResidual = yes
mintpy.topographicResidual.polyOrder = 2  # Quadratic temporal model
mintpy.topographicResidual.pixelwiseGeometry = yes  # Use pixel-wise angles
```

This step estimates and removes phase contributions from DEM inaccuracies, improving relative height quality before absolute calibration. Debian Manpages

Tropospheric correction options

For L-band SAOCOM data, tropospheric correction is critical:

```python
mintpy.troposphericDelay.method = height_correlation  # or ERA5/pyaps
mintpy.troposphericDelay.polyOrder = 1  # Linear phase-elevation model
```

The height_correlation method fits phase-elevation relationships removing stratified delays. For more sophisticated correction, specify ERA5 or ECMWF to use weather model data. Readthedocs +2

Post-MintPy calibration

After MintPy processing generates velocity.h5 and timeseries.h5 files, perform absolute calibration using the Python implementations provided earlier. Extract MintPy results, compare with reference DEM or GNSS, calculate offset or regression parameters, and apply corrections to generate absolutely referenced products.

python

```python
from mintpy.utils import readfile, writefile

# Read MintPy velocity results
velocity, atr = readfile.read('velocity.h5')

# Apply calibration offset (from earlier calculation)
velocity_calibrated = velocity + calibration_offset

# Update metadata
atr['CALIBRATION_OFFSET'] = str(calibration_offset)
atr['REFERENCE_DEM'] = 'Copernicus_GLO30'

# Write calibrated results
writefile.write(velocity_calibrated, 'velocity_absolute.h5',
               metadata=atr)
```

Accuracy expectations and validation strategies

Understanding achievable accuracy for different methods guides expectations and validation planning.

Accuracy hierarchy

Reference DEM statistical calibration achieves 5-10m RMSE depending on reference DEM quality and terrain complexity. Copernicus GLO-30 absolute accuracy is approximately ±4m (linear error at 90% confidence), TINITALY provides higher accuracy in Italy (typically 2-5m depending on region), while systematic offsets from orbital uncertainties add 1-5m for SAOCOM. Charim

GCP-based calibration reaches 0.5-2m RMSE with differential GPS ground control (±2-5cm vertical accuracy), ICESat-2 ATL08 lidar (±50cm for flat terrain), and corner reflectors providing strongest radar returns with precisely surveyed positions. eoPortal +3

GNSS network integration achieves <0.5m for absolute positioning, 3-6 mm/year for deformation rate estimation in time-series (validated with ALOS PALSAR and SAOCOM), ScienceDirect and mm-level precision for relative deformation between GNSS stations. Medium +2

Validation approaches

Independent checkpoints: Withhold 20-30% of available ground control points during calibration. Calculate RMSE at these checkpoints providing unbiased accuracy assessment. For your SAOCOM data, if collecting field measurements, reserve some for validation rather than using all for calibration.

Cross-validation with other sensors: Compare SAOCOM heights with Sentinel-1 or ALOS-2 measurements in same area. Different sensors provide independent validation, though systematic differences from wavelength effects require consideration. L-band penetrates deeper in vegetation than C-band—height differences may represent real physical phenomena rather than errors.

Internal consistency checks: Examine temporal coherence and phase residuals after corrections. High residuals indicate problematic pixels requiring exclusion. Coherence degradation over time suggests temporal decorrelation or unmodeled deformation. ScienceDirect

Statistical validation: Calculate residual statistics at stable points. Mean residual should be near zero (within ±1m). Standard deviation indicates random error magnitude. Examine residual spatial patterns—gradients or trends indicate unmodeled systematic effects requiring additional correction.

For your specific case with SAOCOM time-series and reference DEMs, realistic accuracy expectations are 5-8m RMSE for Copernicus GLO-30 calibration and 2-5m RMSE for TINITALY calibration (higher quality reference). With GNSS validation points, you can achieve 0.5-2m absolute accuracy and <5 mm/year for deformation rates.

Key recommendations for your SAOCOM workflow

Based on comprehensive research findings, implement these prioritized recommendations for converting your relative SAOCOM heights to absolute elevations.

Apply ionospheric correction first. Before any height referencing, correct ionospheric phase delays using split-spectrum method in ISCE. L-band ionospheric contamination can reach equivalent displacements of 1-2 meters—larger than your target accuracy. Process SAOCOM data with split-spectrum enabled, use 4-10 range looks and 20-40 azimuth looks, apply Gaussian filtering (500-1500m radius), and validate residuals against GPS TEC maps qualitatively.

Select reference points manually. Do not rely on automated selection for L-band data. Ionospheric artifacts can create false "high coherence" regions. Identify reference points on bedrock or stable infrastructure, verify temporal coherence >0.85, confirm location is outside deformation zones and has no ionospheric streak contamination, and document selection rationale and coordinates.

Choose calibration method based on available data. If you have GNSS stations in study area, use multi-point GNSS calibration for highest accuracy (target: 0.5-2m). With high-quality TINITALY DEM but no GNSS, use regression-based calibration (target: 2-5m). With only Copernicus GLO-30, use constant offset with robust statistics (target: 5-8m). Consider collecting field GPS measurements at 5-10 strategic locations if higher accuracy is required.

Account for spatial variations in large areas. If your SAOCOM points span >50 km or >500m elevation range, implement spatially varying corrections. Use phase-elevation regression for tropospheric stratification, fit 2D polynomial for orbital ramps if present, and validate spatial correction patterns against known atmospheric models.

Validate rigorously. Reserve 20-30% of reference points for validation, calculate RMSE at validation points, examine residual spatial patterns for systematic errors, and compare with independent data sources if available (other InSAR sensors, leveling surveys, lidar).

Document processing chain completely. Record ionospheric correction parameters and TEC conditions during acquisitions, reference point location and selection criteria, calibration method and parameters used, validation results and accuracy estimates, and reference DEM source and version. Complete documentation enables reproducibility and facilitates comparison with other studies.

Conclusions and future directions

Converting relative SAOCOM InSAR heights to absolute elevations requires systematic application of ionospheric correction, careful reference point selection, and calibration using external data. The inherent relative nature of InSAR phase measurements cannot be overcome through processing alone—external reference data from DEMs or GNSS remains mandatory for establishing absolute heights.

L-band SAOCOM data provides significant advantages for height measurements in vegetated and challenging environments through superior coherence maintenance, but ionospheric effects must be rigorously addressed through split-spectrum or equivalent methods. When properly corrected and calibrated, SAOCOM achieves 2-5m accuracy for DEM generation and 3-6 mm/year accuracy for deformation monitoring—comparable to or exceeding C-band capabilities in many applications.

The Fattahi & Amelung (2013) DEM error correction method improves relative measurement quality and should be incorporated in your processing chain, but requires subsequent absolute calibration steps. The method refines the relative measurements but does not establish absolute reference frames.

Your workflow should prioritize ionospheric correction, implement manual reference point selection with documentation, choose calibration methods matching available reference data quality and accuracy requirements, account for spatial variations in atmospheric and orbital effects for large study areas, and validate results rigorously using independent checkpoints.

With NISAR (NASA-ISRO) expected to launch soon providing systematic global L-band coverage, and ROSE-L (ESA Copernicus) planned for the late 2020s, L-band InSAR height referencing methodologies will become increasingly important for operational applications in forestry, hydrology, cryosphere, and geohazards monitoring. The techniques developed for SAOCOM processing will directly transfer to these future missions, making current methodology development valuable for long-term applications.