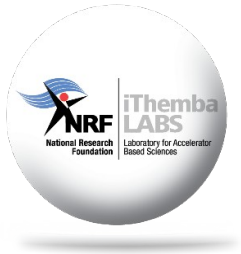
Lecture 1: Introduction to GNSS Processing with GAMIT/GLOBK



DARA Training School · 15 September 2026

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Lecture agenda

- 1. Why GNSS processing? Learning outcomes
- 2. GNSS observables, errors, and products
- 3. GAMIT/GLOBK architecture and workflow
- 4. Directories, control files, sh_gamit / sh_glred
- 5. Quality control and common pitfalls
- 6. Bridge to Lecture 2 (PWV workshop)

Part A · From raw phase observations to scientific products

WHY PROCESS GNSS?

Learning outcomes

- Explain what GAMIT and GLOBK each contribute to a GNSS solution
- Describe the end-to-end chain: RINEX → h-files → positions / velocities
- Identify key control files — especially station.info and a priori coordinates
- Run (conceptually) sh_setup, sh_gamit, and sh_glred and know what to inspect
- Recognise typical failure modes: metadata, orbits, network geometry, QC

Lecture 2 applies this workflow to precipitable water vapour (PWV).

Scientific motivation

- Precise positioning for reference frames, tectonics, and surveying
- Atmospheric sensing: tropospheric delay → precipitable water vapour (PWV)
- Earth orientation, satellite orbits, and multi-technique combinations
- Africa needs denser, well-processed GNSS for geodesy and climate applications
- DARA / AVN context: building local capacity to process and interpret GNSS data

DARA training context

DARA = Development in Africa with Radio Astronomy

Builds skills across radio astronomy, geodesy, and related data science

This module focuses on GNSS processing with GAMIT/GLOBK

Workshop data and example plots come from prior DARA practicals (e.g. GBGA)

Goal: leave able to run, QC, and interpret a real processing chain

Example cohort at a radio astronomy / geodesy training site.

Part B · What the software is actually estimating

GNSS FUNDAMENTALS FOR PROCESSORS

Observables used in high-precision processing

- Carrier phase (primary) — millimetre-level relative precision after ambiguity resolution
- Pseudorange (code) — helps clocks, cycle-slip detection, and absolute ranging
- Dual-frequency combinations (e.g. ionosphere-free LC) reduce first-order ionosphere
- GAMIT works primarily with phase and range in its internal x-file format
- RINEX is the exchange format; makex converts RINEX → GAMIT observables

Error sources that processing must handle

- Satellite and receiver clocks
- Troposphere: hydrostatic + wet zenith delays (and gradients)
- Ionosphere: dispersive; mitigated with dual-frequency modelling
- Antenna phase-centre offsets and variations (PCO/PCV)
- Multipath, ocean/atmospheric loading, Earth tides, relativity
- Orbit quality and reference-frame realisation

For PWV work, tropospheric modelling choices in sestbl. are critical — see Lecture 2.

Typical geodetic products

- Daily station coordinates (loosely constrained then framed)
- Time series and secular velocities
- Zenith total delay (ZTD / TZD) and, with surface pressure, PWV
- Earth orientation parameters (EOP) and orbit adjustments (as configured)
- Quality metrics: phase residuals, ambiguity success, nrms / wrms

Part C · MIT software suite for GNSS phase processing and combination

WHAT IS GAMIT/GLOBK?

GAMIT in one slide

- GAMIT = “GNSS at MIT” — collection of Unix programs for phase processing
- Estimates: relative 3-D station positions, atmospheric zenith delays, EOPs / orbits (as set)
- Core engines inside each day directory: model → autcln → solve (driven by batch b-files)
- Main user entry point: sh_gamit
- Primary scientific output: ASCII h-files (estimates + full covariance, loosely constrained)

GLOBK in one slide

- GLOBK = “Global Kalman filter” — combines geodetic solutions
- Inputs are quasi-observations: GAMIT h-files (after htoglb → binary), optionally VLBI/SLR
- Applies reference-frame constraints uniformly after loose daily solutions
- sh_glred wraps daily combinations, time series, and related bookkeeping
- Outputs: .org solutions, .pos time series, .vel velocities

End-to-end workflow

- 1. Field / archive data → RINEX in rinex/
- 2. sh_setup → tables/ with links to ~/gg/tables
- 3. Edit sites.defaults, sestbl., station.info, a priori (.apr / lfile)
- 4. sh_gamit → day directories, ASCII h-files
- 5. sh_glred (-opt H G T …) → binary h-files, combinations, plots
- 6. Inspect summaries, residuals, and time series before science use

Software layout on the machine

- ~/gg/ is a link to the installed GAMIT/GLOBK tree — do not remove it
- ~/gg/com/ — shell scripts (sh_gamit, sh_glred, sh_setup, …); each has built-in help
- ~/gg/gamit/bin/ and ~/gg/kf/bin/ — compiled executables
- ~/gg/tables/ — global tables (antennas, oceans grids, metadata links, …)
- Experiment directories hold local rinex/, tables/, day folders, glbf/, gsoln/

Tip: typing a script name with no arguments usually prints its help.

Part D · What you must prepare before pressing Run

EXPERIMENT DIRECTORIES & CONTROL FILES

Directory structure

- Top level: your experiment (e.g. year or survey folder)
- rinex/ — local observation (and met) files
- tables/ — experiment control + links into ~/gg/tables
- brdc/, igs/, gfiles/ — navigation, orbits, initial conditions (often auto-filled)
- DDD/ day directories (001, 277, …) — where GAMIT actually runs
- glbf/ — binary h-files; gsoln/ — GLOBK runs and org/pos products

Files you must get right

- **Critical files**
- station.info — antenna, receiver, ARP height, occupancy
- sites.defaults — sites, ftprnx, xstinfo
- sestbl. — models and estimation choices
- process.defaults — session bookkeeping
- sittbl. — a priori constraints for ambiguities
- .apr / lfile. — a priori coordinates

- **Usually leave alone initially**
- autcln.cmd — cleaning defaults
- rcvant.dat, antmod.dat — via global tables
- svnav / IGS metadata links
- **Update periodically**
- dcb.dat (biases)
- EOP / leap seconds as needed

sites.defaults essentials

- Lists sites included for a named experiment
- ftprnx — allow automatic download of public RINEX for that site
- xstinfo — whether metadata may be updated from RINEX headers (use carefully)
- Local unique sites still need files present under rinex/
- Network design: include well-distributed IGS/reference sites for frame and geometry
- IGS station map helps choose partners: https://igs.org/network/

station.info — why metadata kills (or saves) solutions

- Wrong antenna type → systematic height / PCV errors
- Wrong ARP / monument height → biased Up component (and troposphere coupling)
- Wrong occupancy window → missing or mismatched data intervals
- Update from RINEX when appropriate: sh_upd_stnfo -files ../rinex/*.YYo
- Also: sh_upd_stnfo -l sd to merge from sites.defaults selections
- Always diff station.info vs station.info.orig after updates

Part E · Batch processing for daily sessions

RUNNING GAMIT: SH_SETUP & SH_GAMIT

Starting an experiment

```
# Create / enter experiment directory, ensure rinex/ exists with local data
mkdir -p rinex && # place local *.YYo / met files here

# Build tables/ and link global resources for the processing year
sh_setup -yr 2023

# Edit in tables/: sites.defaults, sestbl., station.info, apr/lfile as needed
# Then run (example):
sh_gamit -expt dara -c -s 2023 277 278 -pres ELEV -orbit IGSF \
         -copt x k p -dopt c ao
```

Flags shown match the DARA PWV workshop style used in Lecture 2.

What sh_gamit does for you

- Fetches / prepares orbits (e.g. IGS final) and builds g- / t-files as needed
- Builds clock (j-) files; converts RINEX via makex
- Writes batch b-files and iterates model → autcln → solve
- Updates a priori if adjustments are large; produces day-directory summaries
- Writes ASCII h-files for GLOBK; optional residual plots (-pres ELEV)
- You still own: metadata, site list, models in sestbl., and QC afterwards

Useful sh_gamit options (workshop-relevant)

- -expt NAME — 4-character experiment name (e.g. dara)
- -s YEAR DOY1 DOY2 — session range
- -orbit IGSF — IGS final orbits (or other orbit choices as available)
- -pres ELEV — elevation-dependent residual plots
- -copt / -dopt — control compression and deletion of intermediate files
- -c — continue / recover-oriented behaviour in long batch runs
- Always skim the day summary (e.g. sh_gamit*.summary) after a run

Part F · From daily h-files to framed coordinates and time series

RUNNING GLOBK: SH_GLRED

Post-processing chain

- htoglb — ASCII h-files → binary h-files in glbf/
- glist / glred — chronological combination of binary h-files
- globk.cmd / glorg.cmd — a priori sigmas, stab sites, organisation of frame
- sh_glred -cmd — initialise command files if needed
- sh_glred -s Y1 D1 Y2 D2 -expt NAME -opt H G T — common daily combo + plots
- Inspect .org, .pos, and residual/time-series plots before trusting coordinates

Typical GLOBK invocation

```
# Create / refresh command templates if missing
sh_glred -cmd

# Combine days, convert h-files, generate time series / plots
sh_glred -s 2023 277 2023 278 -expt dara -opt H G T

# H = htoglb   G = glred/globk path   T = time series / plot helpers
# Edit gsoln/globk.cmd and glorg.cmd for frame stabilisation sites
```

Short-term vs long-term GLOBK aims

- Short-term: combine days where velocity is negligible (survey / few days)
- Reduce scatter; produce cleaner coordinates for that window
- Long-term: estimate velocities from continuous or repeated occupations
- Always plot time series (sh_plot_pos) and remove outliers before final velocities
- Workshop (Lecture 2) uses a 2-day window — enough to exercise the chain, not for velocities

Example GLOBK time series — GBGA

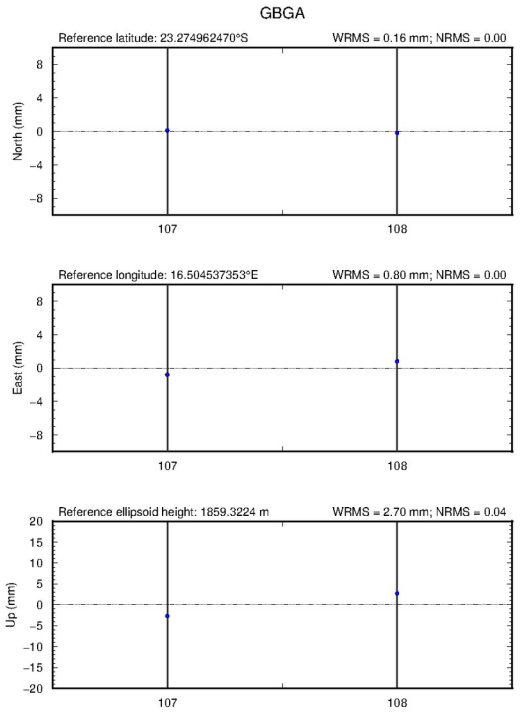
North / East / Up residuals after daily combination

Look for repeatability (WRMS) and outliers

Horizontal usually tighter than Up

Up couples strongly to troposphere — relevant for PWV

Two-day workshop spans are for method practice, not velocity science



DARA example: MEAN.GBGA residuals for DOYs 107–108.

Part G · What to look at before you publish a coordinate

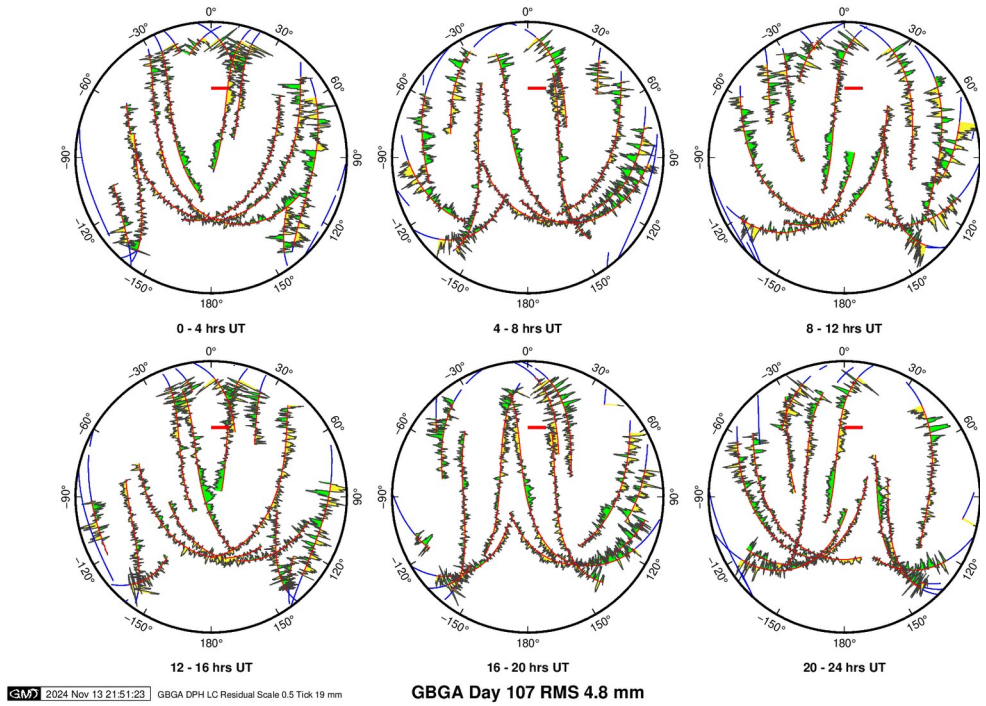
QUALITY CONTROL & PITFALLS

QC checklist after sh_gamit

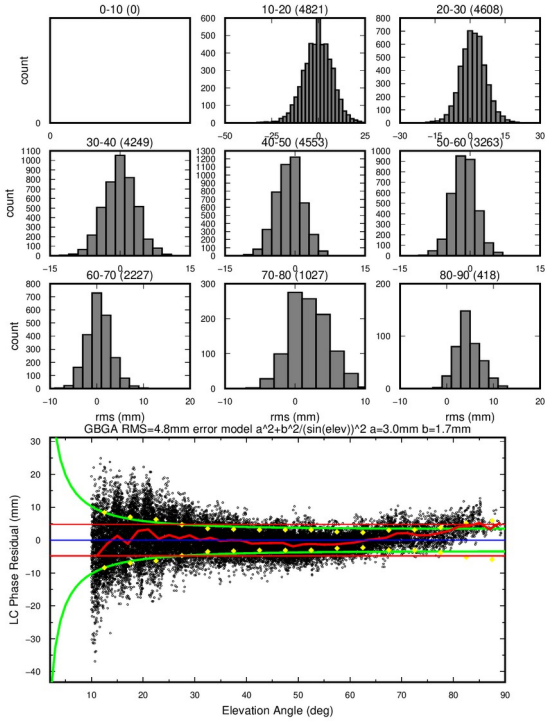
- Did all intended sites appear in the solution?
- Ambiguity resolution rates and nrms in the daily summary
- Phase residual plots: systematics with elevation or time?
- Large coordinate adjustments → check apr / station.info / bad RINEX
- Missing met warnings matter if you care about PWV (Lecture 2)
- Re-run only after fixing root cause — avoid blind reprocessing loops

Example QC plots — GBGA phase residuals

Skyplot residuals (4-hour panels)



Elevation-dependent LC residuals



DARA example: GBGA day 107 — RMS ≈ 4.8 mm; noise grows at low elevation as expected.

Common pitfalls

- RINEX3 vs RINEX2 / Hatanaka compression not converted for GAMIT expectations
- Marker name vs 4-char site code mismatches
- Incomplete station.info windows for the session
- Too few / poorly distributed reference sites
- Stale tables (antennas, DCBs) after new equipment or satellites
- Treating loosely constrained h-file coordinates as final ITRF positions

RINEX preparation overview

- Archives often deliver .crx.gz (Hatanaka + gzip)
- gzip -d → CRX2RNX → optionally gfzrnx to RINEX2 GPS-only for legacy flows
- Confirm sample interval, satellite systems, and met file availability
- Naming must match what sites.defaults / station.info expect (e.g. gbga2770.23o)
- Lecture 2 automates this chain in the workshop Python menu (Step 2)

Part H · Lecture 2 builds on today's workflow

WRAP-UP & BRIDGE TO PWV

Key takeaways

- GAMIT estimates daily GNSS parameters from phase; GLOBK combines and frames them
- Metadata and network design dominate success more than exotic option flags
- sh_setup → edit tables → sh_gamit → sh_glred is the standard spine
- Always QC summaries and residuals
- Tropospheric delays estimated in GAMIT are the gateway to GNSS meteorology

Preview of Lecture 2

- Science: Zenith Total Delay → Zenith Wet Delay → Precipitable Water Vapour
- sestbl. settings for met output (RNX GPT, Output met = Y, GMAP, …)
- Workshop script dara_gamit_globk_steps.py — interactive steps 1–8
- Case study: station GBGA, year 2023, DOYs 277–278
- sh_metutil + plot_metutil.py to turn o-files + met into PWV time series

Bring: SSH access notes, and skim Workshop_Exercise_Steps.pdf before Lecture 2.

Discussion / questions

- Which part of the chain feels least clear: data prep, GAMIT, or GLOBK?
- What GNSS products does your home institution already produce?
- Open questions before the PWV practical