Estimable phase and code biases in the frame of global multi-GNSS processing

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Global GNSS processing with the raw observation approach

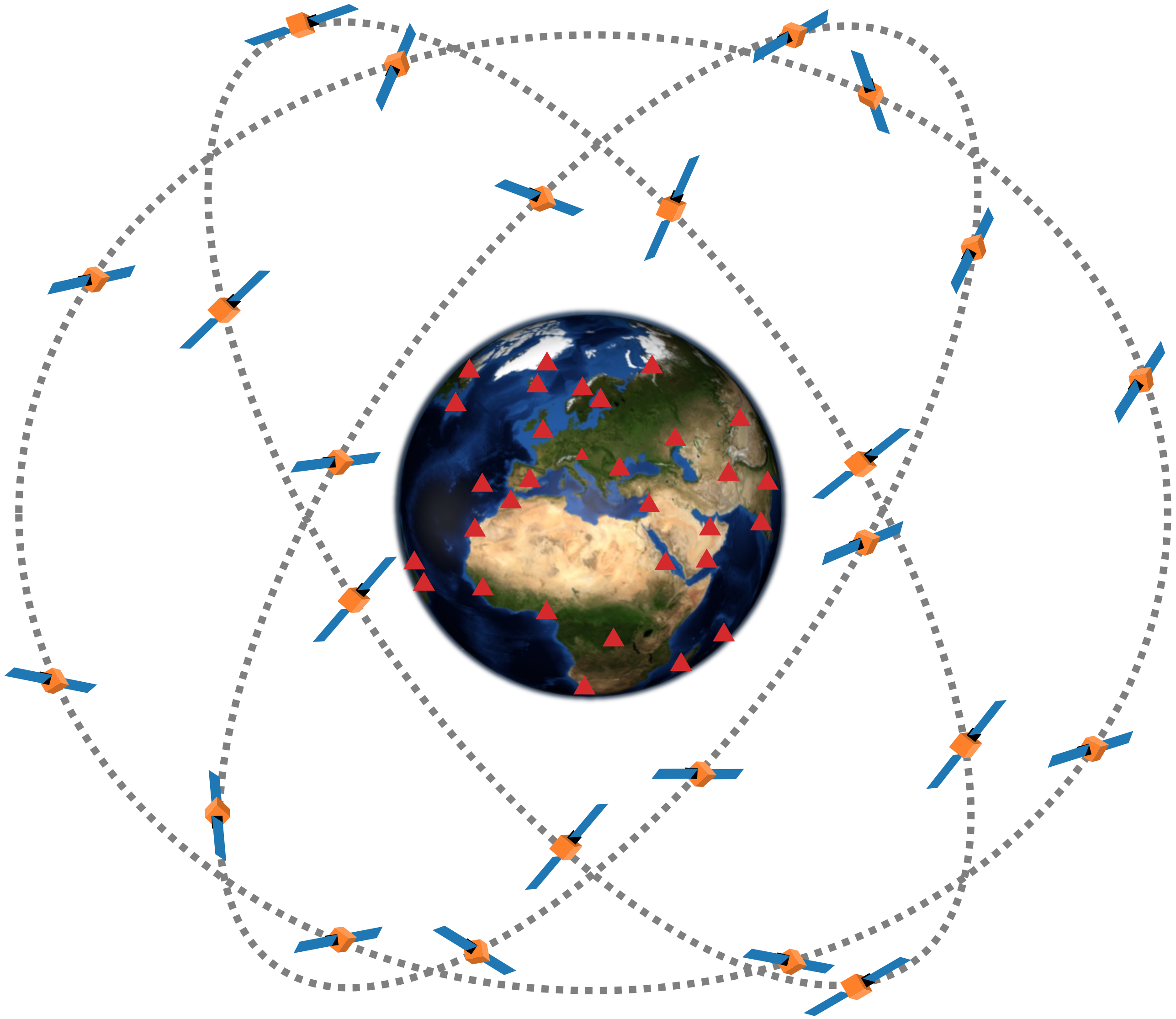
We want to process all available signals on all available frequencies.

We need to consider

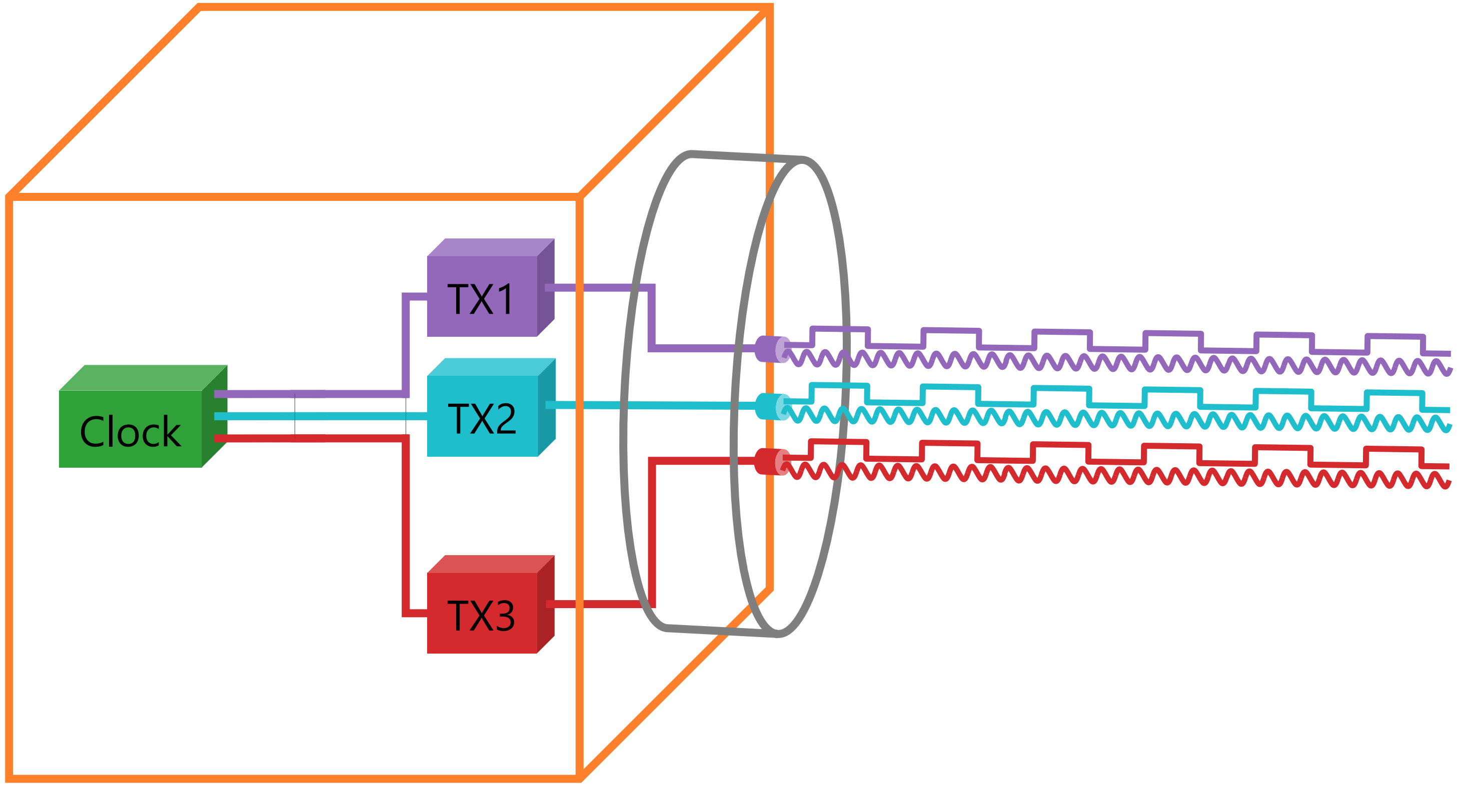
- clock error
- signal biases

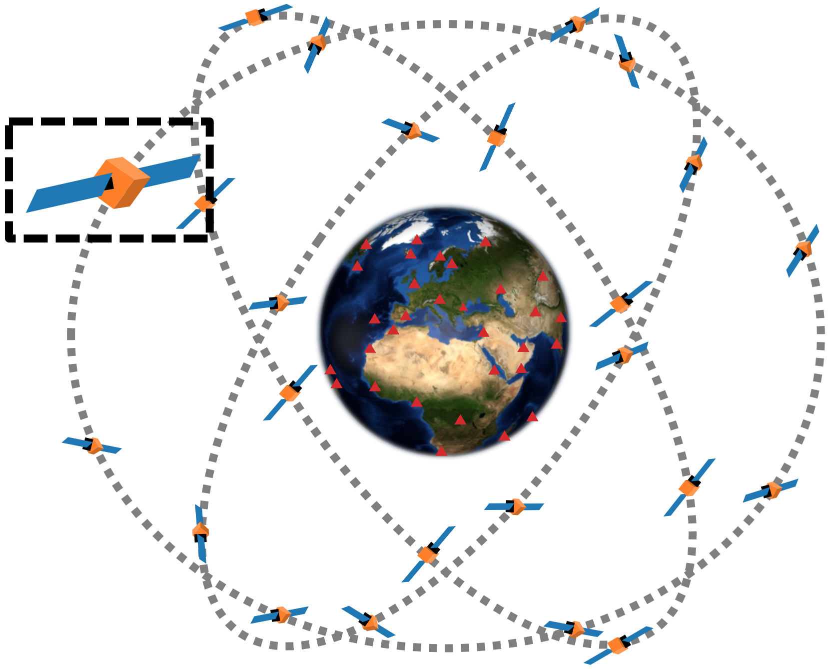
at each satellite and receiver.

Each code and phase observation type has its own signal bias.



Transmitter signal biases





Transmitter clock and signal biases are unknown parameters.

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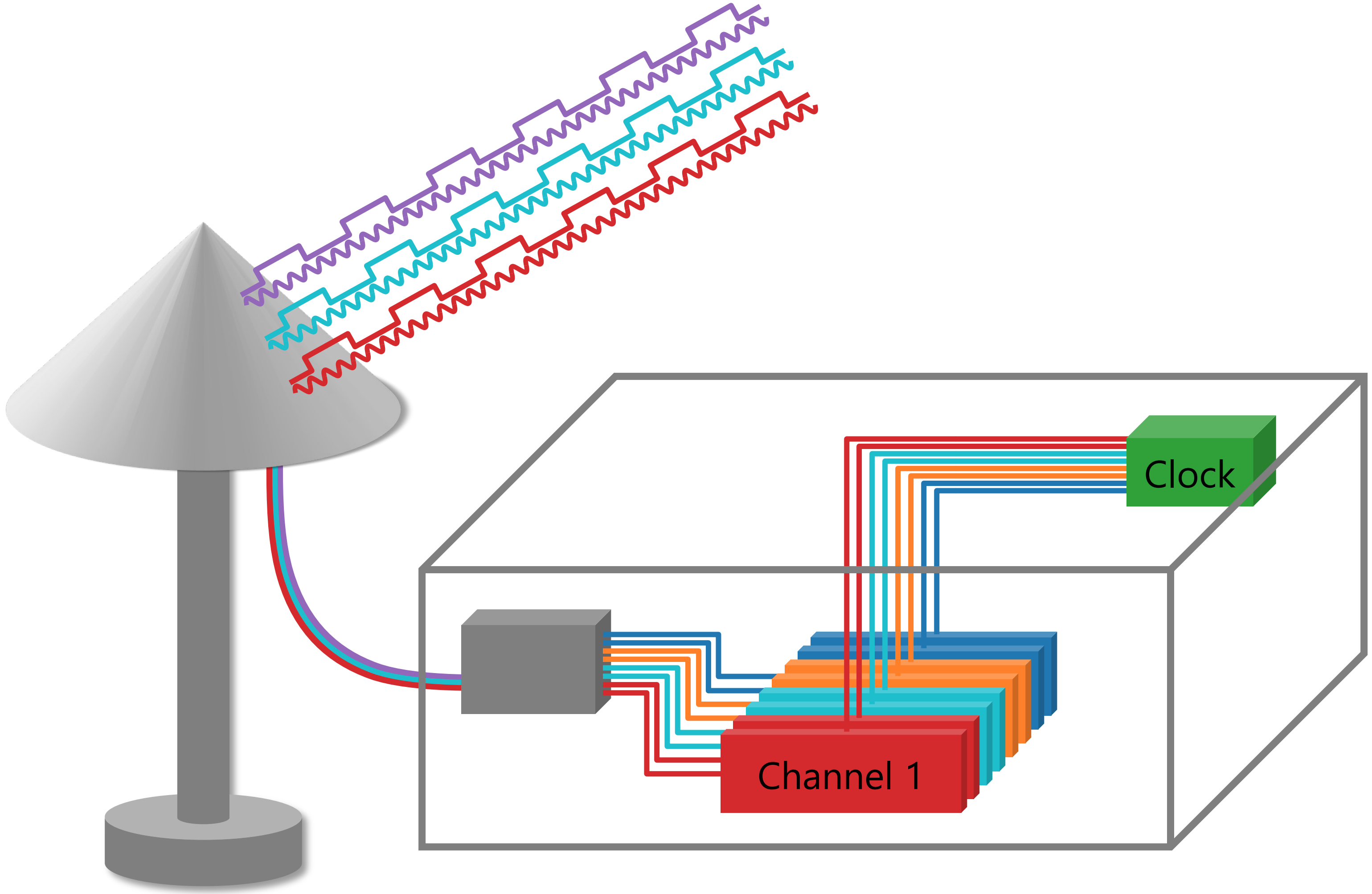
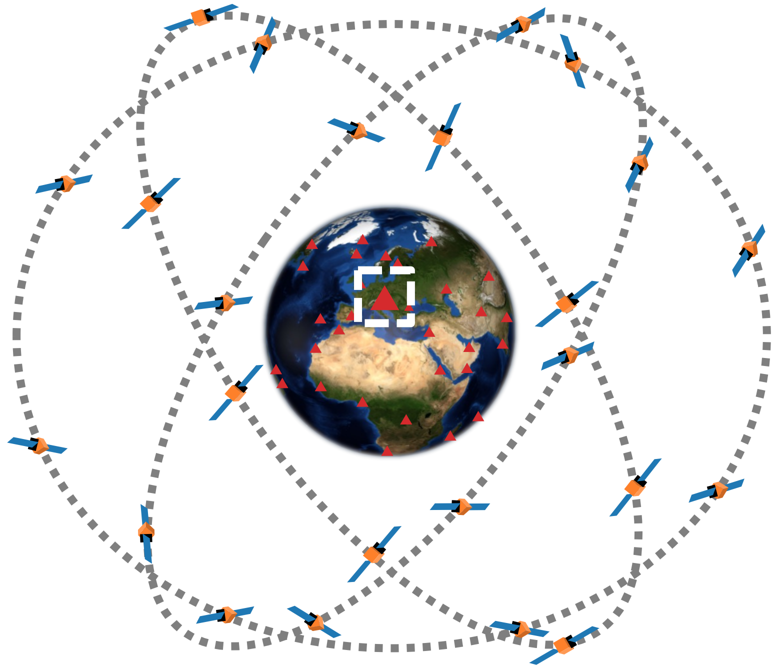
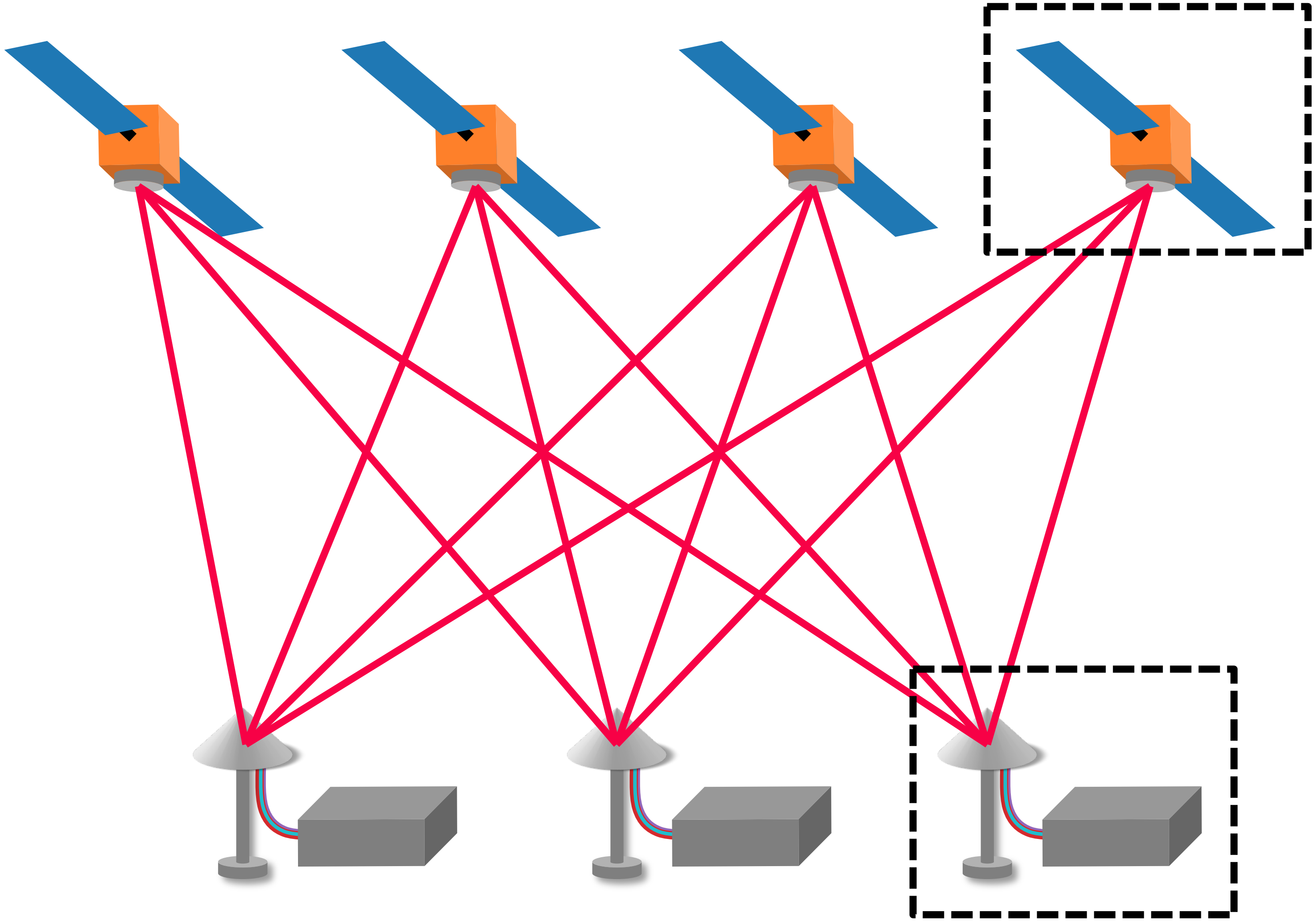
Receiver signal biases

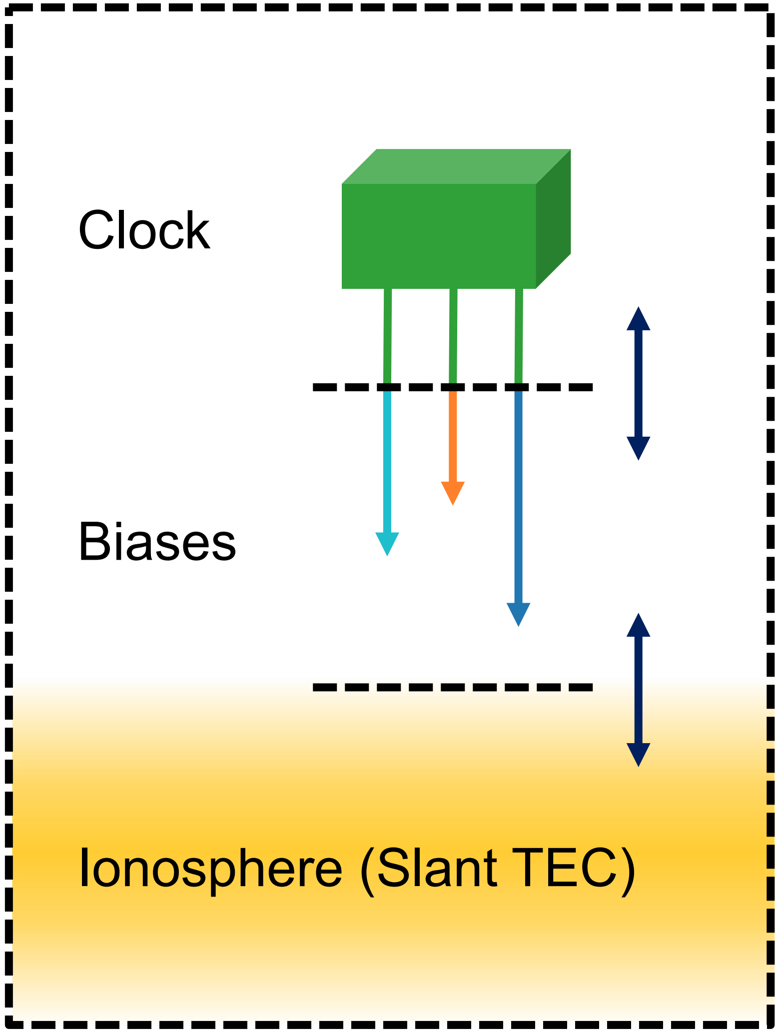




Receiver clock and signal biases are also unknown parameters.

Code biases – Local rank deficiencies





Clocks and signal biases cannot be determined absolutely.

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Estimable code bias linear combinations at a receiver

- Simplified observation equations (one receiver to all satellites)

$$\text{obs}[\text{C}fa]_r^s = \text{bias}[\text{C}fa]_r + \text{clock}_r + \text{iono}[f](STEC_r^s)$$

- Set up normal equations
- Eliminate clock and ionosphere parameters
- Eigenvalue decomposition

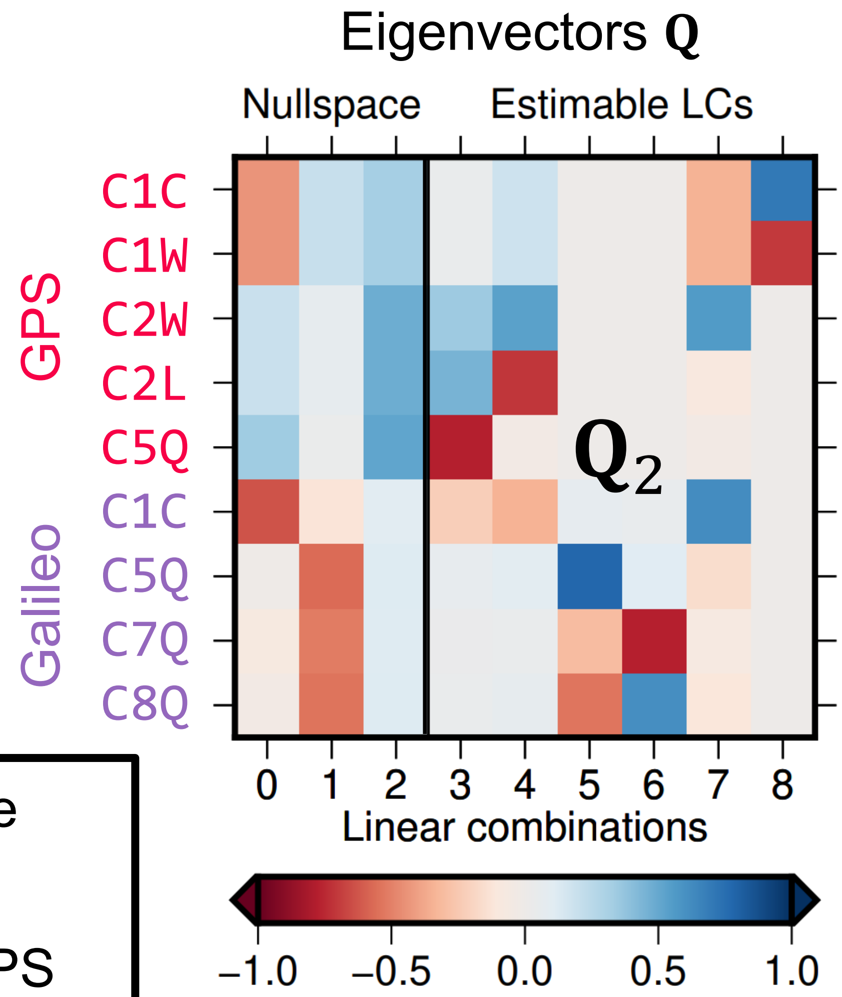
$$\mathbf{N} = \mathbf{Q}\boldsymbol{\Lambda}\mathbf{Q}^T$$

- New parameters (estimable linear combinations)

$$\mathbf{x} = \mathbf{Q}_2\bar{\mathbf{x}}$$

Nullspace

- Clock
- TEC GPS
- TEC Galileo

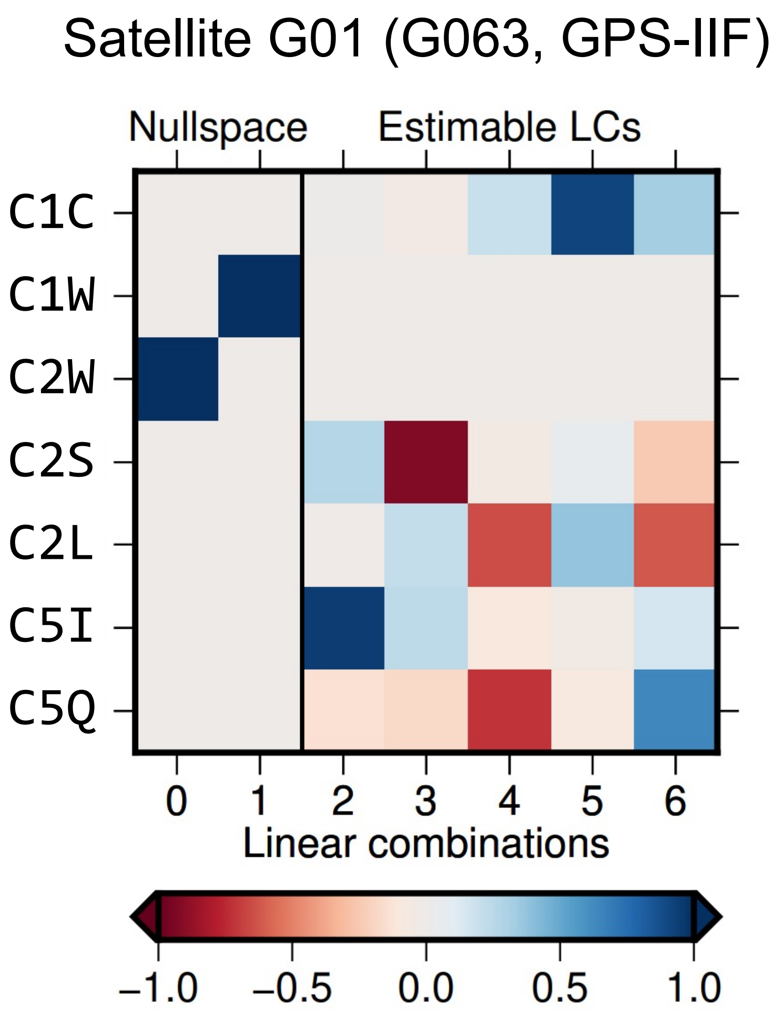


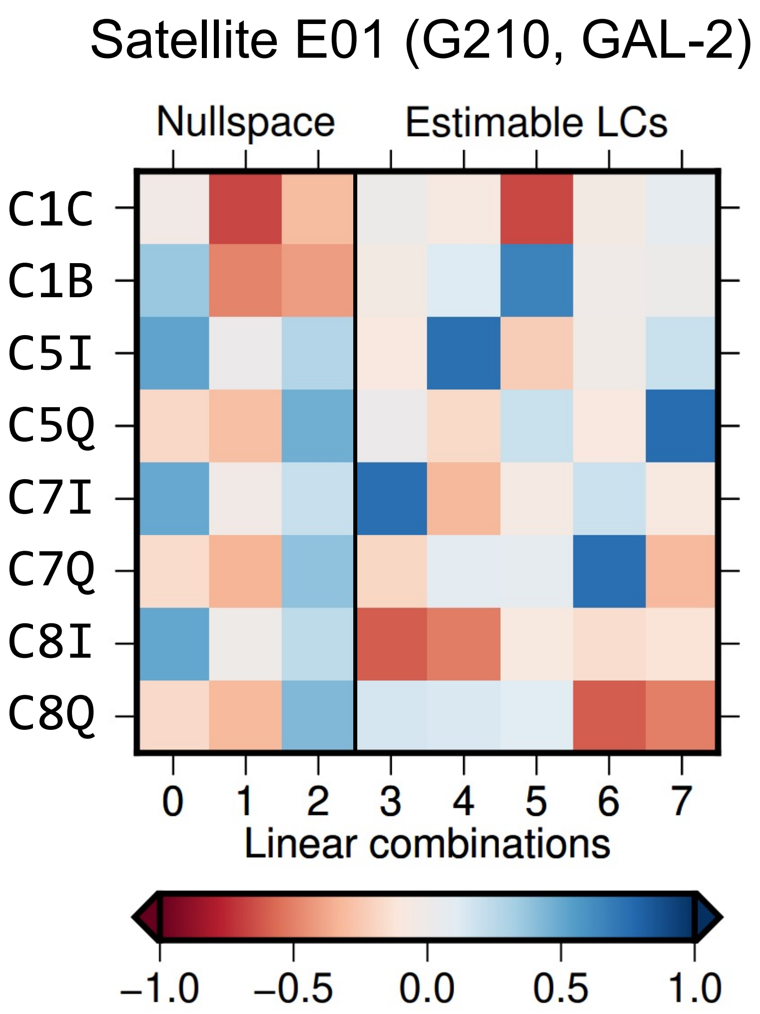
Estimable code bias linear combinations at a satellite

- Same approach as at receiver

GPS
special case:

C1W and C2W
set to zero





Galileo
special case:

Two receiver
groups with
distinct
observation types
(C/Q vs. X)

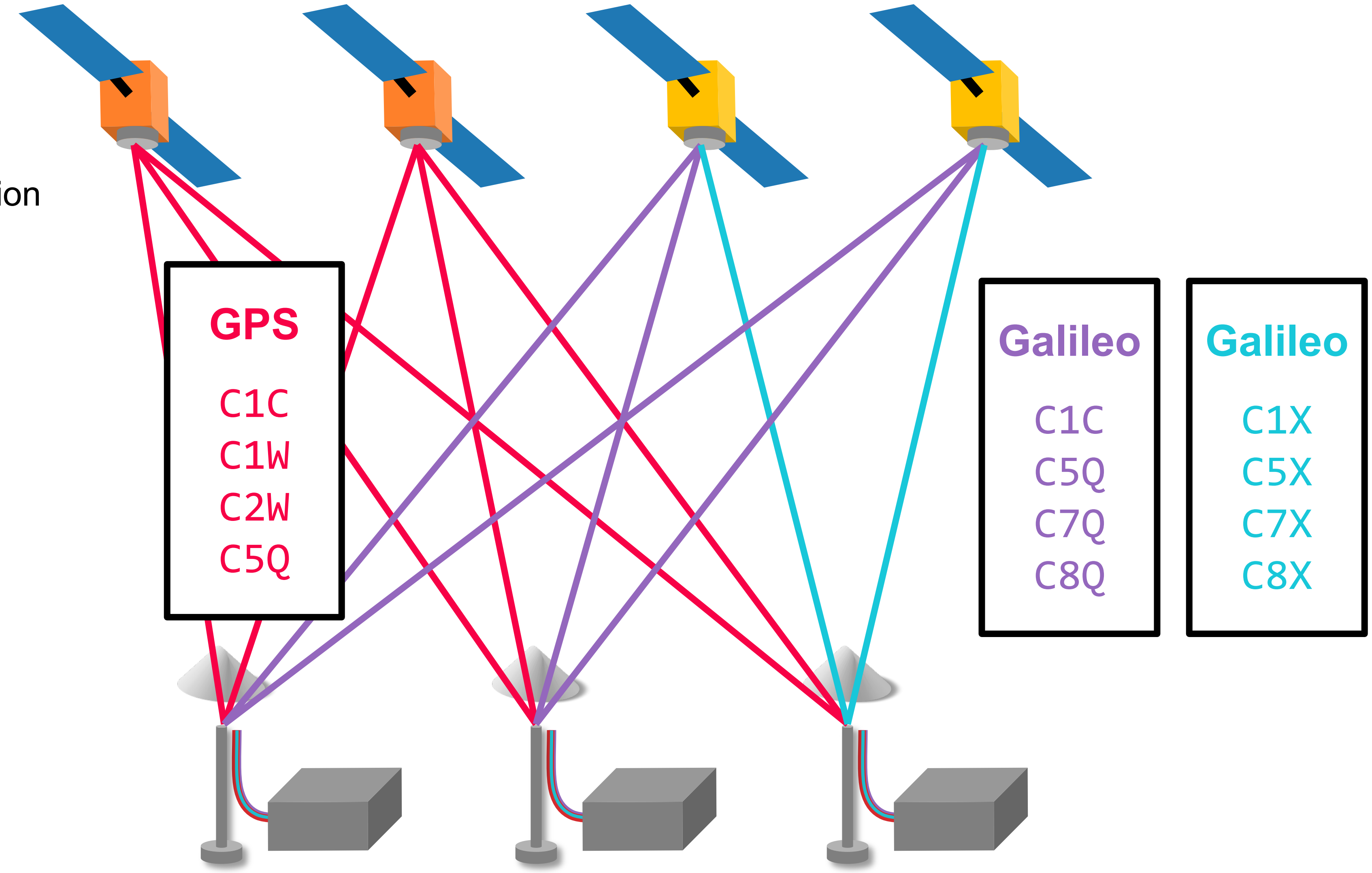
Code biases: Global rank deficiencies

- Local rank defencies are removed
- Based on simulated simplified observation equations:

$$[Cna]_r^s = (\mathbf{Q}\bar{\mathbf{x}})_r + (\mathbf{Q}\bar{\mathbf{x}})^s + \Delta t_r + \Delta t^s + \text{iono}[n](STEC_r^s)$$

  - Setup normal equations
  - Eliminate clocks and STECs
  - Eigen value decomposition
  - Add pseudo equations (constraints

$$\mathbf{0} = \mathbf{Q}_1^T \mathbf{x}$$



Ambiguities and phase biases

- 4 Assumptions
  1. Receiver and satellite phase biases constant over processing period (e.g. one day, except GPS IIF L5 phase biases which have a time-variable biase)
  2. Based on Assumption 1 ambiguities of multiple tracks between same receiver and satellite only differ by integer number of cycles
  3. Only one carrier phase per frequency at a satellite (L1C, L1W, L1S share a common phase bias)
  4. Different phase signals are processed independently at the receiver
- Float ambiguities:

$$n[Lna]_r^s = bias[Ln]^s + bias[Lna]_r + \lambda_n N[Lna]_r^s$$

GPS
L1*G
L2*G
L5*G

receiver
L1CG
L1WG
L1LG
.
.
.

integer
L1*G
L2*G
L5*G

Ambiguities and phase biases

- Float ambiguities

$$n[Lna]_r^s = bias[Ln]^s + bias[Lna]_r + \lambda_n N[Lna]_r^s$$

- Cannot estimate more parameters than tracks for each phase type
  - L1CG, L1WG, L2WG, …

After a cycle slip (or a new track) a new integer ambiguity is setup
$b_{WTZR} + N_{WTZR,t2}^{G01}$

tracks	AREQ	GRAZ	WTZR	ZIMM
G01	b_{AREQ}	b_{GRAZ}	b_{WTZR}	b_{ZIMM}
G02	$b_{AREQ} + b^{G02}$	$b_{GRAZ} + b^{G02} + N_{GRAZ}^{G02}$	$b_{WTZR} + b^{G02} + N_{WTZR}^{G02}$	$b_{ZIMM} + b^{G02} + N_{ZIMM}^{G02}$
G03	$b_{AREQ} + b^{G03}$	$b_{GRAZ} + b^{G03} + N_{GRAZ}^{G03}$	$b_{WTZR} + b^{G03} + N_{WTZR}^{G03}$	$b_{ZIMM} + b^{G03} + N_{ZIMM}^{G03}$
G04	$b_{AREQ} + b^{G04}$	$b_{GRAZ} + b^{G04} + N_{GRAZ}^{G04}$	$b_{WTZR} + b^{G04} + N_{WTZR}^{G04}$	$b_{ZIMM} + b^{G04} + N_{ZIMM}^{G04}$

Ambiguity resolution

- Full normal equations

$$\begin{pmatrix} \mathbf{N}_{11} & \mathbf{N}_{12} \\ \mathbf{N}_{12}^T & \mathbf{N}_{22} \end{pmatrix} \begin{pmatrix} \hat{\mathbf{x}}_1 \\ \hat{\mathbf{x}}_2 \end{pmatrix} = \begin{pmatrix} \mathbf{n}_1 \\ \mathbf{n}_2 \end{pmatrix}$$

← other parameters
← ambiguities

- Parameter elimination (same algorithm as Cholesky decomposition)

$$\mathbf{N}' = \mathbf{N}_{11} - \mathbf{N}_{12}\mathbf{N}_{22}^{-1}\mathbf{N}_{12}^T$$
$$\mathbf{n}' = \mathbf{n}_1 - \mathbf{N}_{12}\mathbf{N}_{22}^{-1}\mathbf{n}_2$$

- Normals passed to LAMBDA method

- Solve other parameters $\hat{\mathbf{x}}_1$ with fixed integer parameters $\hat{\mathbf{x}}_2$

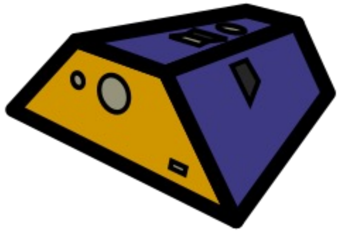
- Resolved integers removed from the observations, ambiguites not setup as parameters anymore

Want to know more?

Detailed description can be found in doctoral thesis

Strasser (2022) DOI [10.3217/978-3-85125-885-1](https://doi.org/10.3217/978-3-85125-885-1)

Approach is implemented into our open-source software



GROOPS

Available at GitHub

https://github.com/groops-devs/groops

Now with example scenarios for GNSS processing, LEO orbit determination, gravity field determination, and more.