GNSS-based Clock Synchronisation of Bistatic and Multistatic SAR Systems: a Performance Assessment

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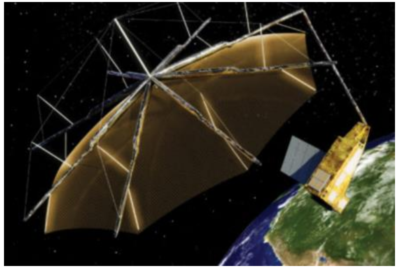
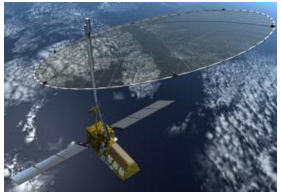
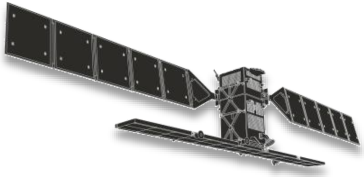
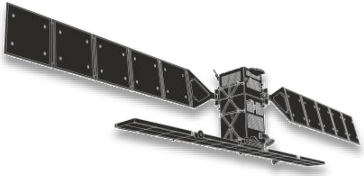
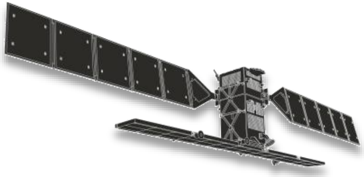
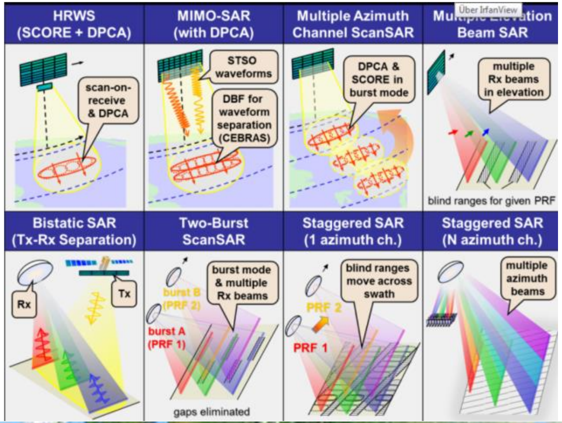
Future SARs

Some thoughts

- Reflector-based systems
- Low-frequency systems
- Multichannel-DBF systems
  - Elevation
  - Azimuth
- On-board processing schemes
- High-orbit systems
- Distributed
- Bistatic and Multistatic

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Why Bistatic and Multistatic?

You ca

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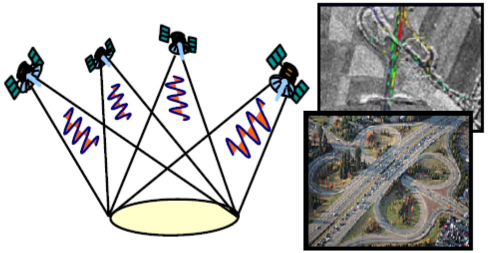
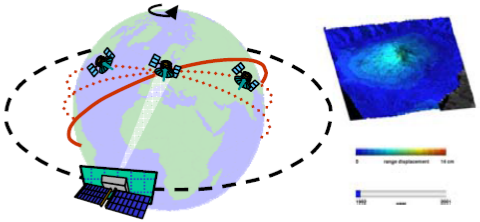
Cross-Track Interferometry

Along-Track Interferometry

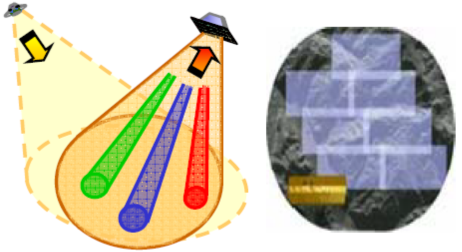
Moving Target Indication



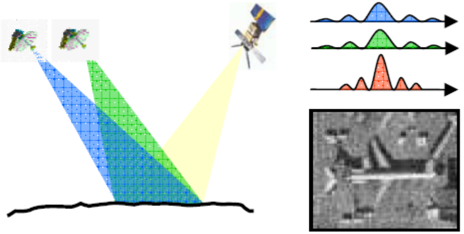
Frequent Monitoring



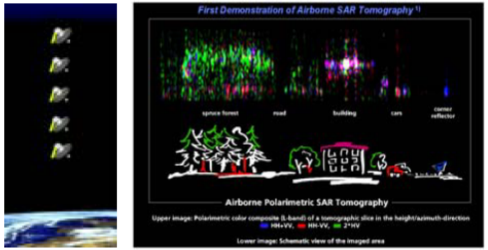
Wide Swath Imaging



Resolution Enhancement



SAR Tomography



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Interference Suppression

Silent Operation

Increased Radiom. Sensitivity

Double Differential InSAR

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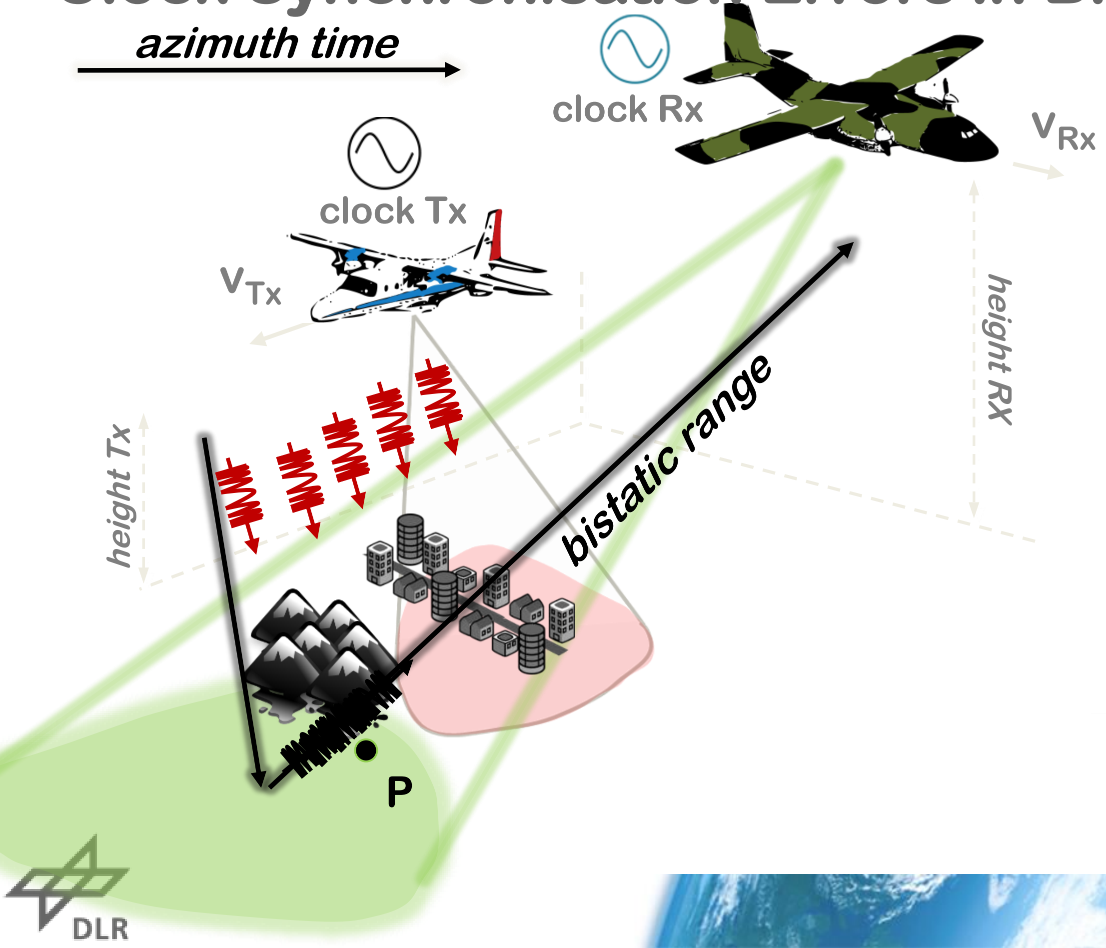
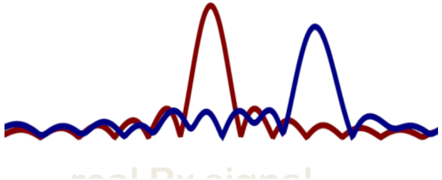
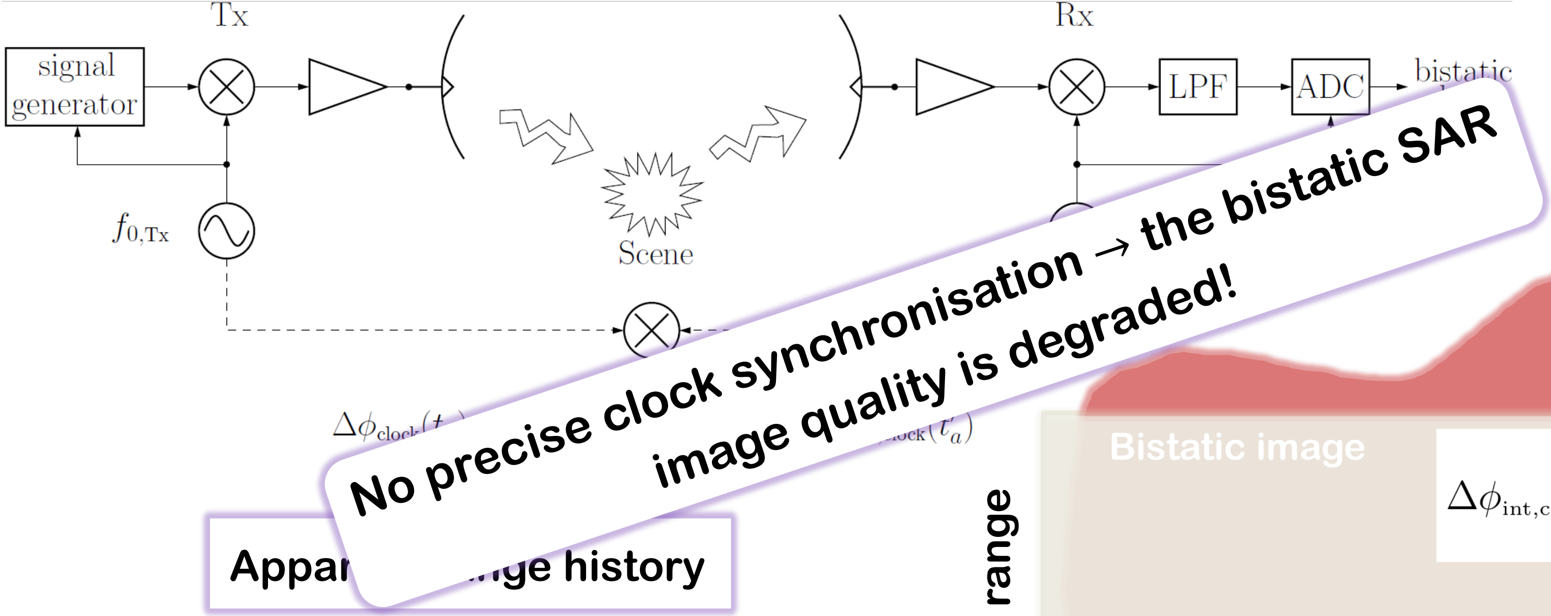
Clock Synchronisation Errors in Bistatic SAR



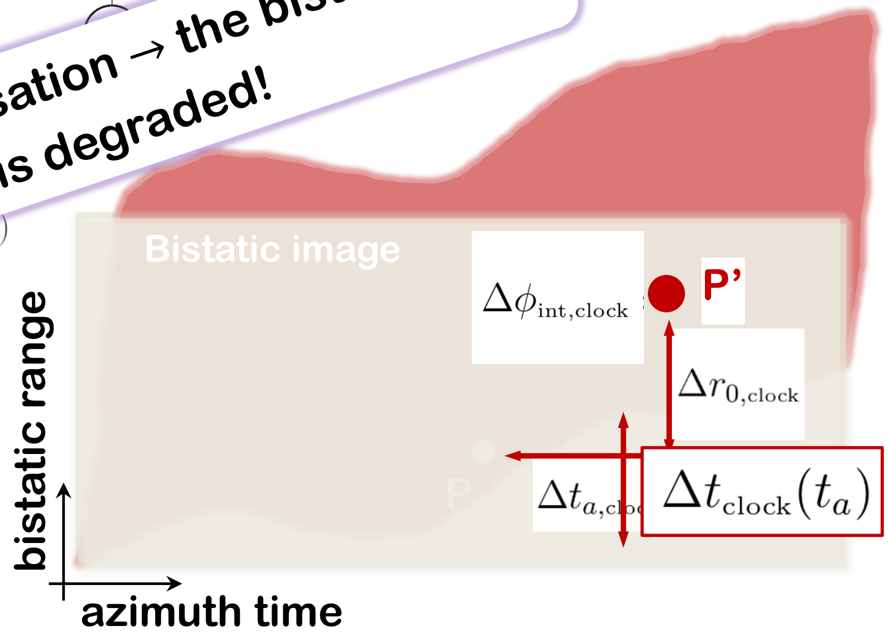
Bistatic Data Synchronisation



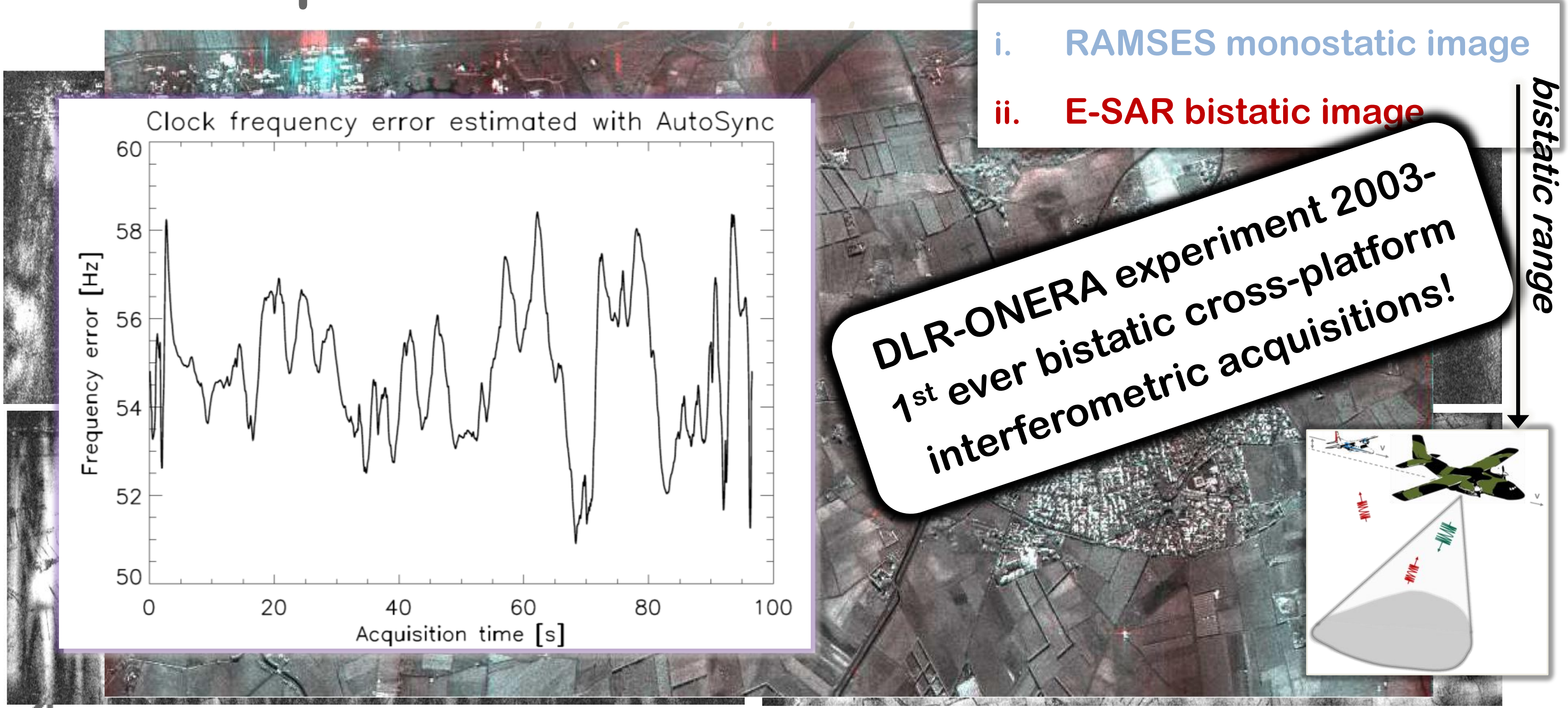
Clock Errors in Bistatic and Multistatic SAR



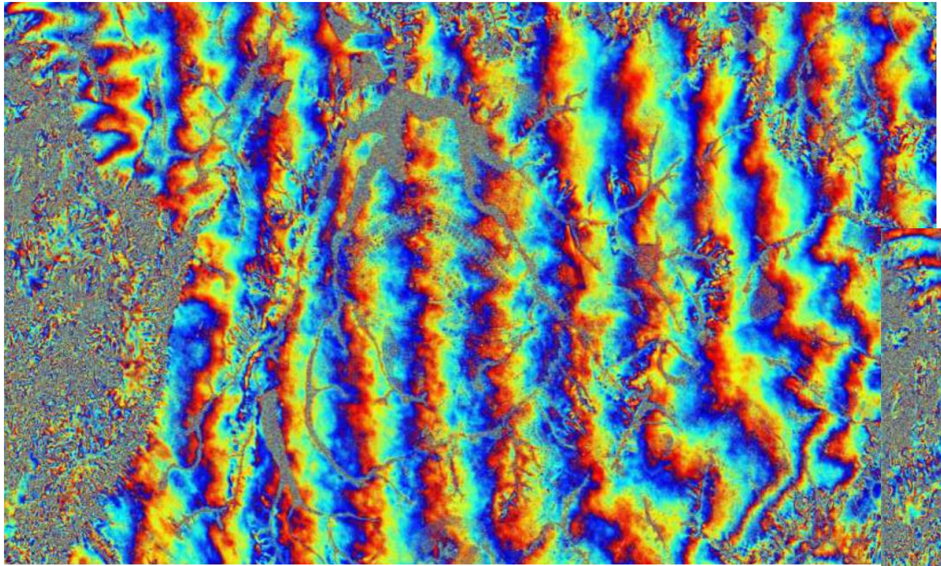
$$r(t_a) \to r(t_a) + \lambda \cdot \int_{t_{a,0}}^{t_a} \mathrm{d}t'_a \cdot \Delta f_{0,\mathrm{clock}}(t'_a)$$



An Example: a Bad One…

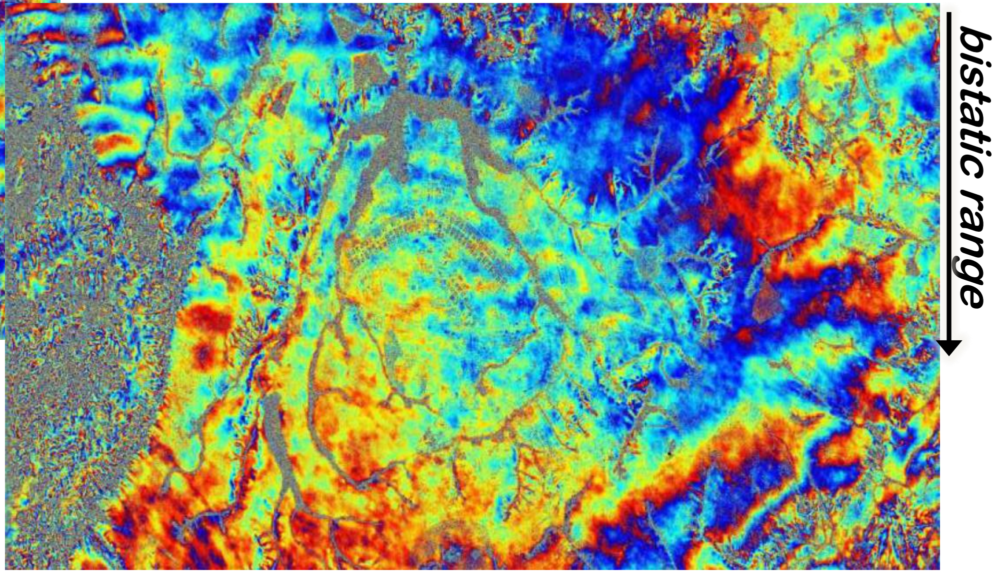


Another Example: a Good One…

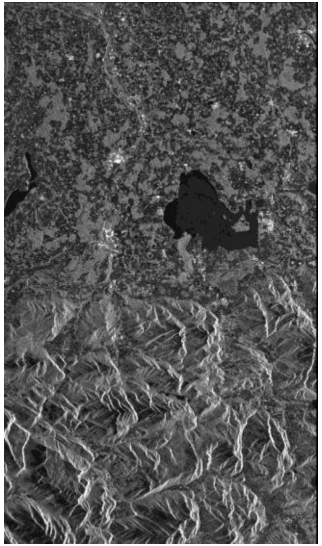


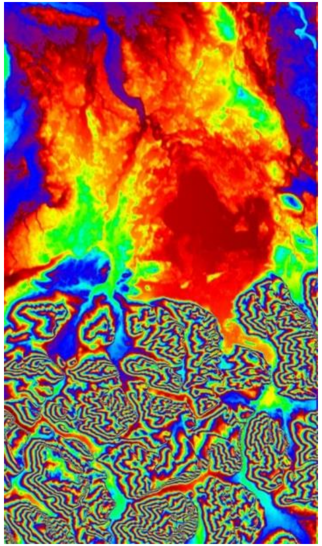
non-synchronised

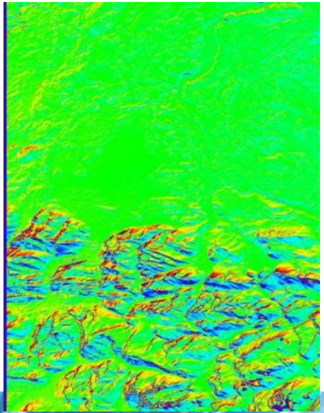
1st bistatic repeat-pass interferograms, Brasilia area

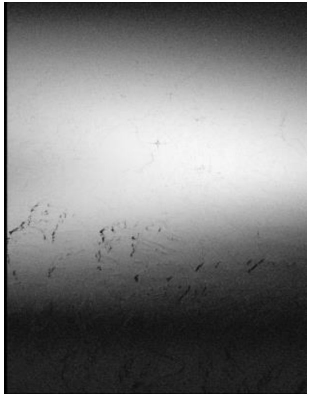


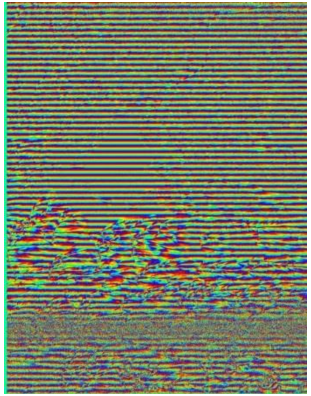
The Full Picture...

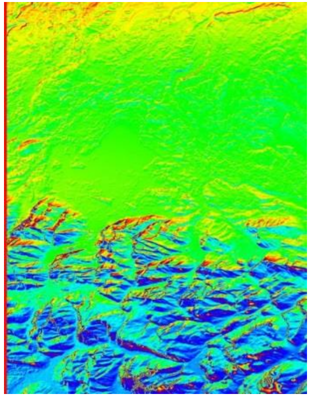












Data simulated from L-band reflectivity image using bistatic E2E simulator

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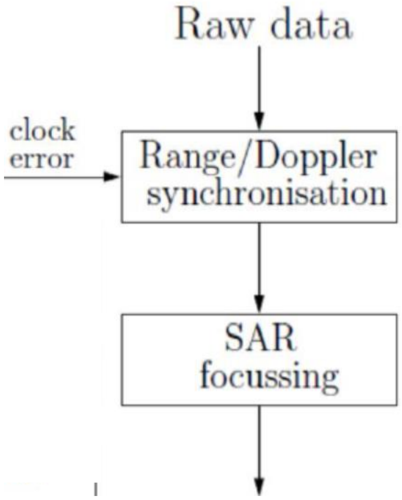
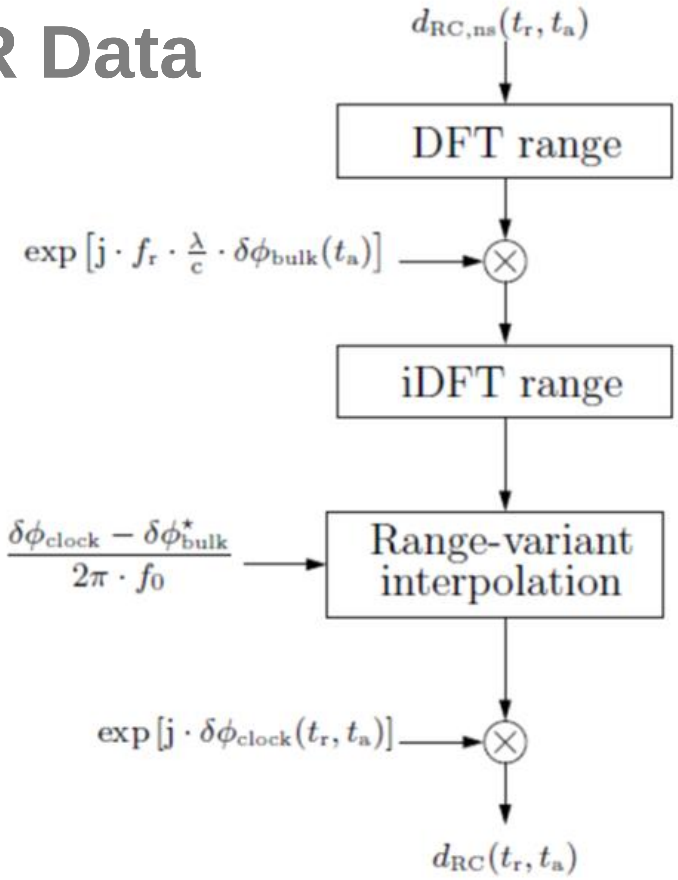
Synchronisation of Bistatic SAR Data

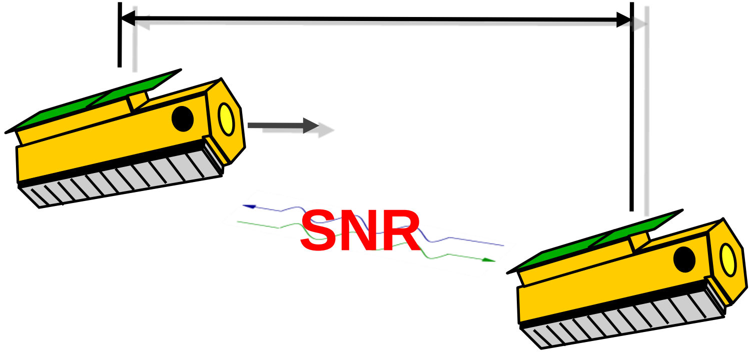
Overview

- Before range-variant part of SAR imaging kernel
- Can be done together with replica/drift compensation
- Estimation strategies
  - GNSS Tagging (internal)
  - SyncLink (internal)
  - AutoSync (autonomous)

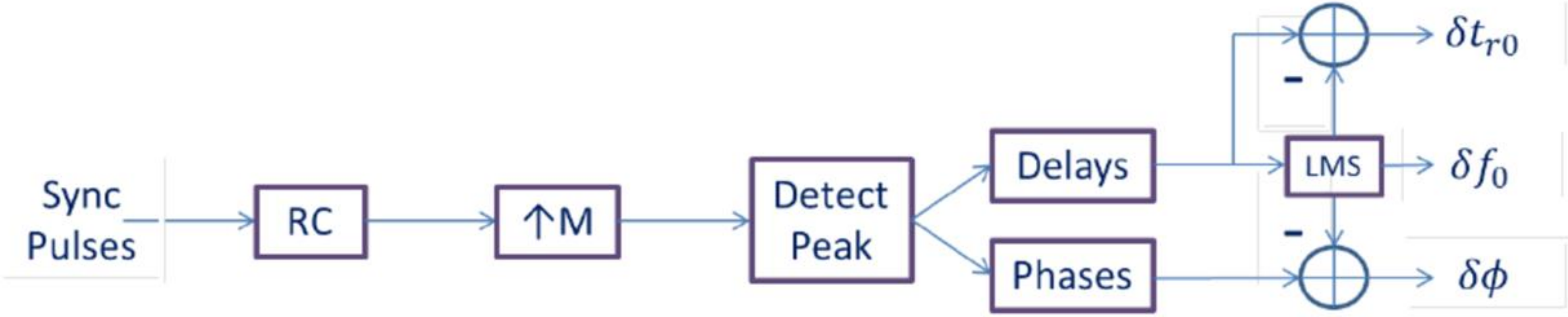




Synchronisation Link



- Great solution
- Additional hardware
- Development conflicts
- Interrupted operation



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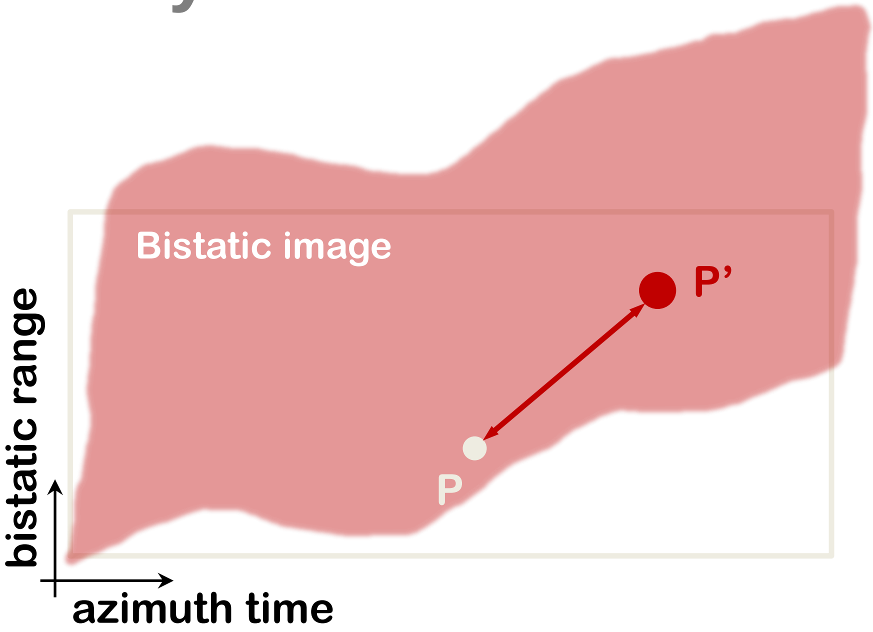
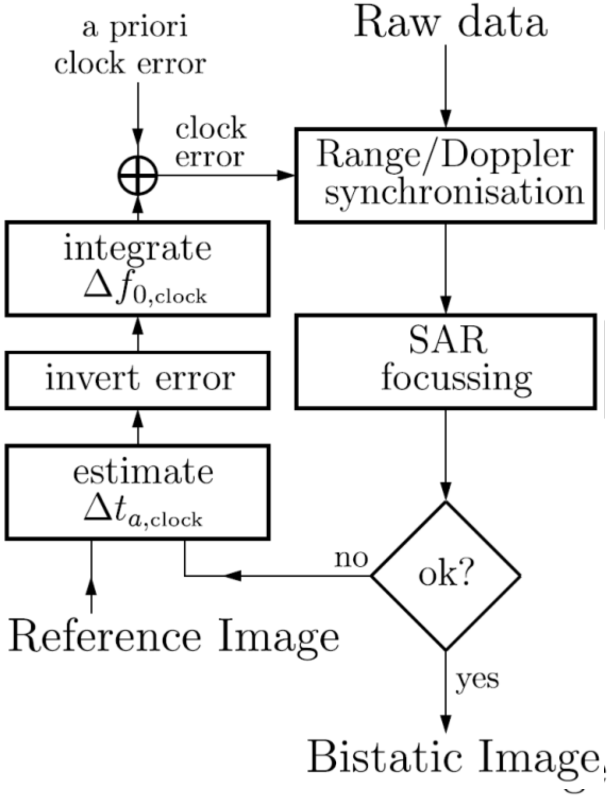
AutoSync in Bistatic SAR



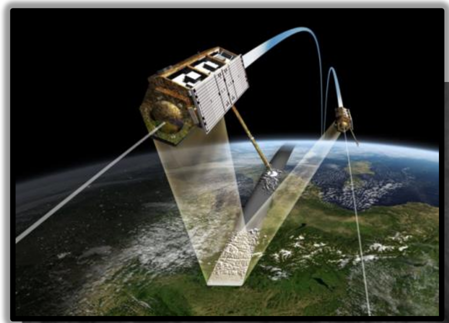
Inversion model

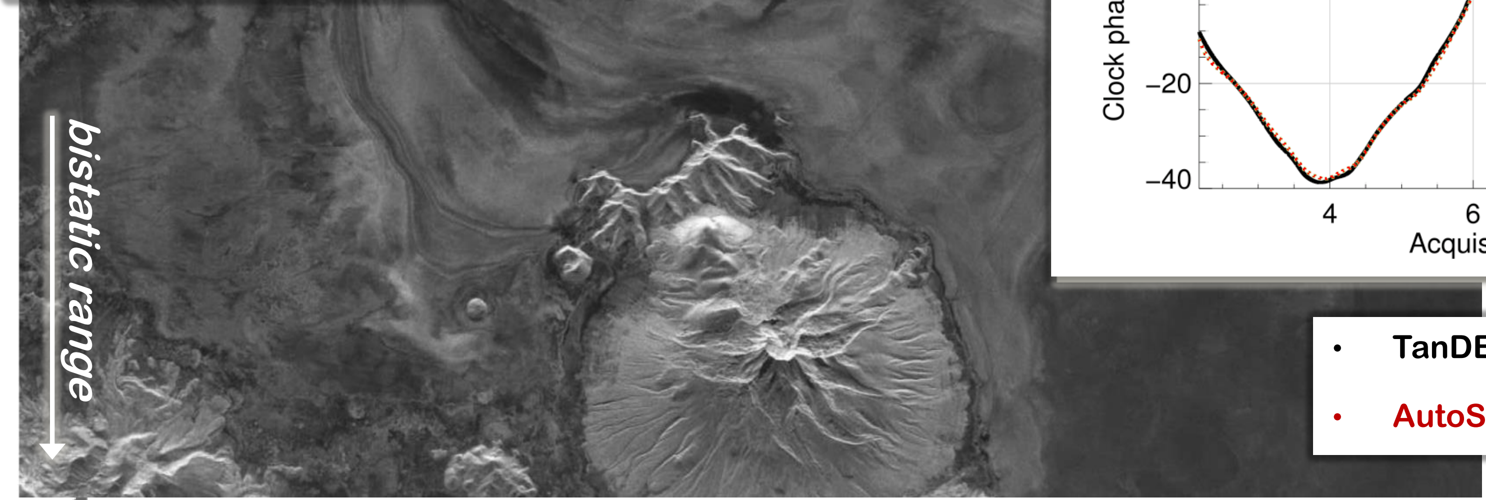
$$\Delta t_a(t_a, r_0) \approx \frac{\partial \Delta t_a}{\partial \Delta\phi_{\text{clock}}} \cdot \frac{\mathrm{d}\Delta\phi_{\text{clock}}}{\mathrm{d}t_a} \approx \frac{r_0}{v^2} \cdot \frac{\lambda}{2} \cdot \Delta f_{0,\text{clock}}(t_a)$$

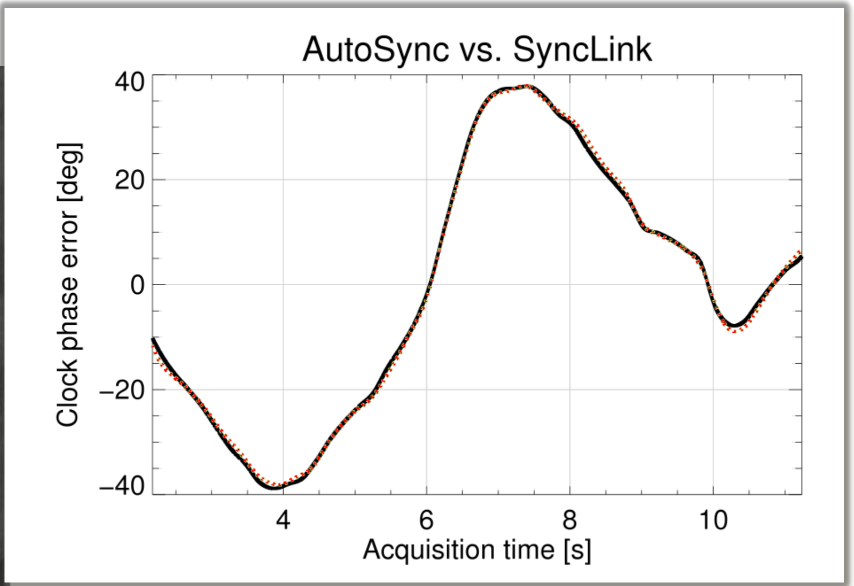
Reference image approach



AutoSync validation with TanDEM-X SyncLink

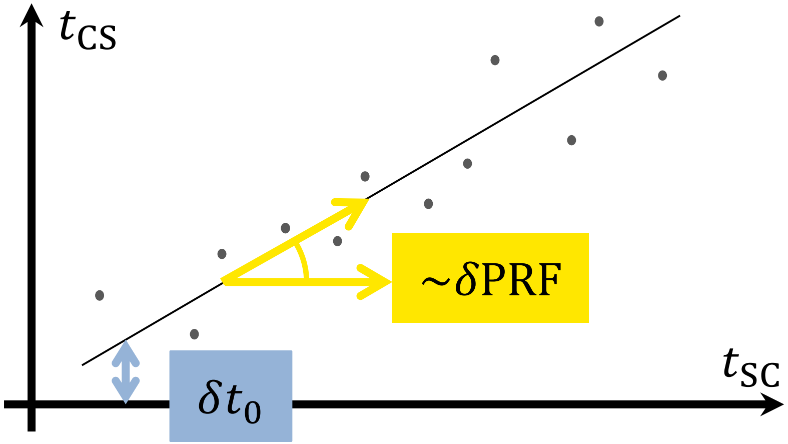






- TanDEM-X SyncLink
- AutoSync

GNSS-based: the Boring One…



Overview

- Based on comparison of instrument and GNSS time stamps
- Coarse estimate of bistatic range error and carrier offset
- Helps in further processing and calibration steps

$$\delta f_0 = \frac{\mathrm{PRF} \cdot (\Delta t_{\mathrm{CS}} - \Delta t_{\mathrm{SC}})}{N_{\mathrm{a}}} \cdot f_0$$

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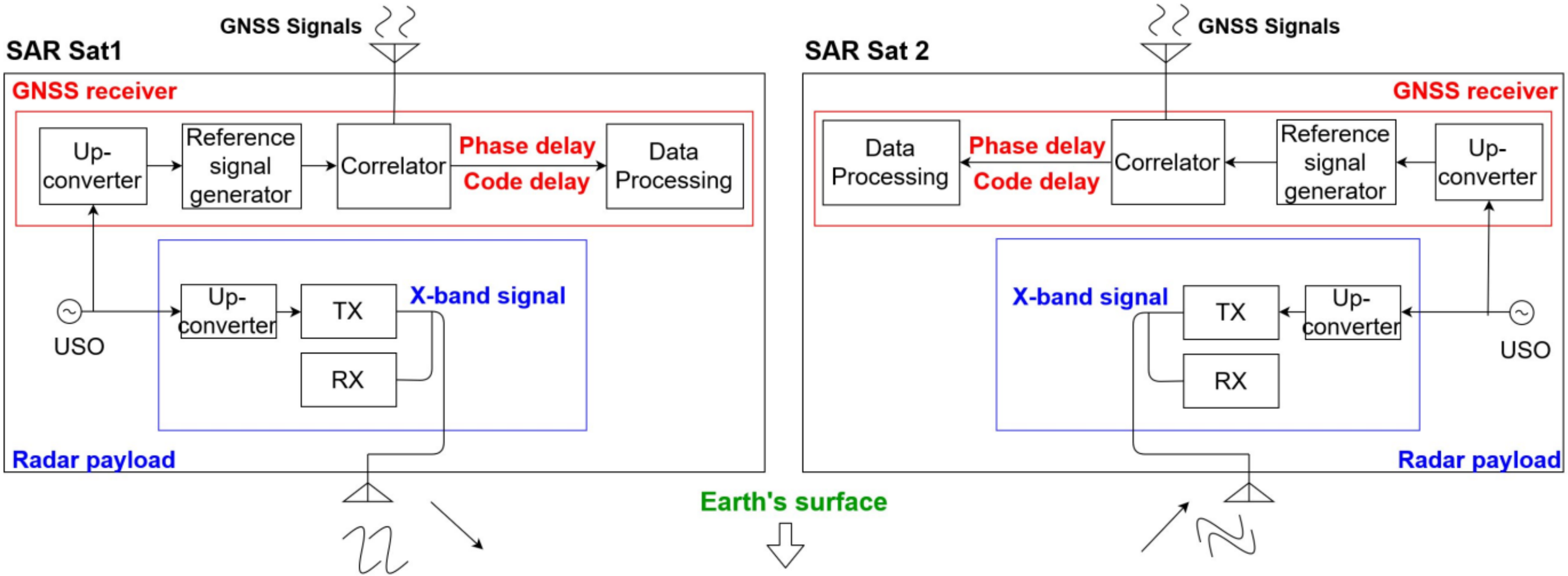
GNSS-based: the Exciting One…



Synchronise instrument and GNSS with the radar reference and ask for the "clock bias" to your favourite POD provider

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GNSS-based: why now?

$$\psi_{u_0}(t) = \frac{f_0}{f_{\text{nav}}} \cdot \psi_{u_{\text{nav}}}(t) = \frac{\lambda_{\text{nav}}}{\lambda_0} \cdot \psi_{u_{\text{nav}}}(t)$$

Overview

- Different processing levels
- Native POD process
- Post process approach

Strong option to be implemented in ESA's EE10 candidate mission Harmony

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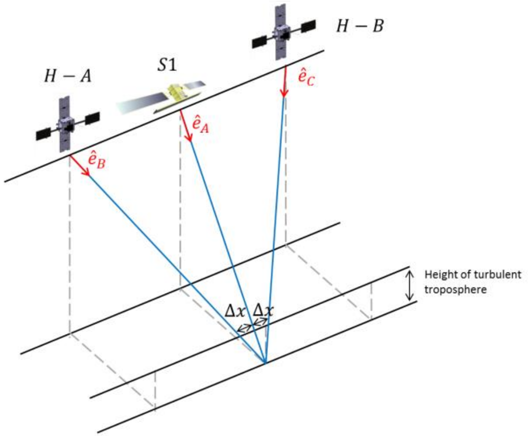
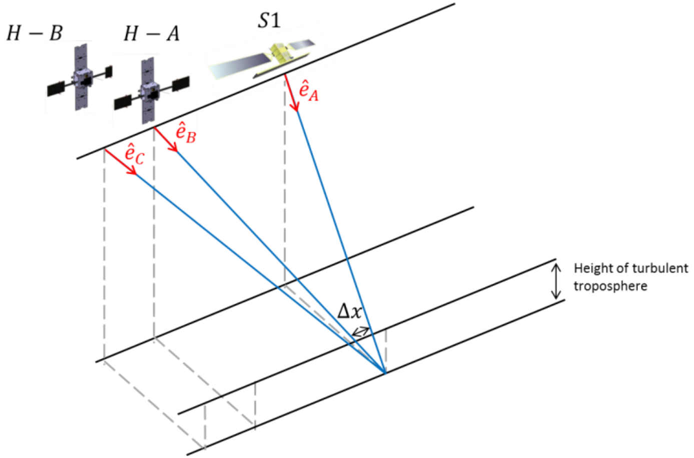
Harmony’s Imaging Techniques

- **Ocean – air interaction**
  - **Based on the ability to combine ATI or DCA measurements from a STEREO observation geometry**
- **Global 3-D strain rate map**
  - Harmony’s unique acquisition geometry allows for the accurate retrieval of the **N-S** component of the **deformation** by exploiting **time series** from both Sentinel-1 and the Harmonies.
- **Topographic change**
  - Repeated acquisitions with **single-pass interferometry** will allow the accurate retrieval of **topograhic changes in the cryosphere**





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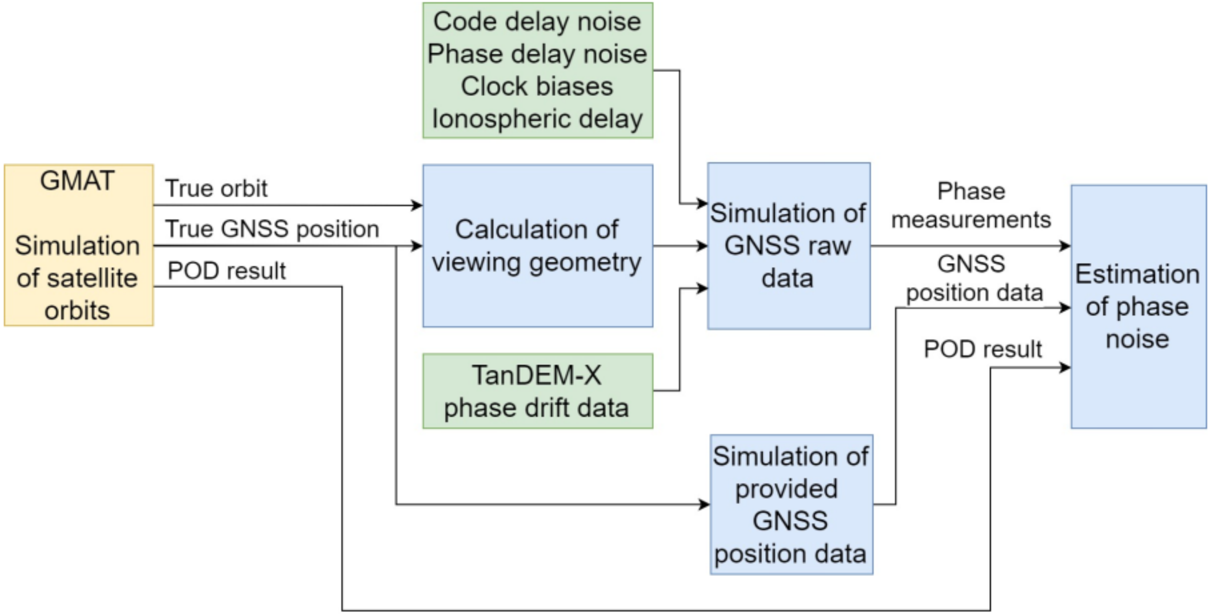
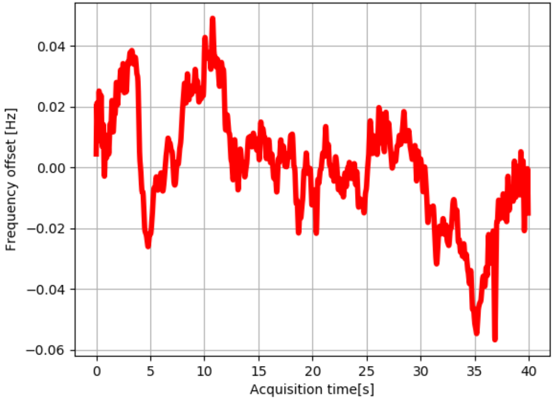
Simulation Framework



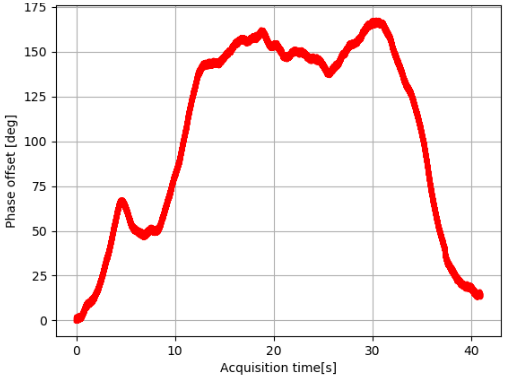
Overview

- Using GMAT orbits
- Using TanDEM-X realisations
- Phoenix GNSS receiver specs
- GNSS raw data simulation
- LMS estimation process
- Kinematic solution

Simulation Framework



Parameter	Value
GNSS data sampling rate	1 MHz
GNSS signal frequency	1575.42 MHz
Radar payload frequency	9656 MHz
Pseudorange standard deviation	0.0005 m
GNSS position bias	2 m
Ionospheric range error	10 m
Baseline error in X (ECI)	5 mm
Baseline error in Y (ECI)	3 mm
Baseline error in Z (ECI)	6 mm
Baseline velocity error in X (ECI)	0.5 mm/s
Baseline velocity error in Y (ECI)	0.3 mm/s
Baseline velocity error in Z (ECI)	0.6 mm/s



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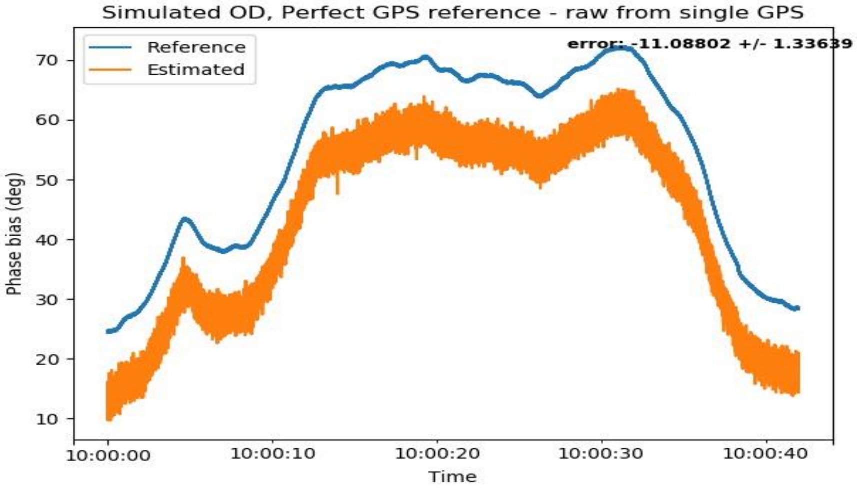
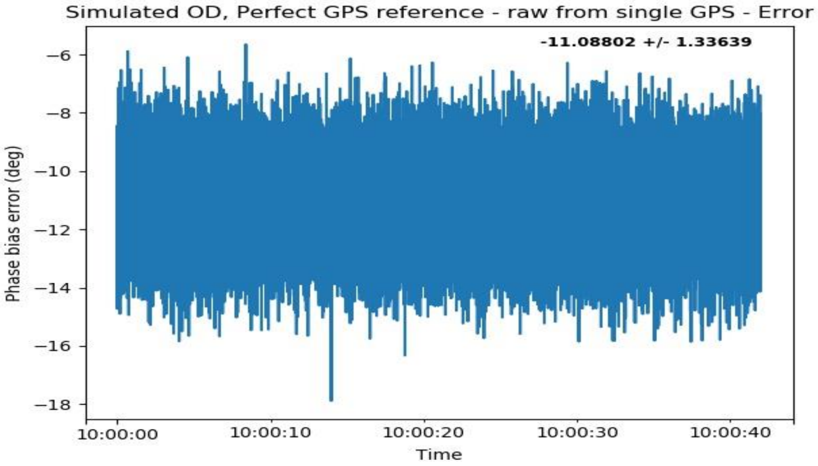
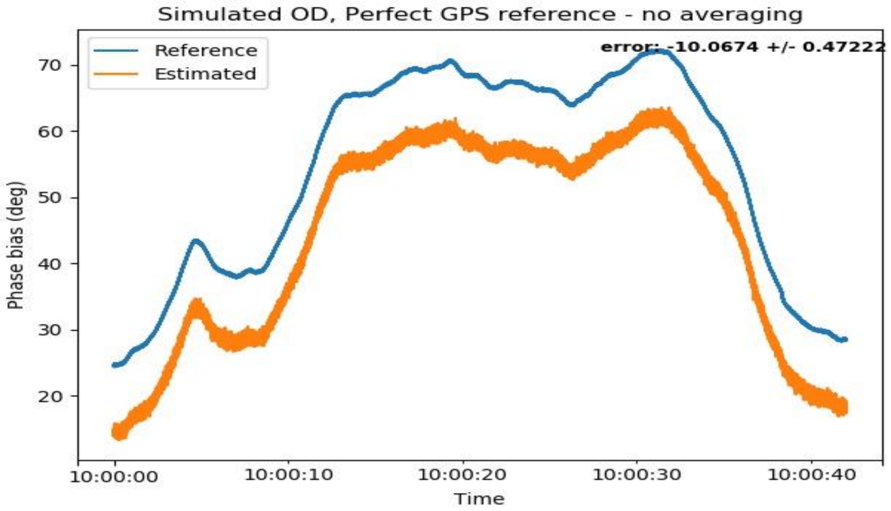
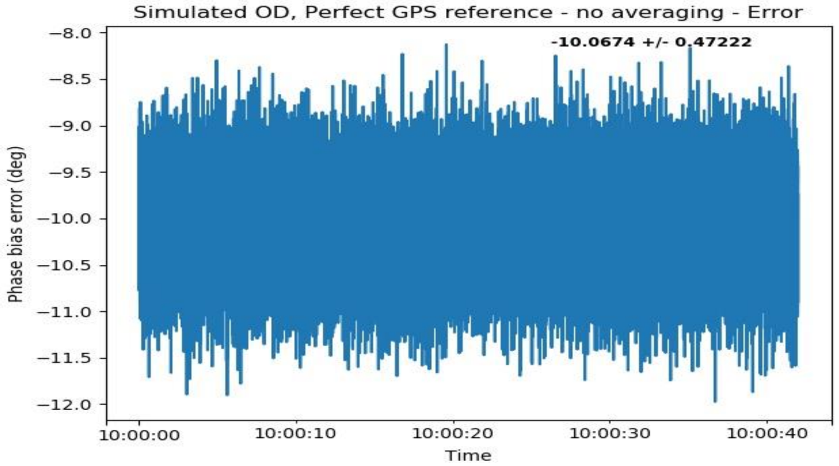
Non-ideal orbit determination – ideal GPS position – no averaging – data from single GPS





Non-ideal orbit determination – ideal GPS position – no time averaging – 8 GPS averaging





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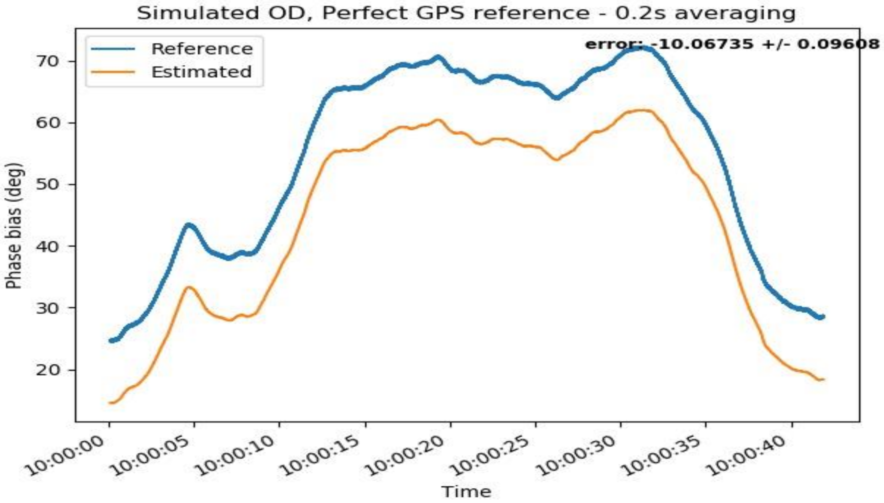
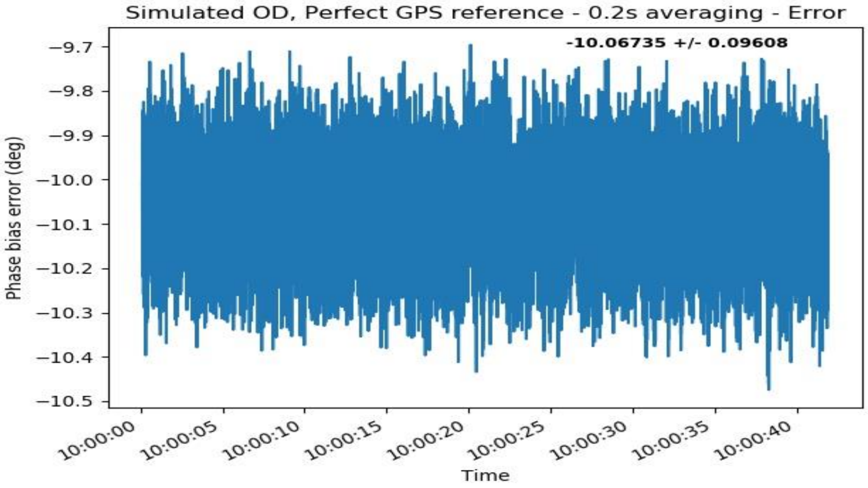
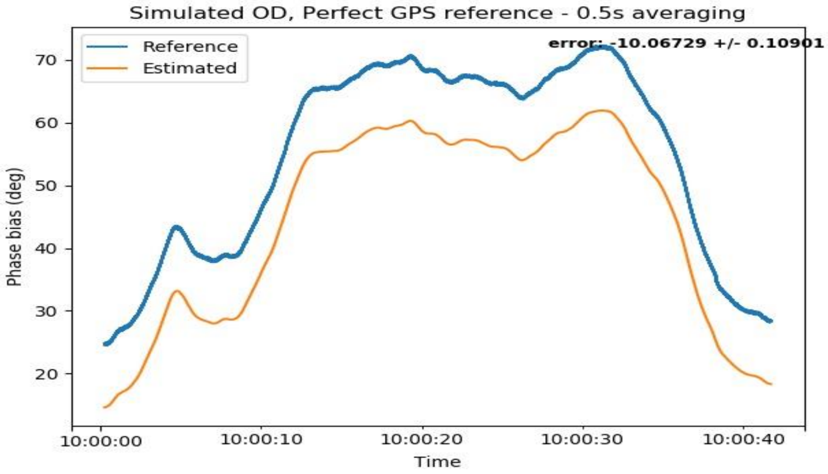
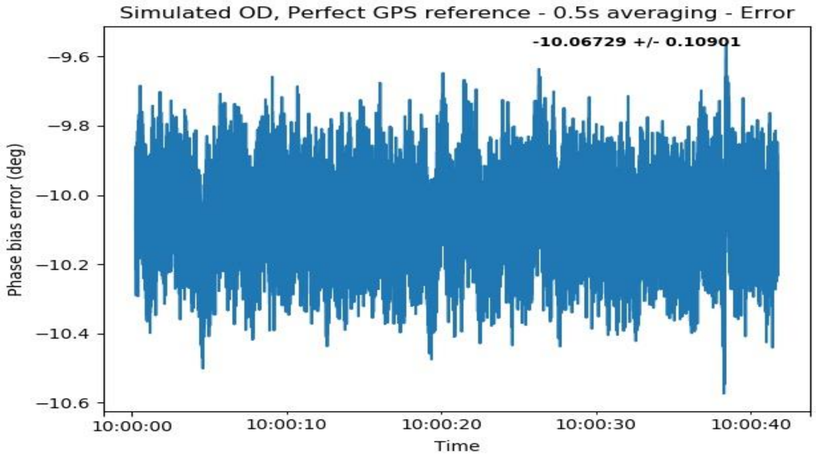
Non-ideal orbit determination – ideal GPS position – 0.2 s – 8 GPS averaging





Non-ideal orbit determination – ideal GPS position – 0.5 s – 8 GPS averaging





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Conclusions

- Performance assessment based on GNSS raw data simulation
- Half-way in sophistication
    - Realistic GNSS model
    - Kinematic estimation
    - Ideal spacecraft/instrument
    - Homogeneous ionosphere
- Seems to be a robust solution for the synchronisation problem
- Confidence Harmony’s imaging approach is solid