Introducing ISG

Use of advanced Kalman filtering and statistical techniques

for error correction and positioning accuracy in Geoscience Australia's Ginan software toolkit

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Australia

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Industrial Sciences Group

15 years' experience in implementing state-of-the-art research in advanced analytics to deliver commercial outcomes

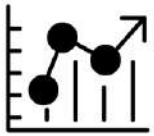
8 Core Capabilities all under 'One Roof'

Multi-disciplinary and

multi-sector approach

with skills and expertise in:

Advanced Analytics

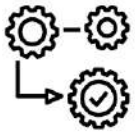


Astrodynamics

Space Situational Awareness

GNSS/Geodesy

Process Optimisation



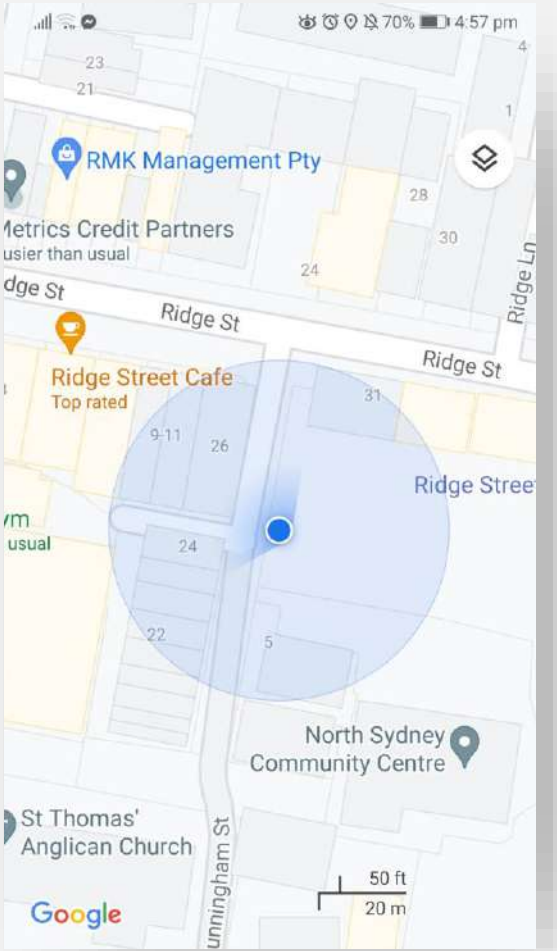
Simulation

Machine Learning

Scientific Programming

Outline

Section 1	**The Ginan software toolkit ISG's contributions to Ginan**
Section 2	**Smoothing**
Section 3	**First-order Gauss Markov modelling**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23
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Ridge St
Ridge Street Cafe
Top rated
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9-11
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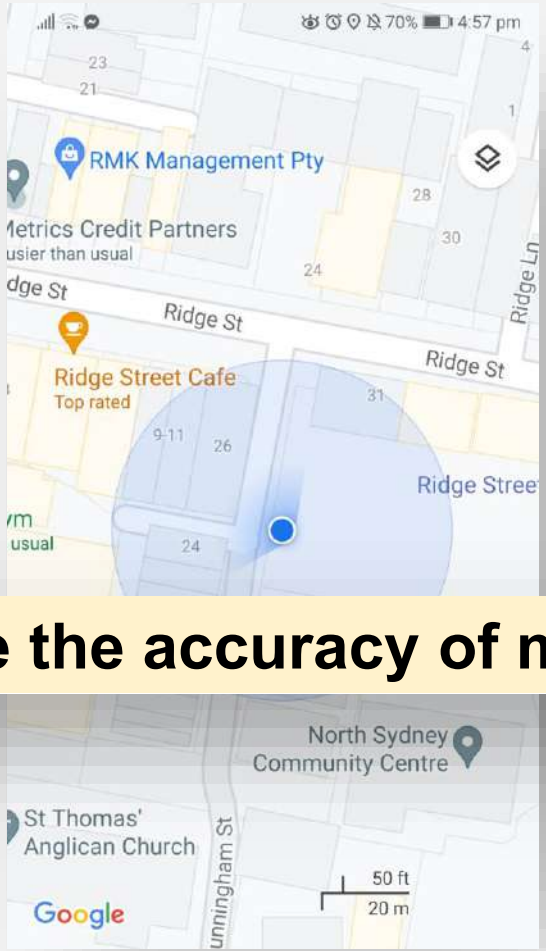
22
5
North Sydney
Community Centre
St Thomas'
Anglican Church
50 ft
20 m
Google



“How do I improve the accuracy of my GPS position?”

01

The Ginan Software Toolkit

A Brief Overview

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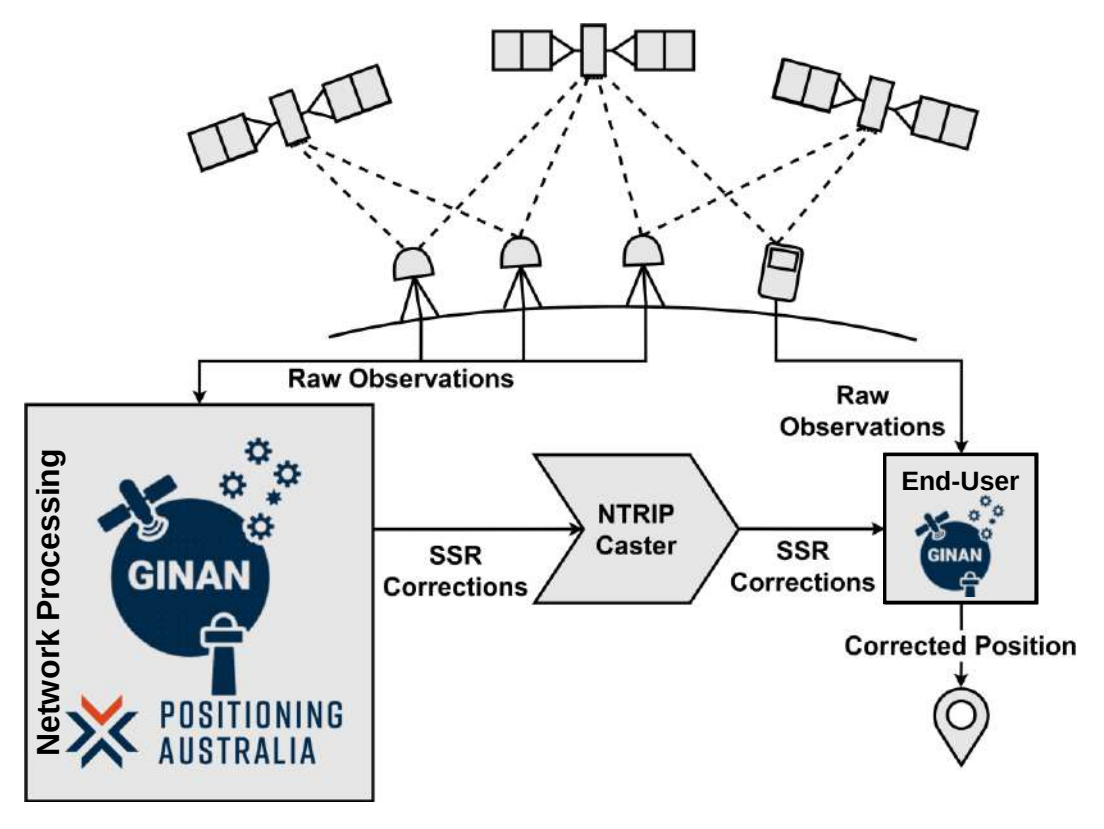
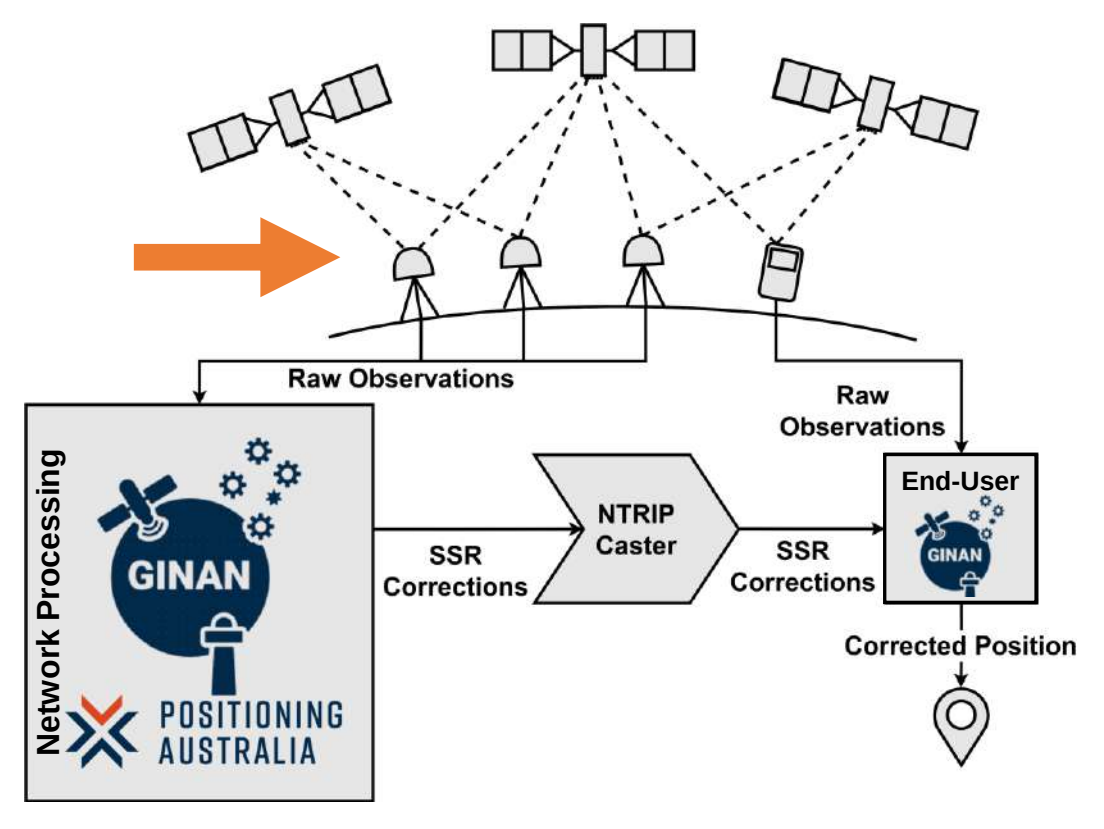
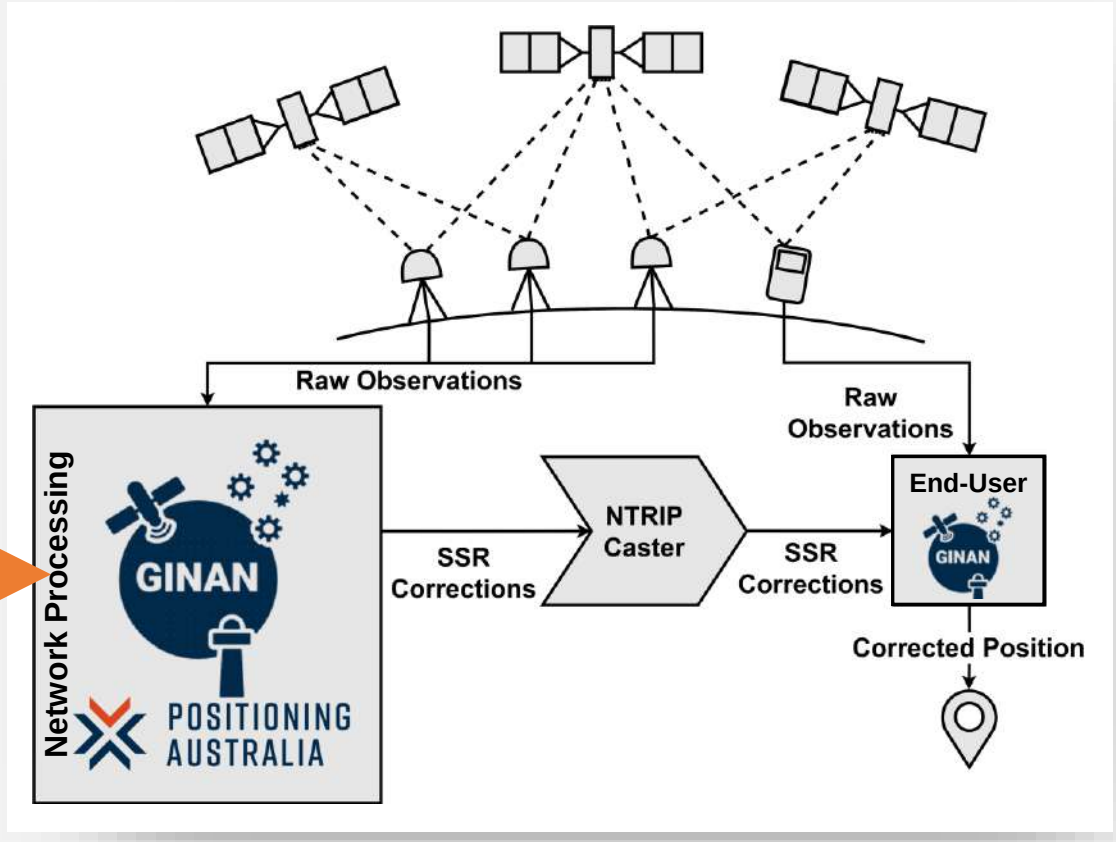
Ginan – Overview



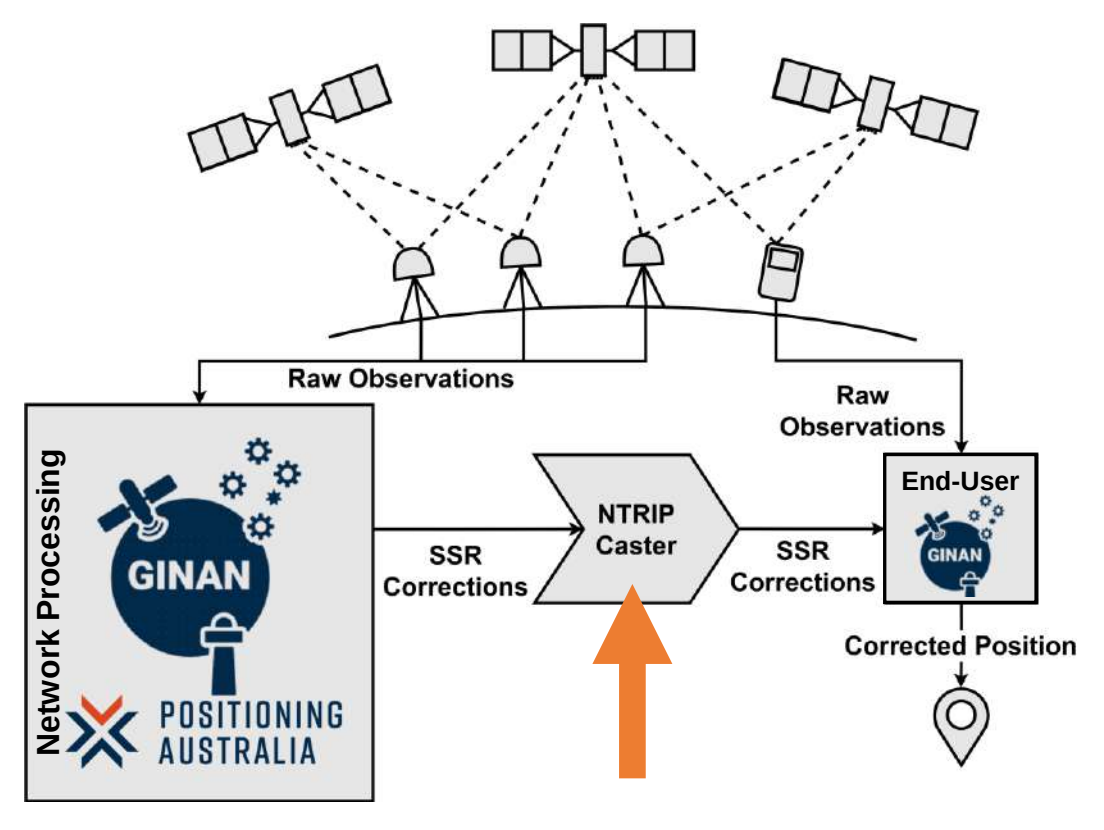
Ginan – Overview



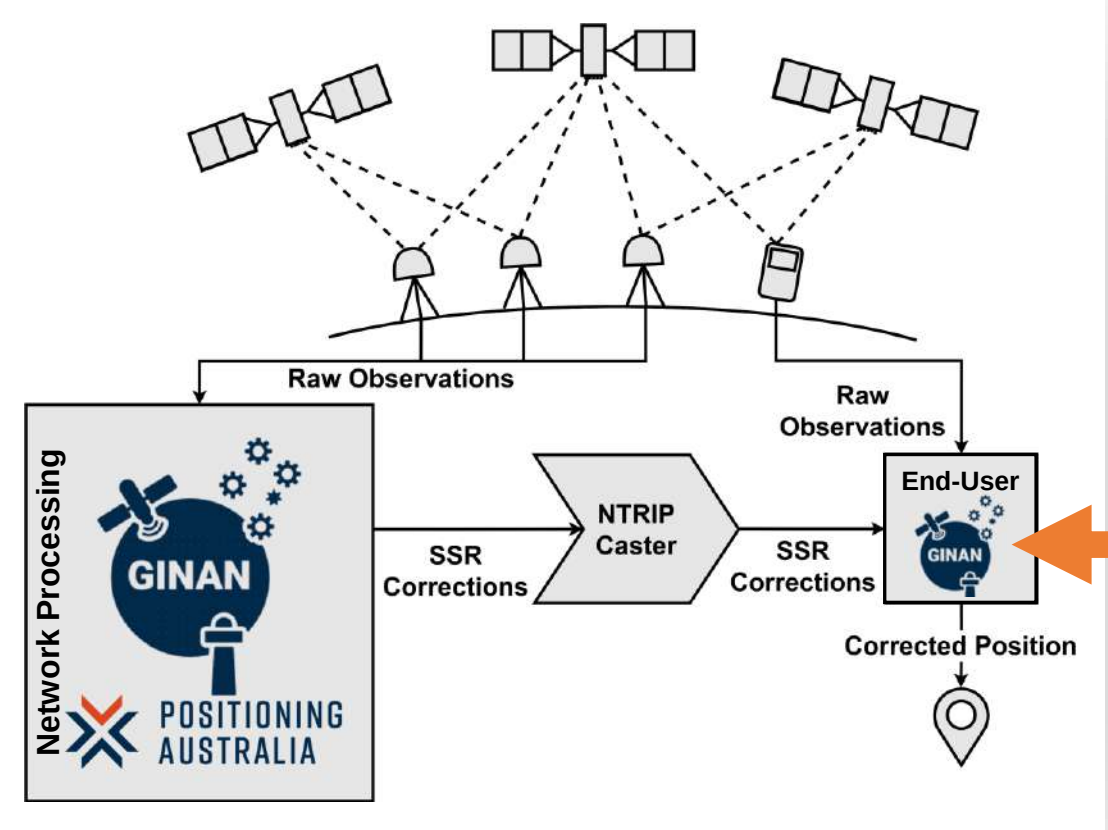
Ginan – Overview



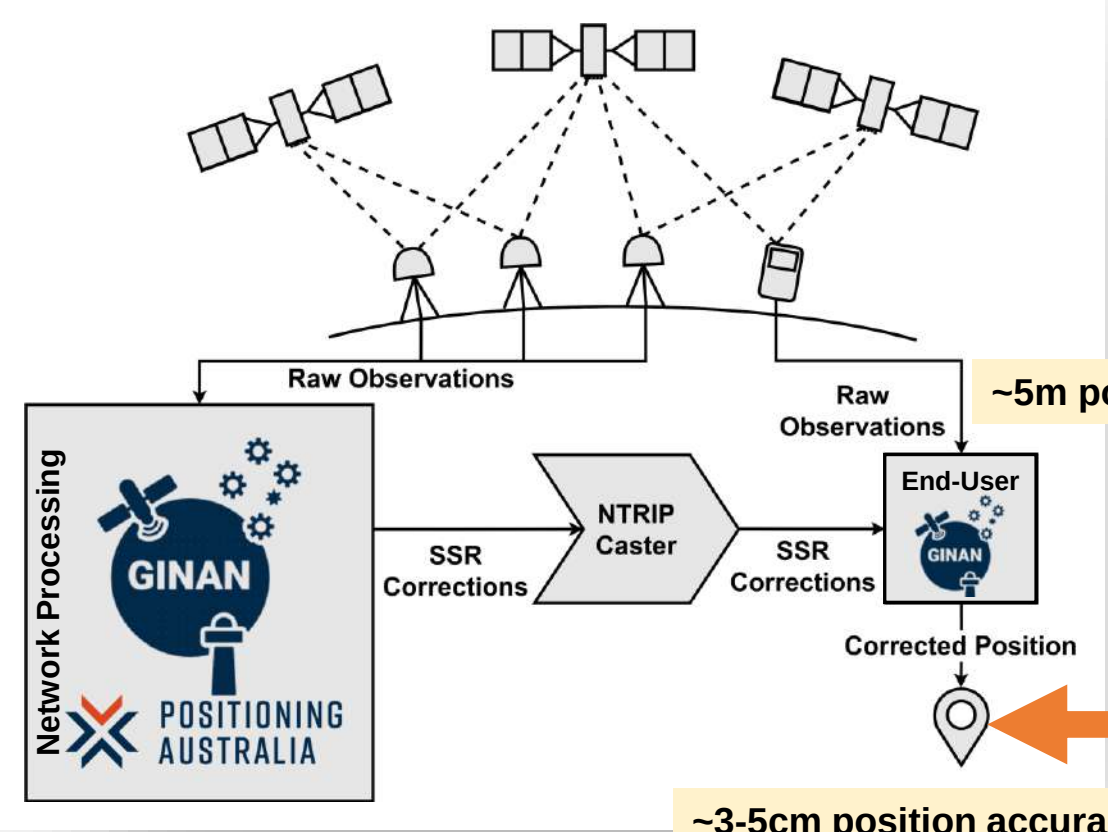
Ginan – Overview



Ginan – Overview



Ginan – Overview

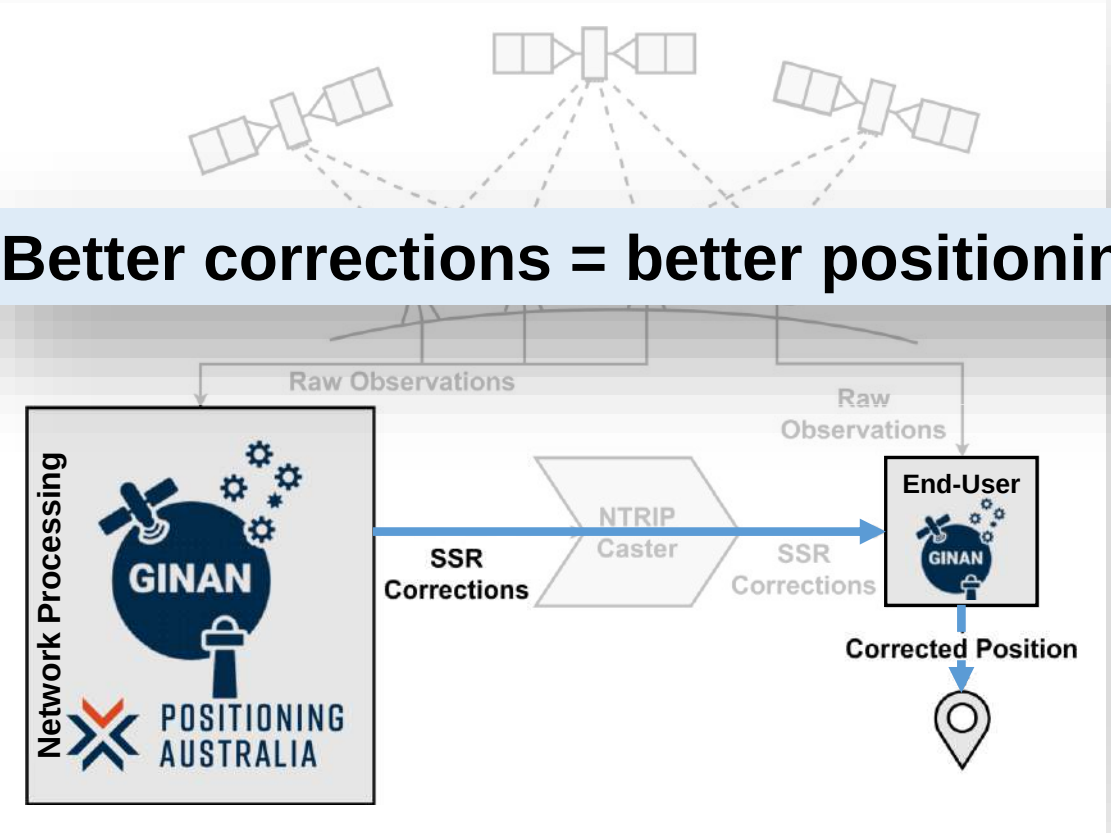


~5m position accuracy

~3-5cm position accuracy

Ginan – Overview

Better corrections = better positioning



Ginan – ISG Contributions

- **Smoothing** – RTS, fixed-lag
- **State-transition modelling** – clock rate & acceleration, First-order Gauss-Markov
- **Filter stability** – non-PD covariance reshaping, Joseph stabilisation
- **Outlier detection** – time-series, Chi-squared, cycle slip detection + repair
- Processing **satellite laser ranging** data
- …

02

Smoothing

The Benefit of Hindsight

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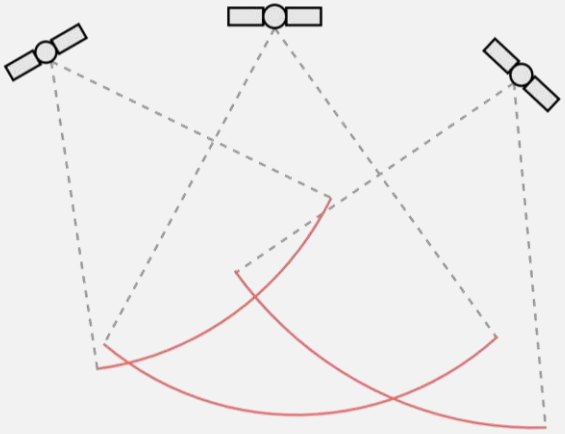
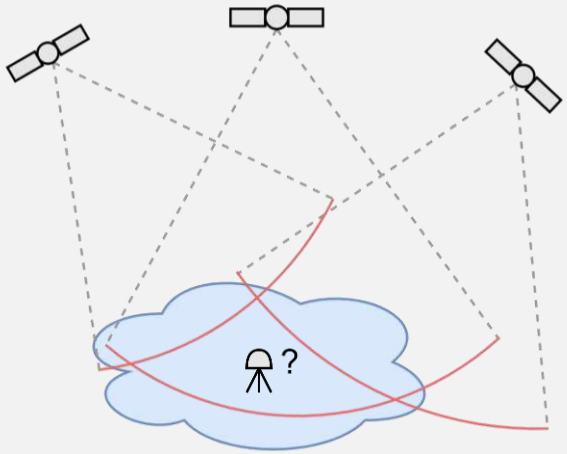
Smoothing – An Example

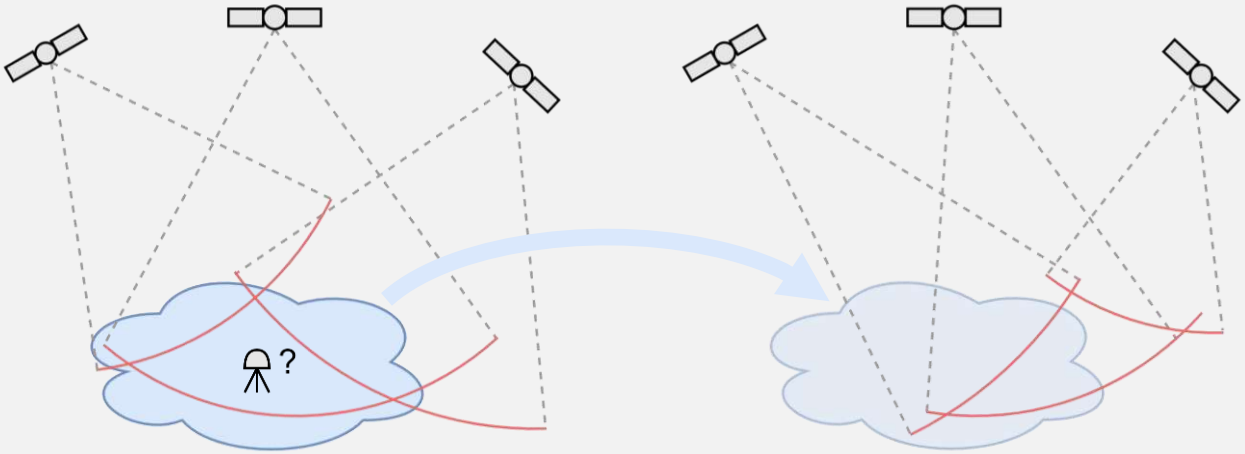


Smoothing – An Example



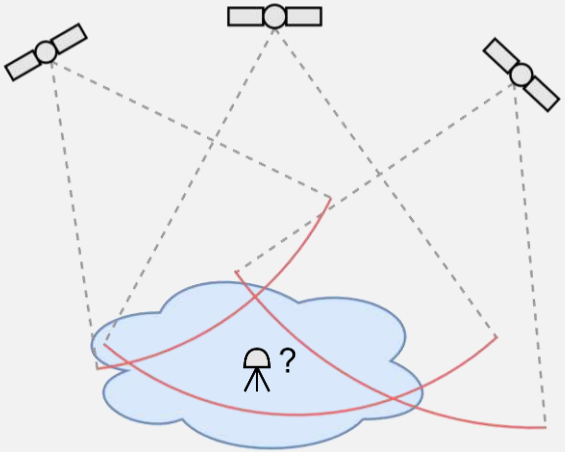
t = 0

Smoothing – An Example

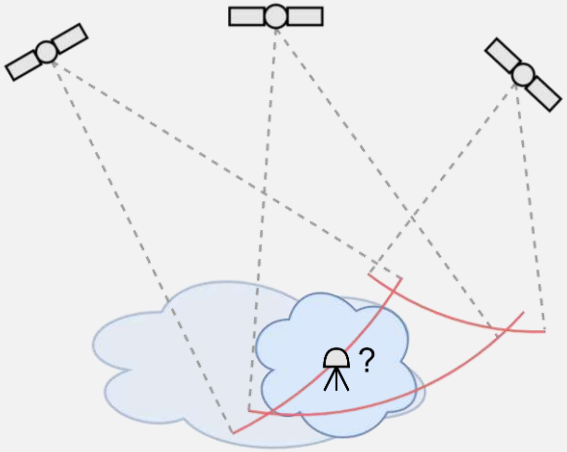


t = 0 **t = 1**

Smoothing – An Example

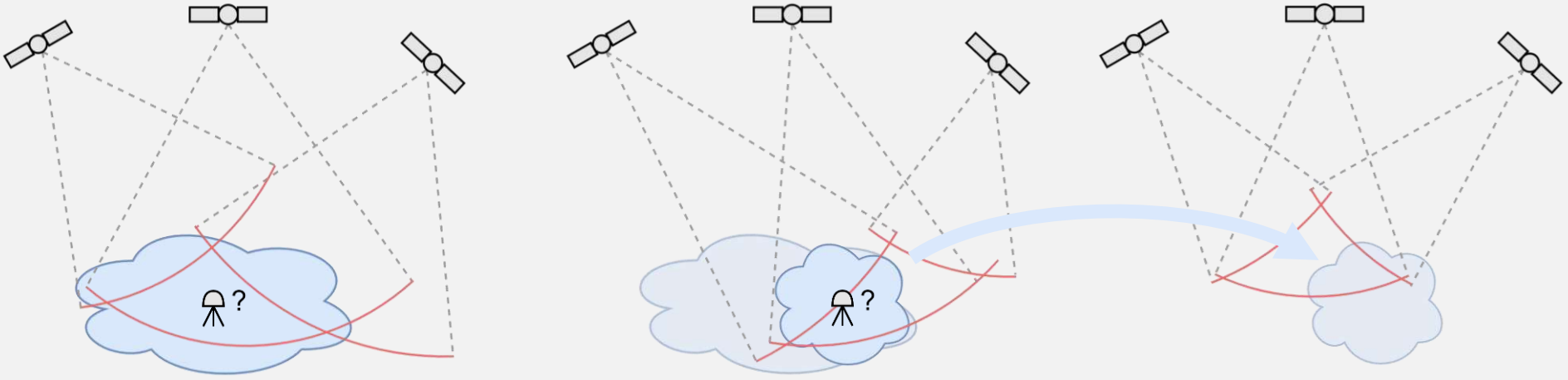


t = 0



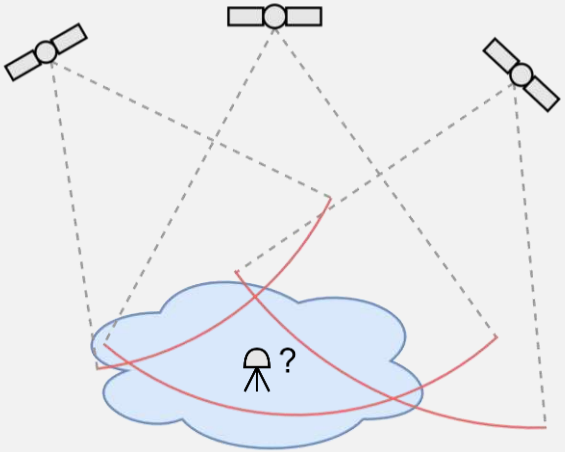
t = 1

Smoothing – An Example

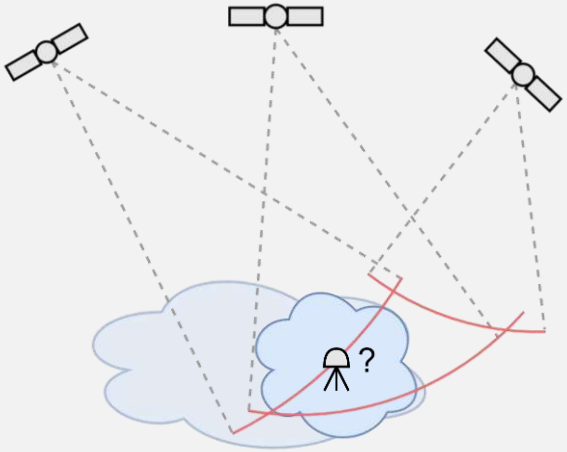


t = 0 t = 1 t = 2

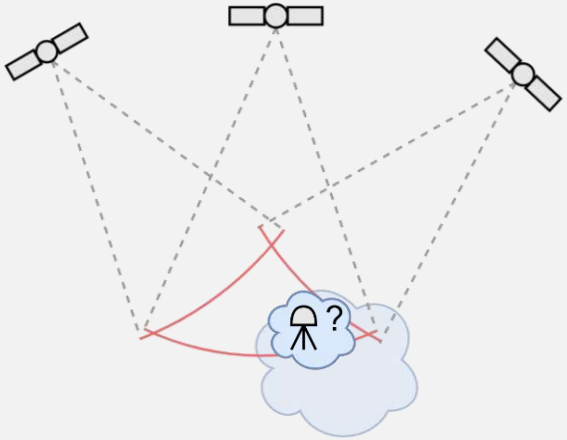
Smoothing – An Example



t = 0

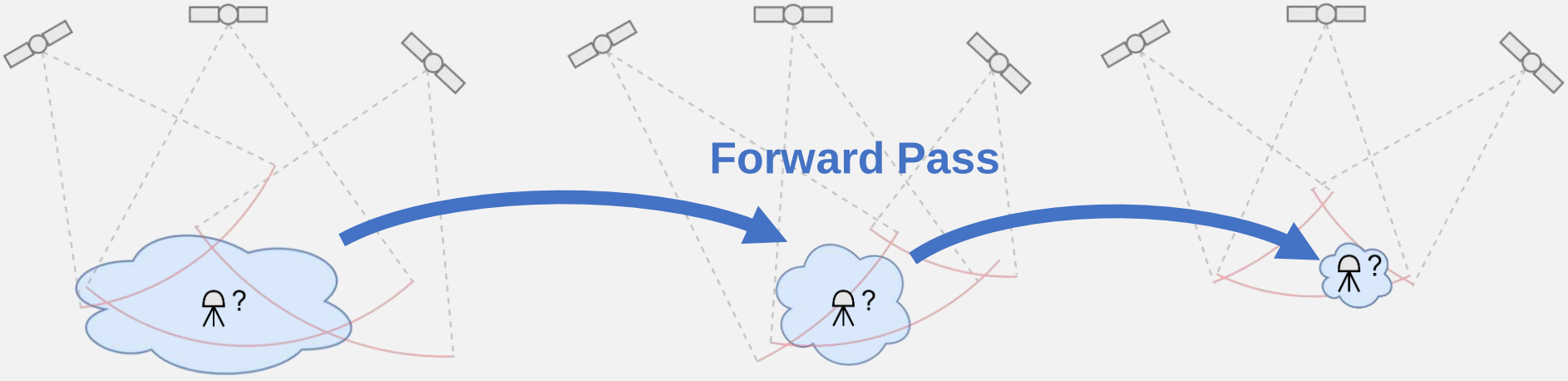


t = 1

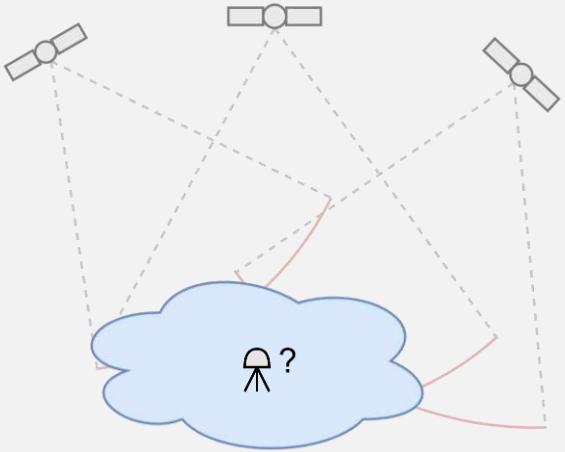


t = 2

Smoothing – An Example



Smoothing – An Example



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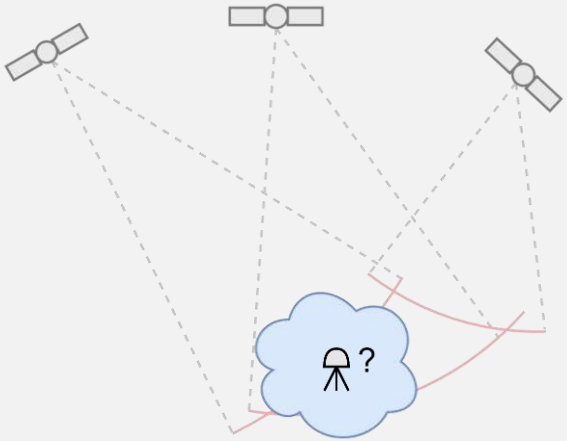
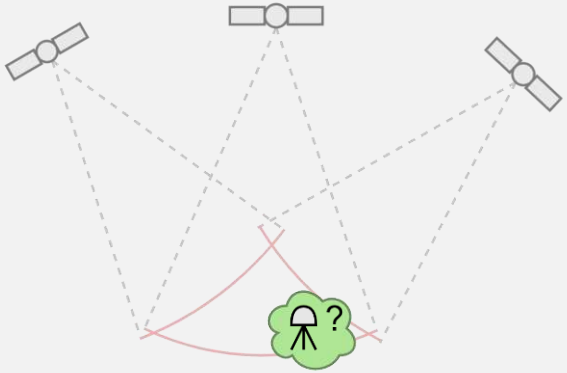
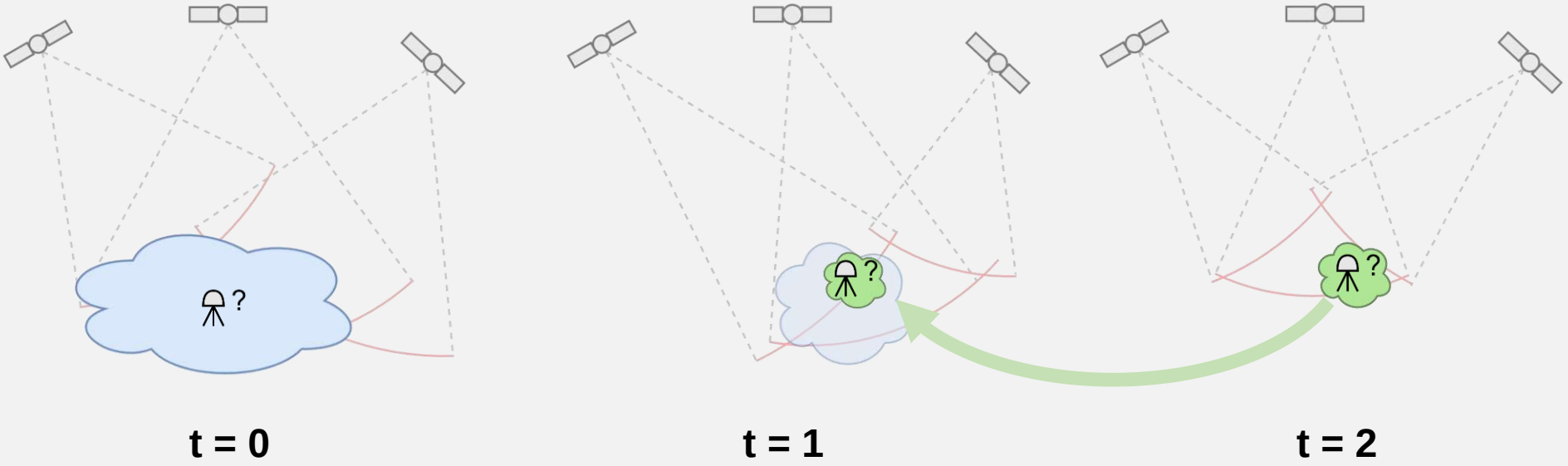


t = 1



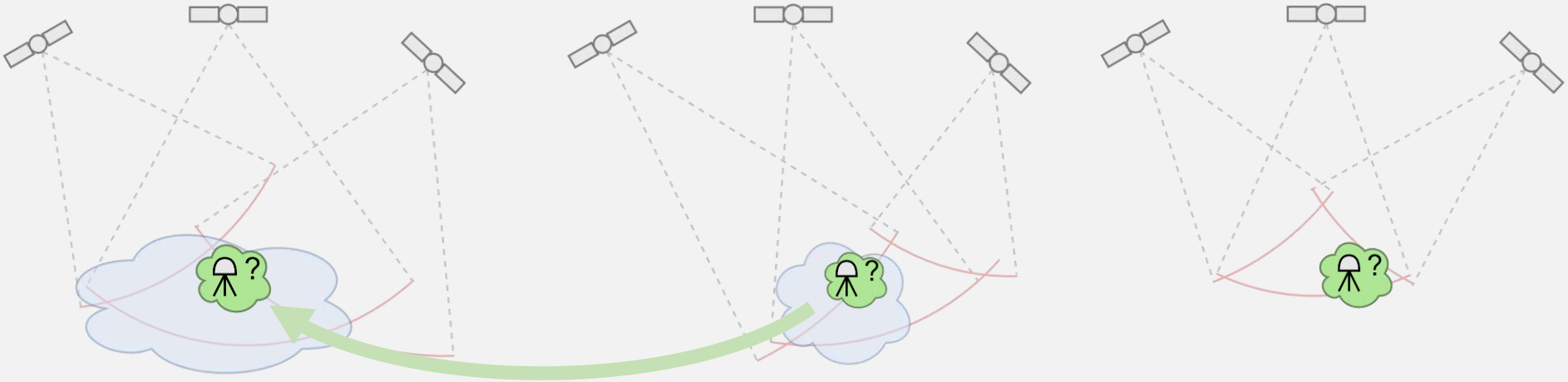
t = 2

Smoothing – An Example



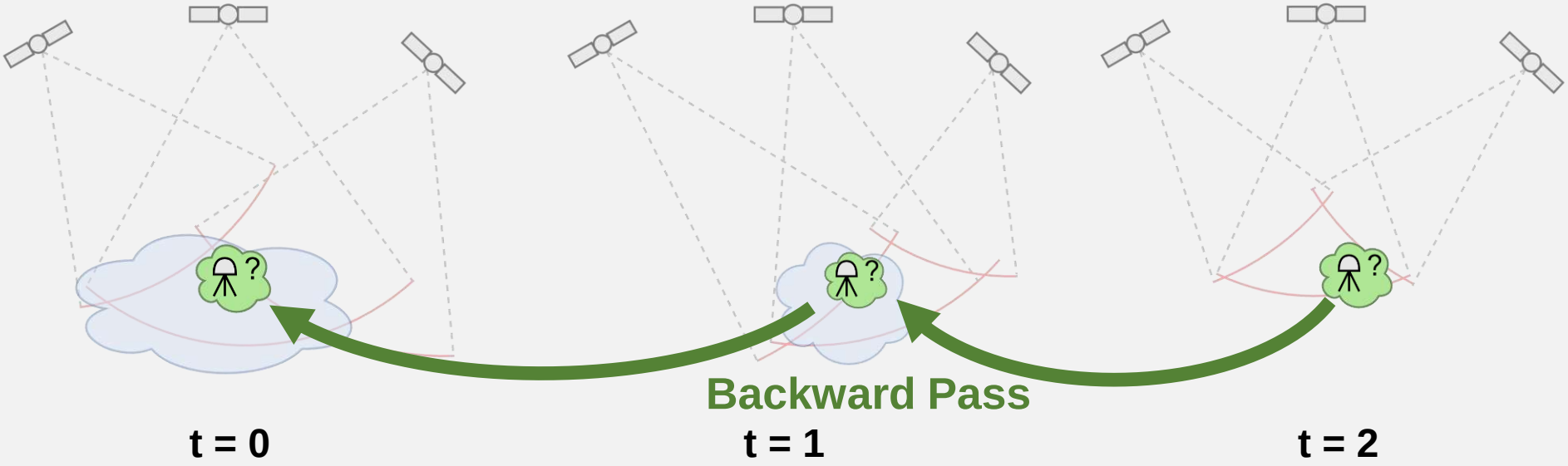
t = 0 t = 1 t = 2

Smoothing – An Example

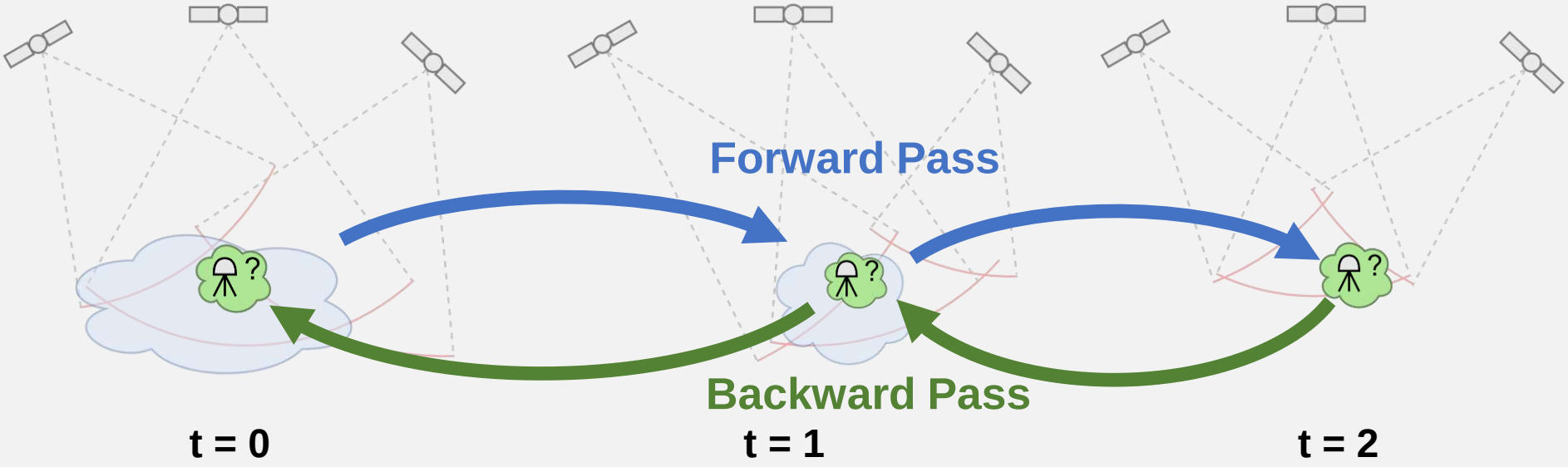


t = 0 t = 1 t = 2

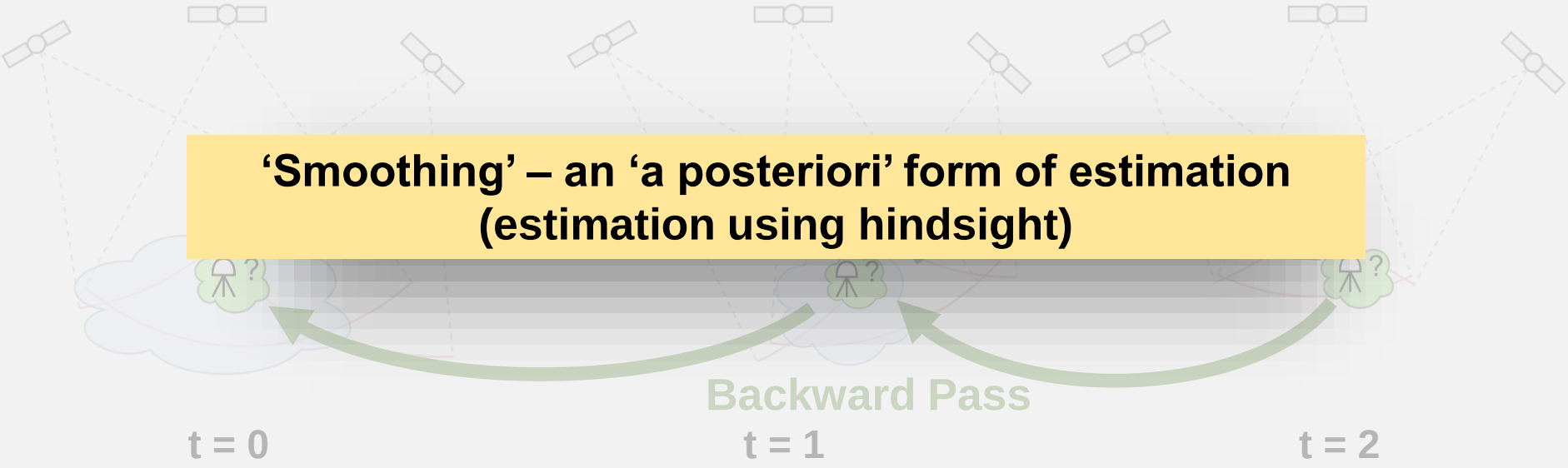
Smoothing – An Example



Smoothing – An Example



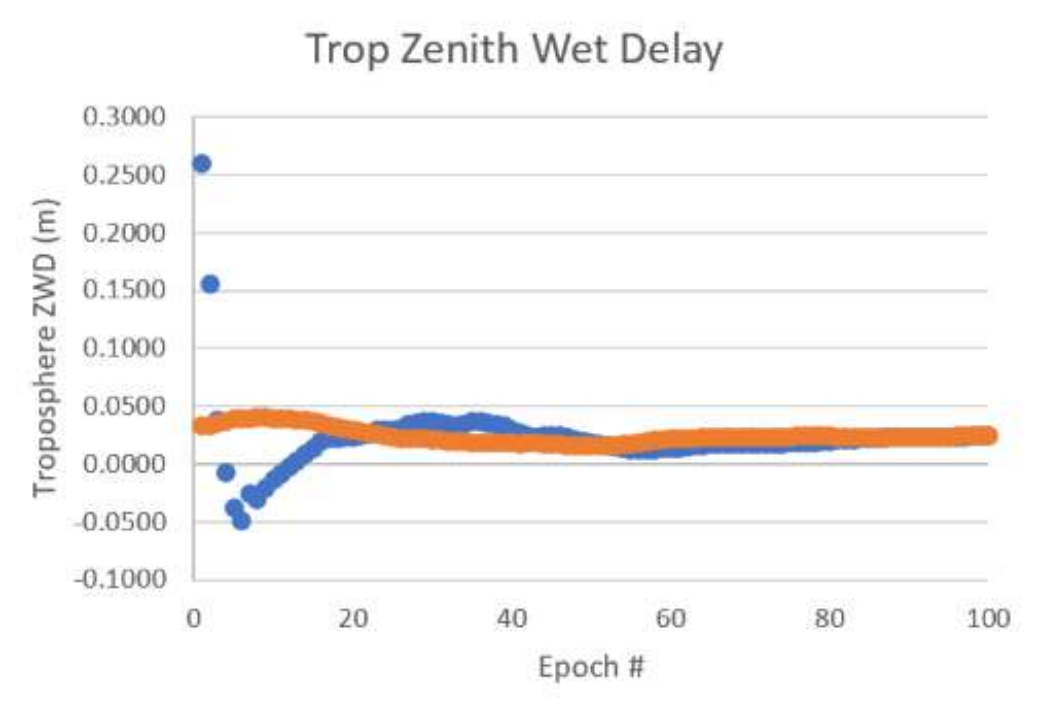
Smoothing – An Example



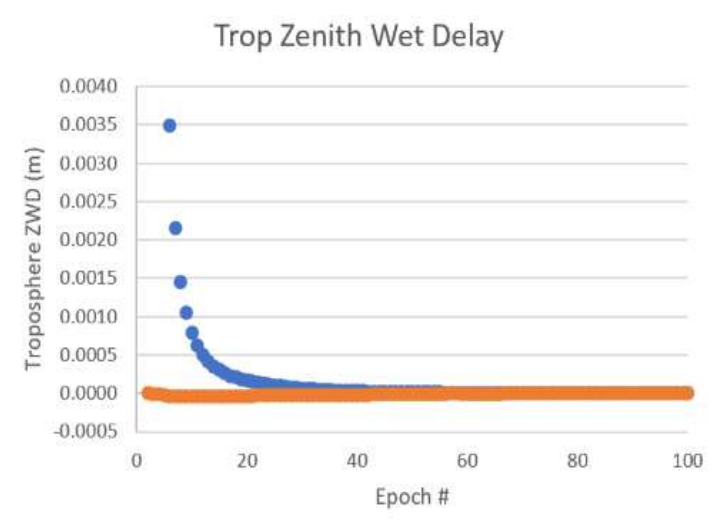
‘Smoothing’ – an ‘a posteriori’ form of estimation (estimation using hindsight)

Smoothing in Ginan

Forward Pass
Backward Pass



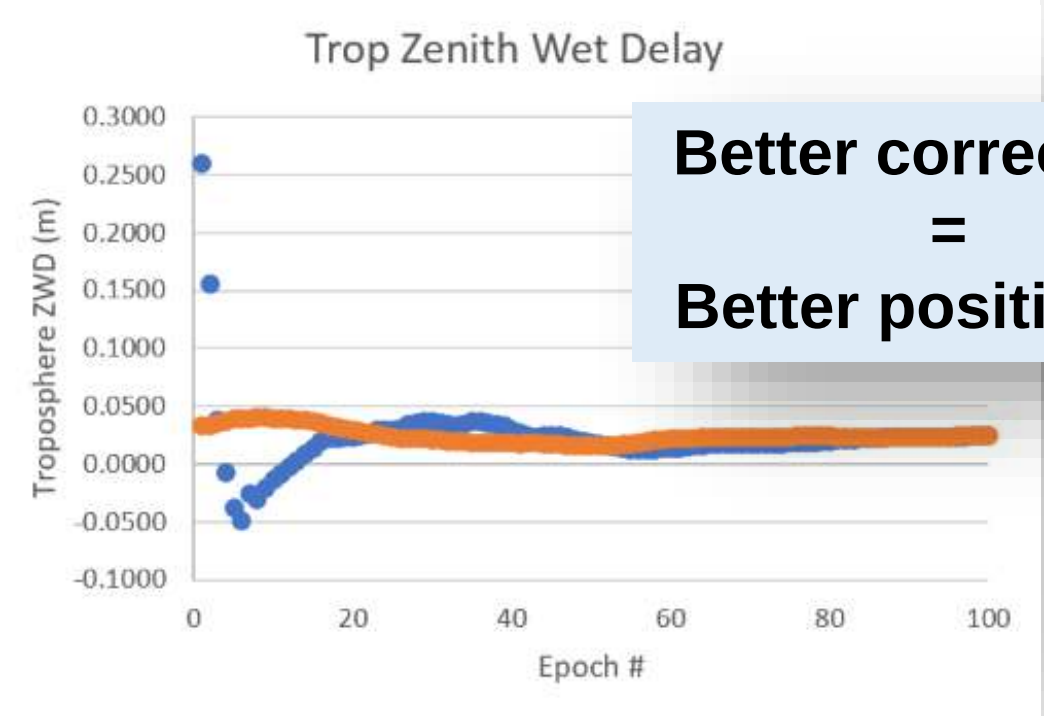
State Estimate



Variance

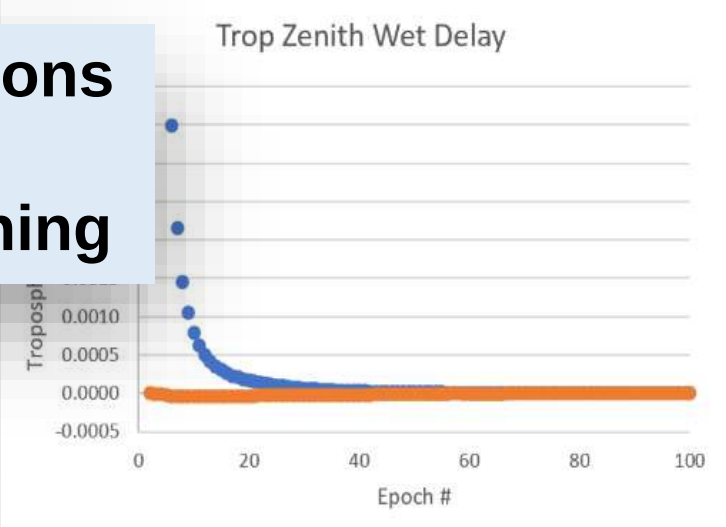
Smoothing in Ginan

Forward Pass
Backward Pass



State Estimate

Better corrections
=
Better positioning



Variance

03
First-Order Gauss-Markov Modelling

Using the Right Model

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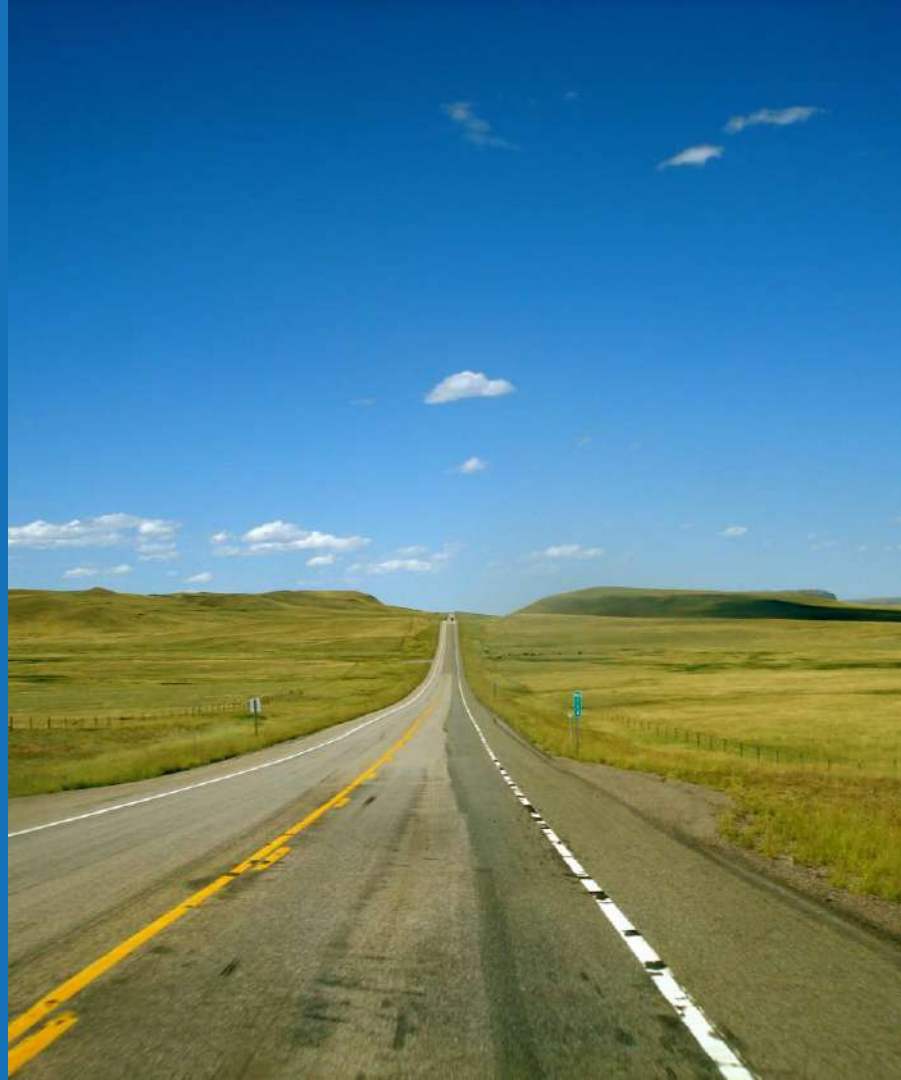
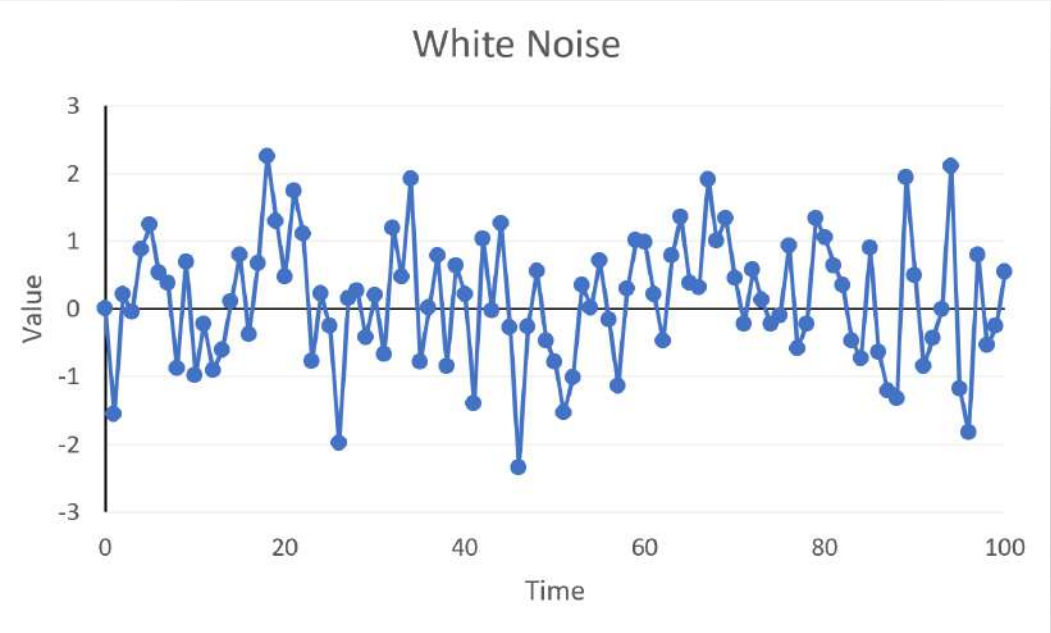
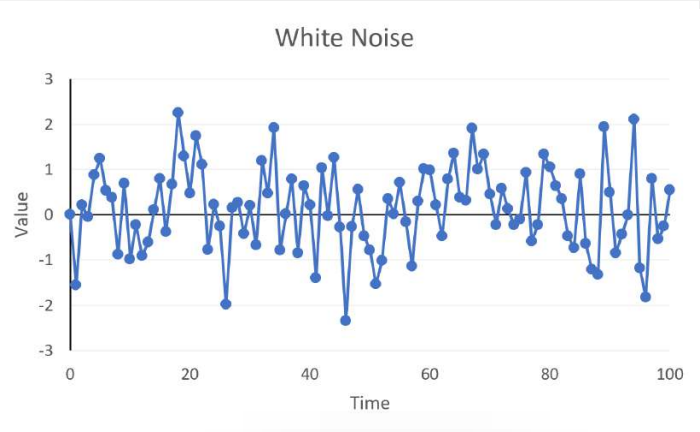


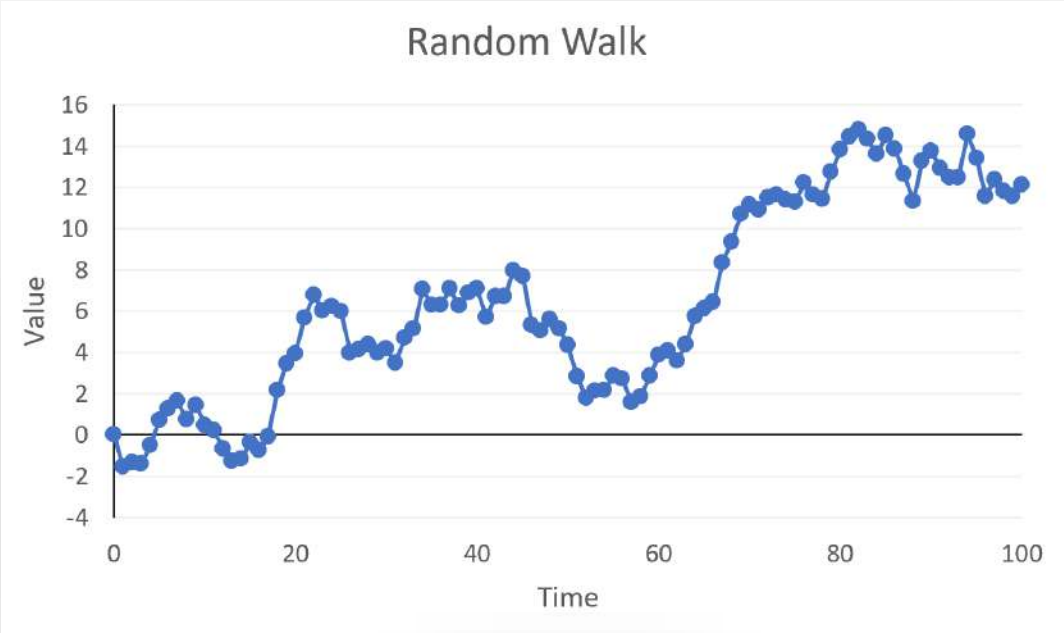
White Noise to Random Walk



Zero correlation
Zero-mean

White Noise to Random Walk

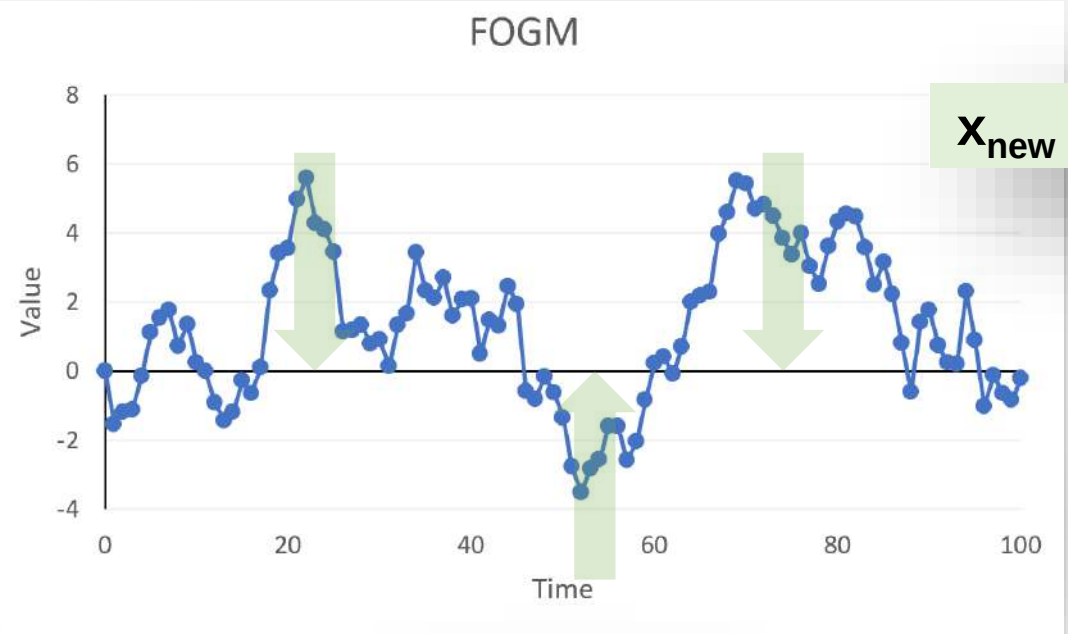




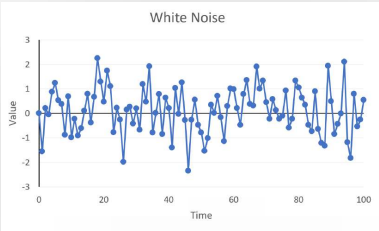
Zero correlation
Zero-mean

∞ correlation
No mean

White Noise to Random Walk



$$x_{new} = x_{old} \cdot e^{-\beta \Delta t}$$

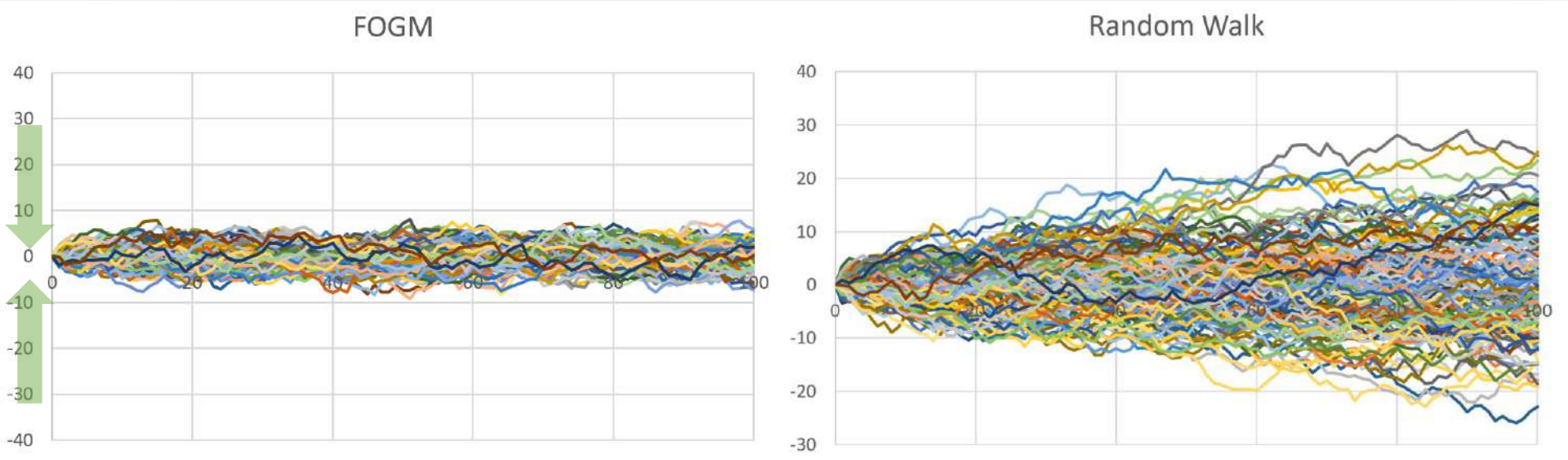


Zero correlation
Zero-mean

Finite correlation
Zero-mean

∞ correlation
No mean

White Noise to Random Walk



FOGM modelling in Ginan

- [Graph of FOGM results]

Better corrections
=
Better positioning

Conclusions

Better corrections = Better positioning

Conclusions

- Outcomes
- [???]

Better corrections = Better positioning

Questions

Appendix

RTS Smoothing Equations

$$\hat{\mathbf{x}}_{k|n} = \hat{\mathbf{x}}_{k|k} + \mathbf{C}_k \left(\hat{\mathbf{x}}_{k+1|n} - \hat{\mathbf{x}}_{k+1|k} \right)$$

$$\mathbf{P}_{k|n} = \mathbf{P}_{k|k} + \mathbf{C}_k \left(\mathbf{P}_{k+1|n} - \mathbf{P}_{k+1|k} \right) \mathbf{C}_k^{\mathsf{T}}$$

where

$$\mathbf{C}_k = \mathbf{P}_{k|k} \mathbf{F}_{k+1}^{\mathsf{T}} \mathbf{P}_{k+1|k}^{-1}.$$

RTS Smoothing Equations

$$\hat{\mathbf{x}}_{k|n} = \hat{\mathbf{x}}_{k|k} + \mathbf{C}_k \left(\hat{\mathbf{x}}_{k+1|n} - \hat{\mathbf{x}}_{k+1|k} \right)$$

$$\mathbf{P}_{k|n} = \mathbf{P}_{k|k} + \mathbf{C}_k \left(\mathbf{P}_{k+1|n} - \mathbf{P}_{k+1|k} \right) \mathbf{C}_k^{\mathsf{T}}$$

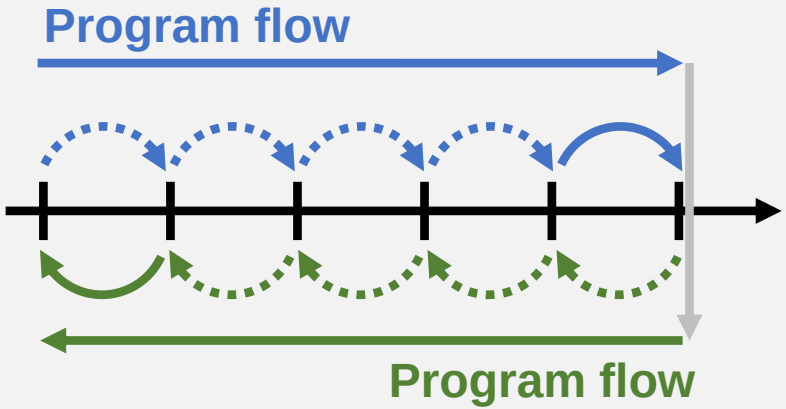
where

$$\mathbf{C}_k = \mathbf{P}_{k|k} \mathbf{F}_{k+1}^{\mathsf{T}} \mathbf{P}_{k+1|k}^{-1}$$

More process noise =
→ Larger $P_{k+1|k}$
→ Smaller $P_{k+1|k}^{-1}$
→ Smaller C_k
→ Smaller impact of future states

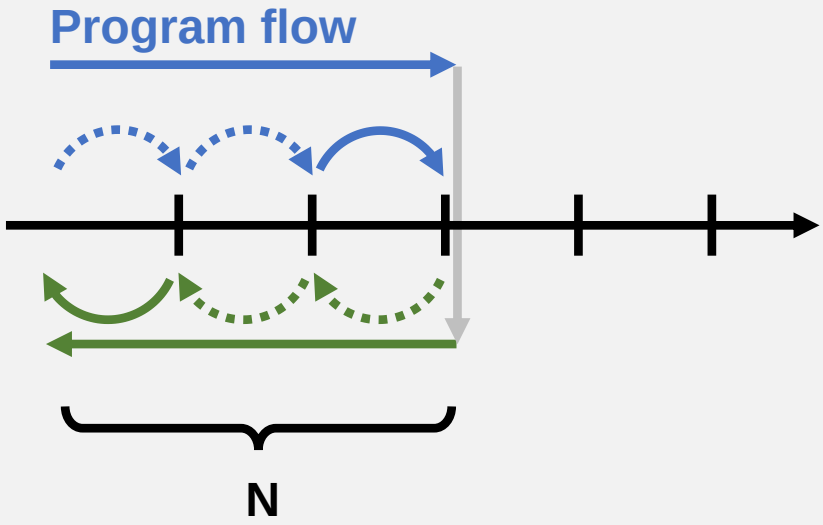
Fixed-Interval Smoothing (RTS)

- Batch-processes data within a fixed time interval (e.g. daily)
- Improves estimation accuracy across whole interval, particularly towards the start of run



Fixed-lag Smoothing

- Processes data in near-real-time, depending on lag **N**
- Improves estimation accuracy within the last **N** timesteps



Fixed-lag Smoothing

- Processes data in near-real-time, depending on lag **N**
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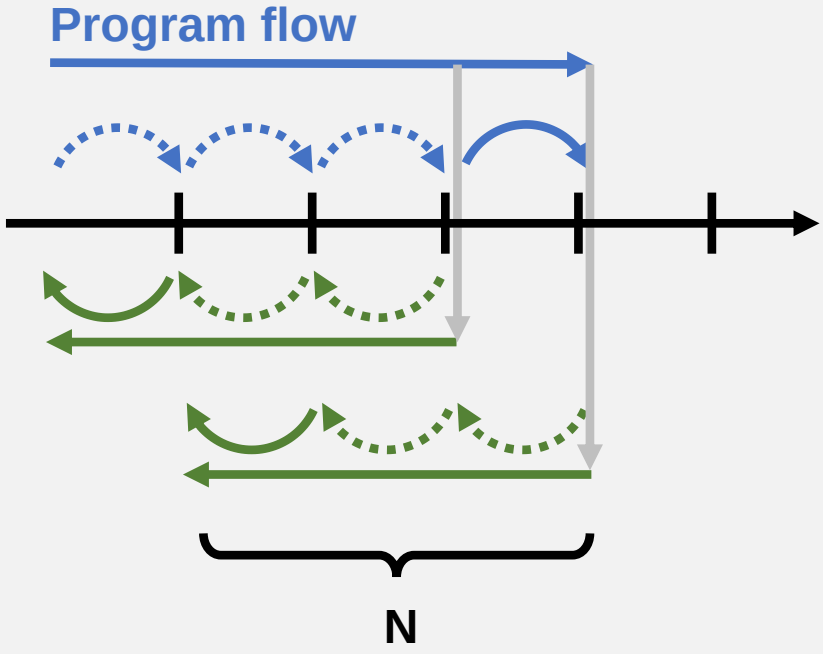

Fixed-lag Smoothing

- Processes data in near-real-time, depending on lag **N**
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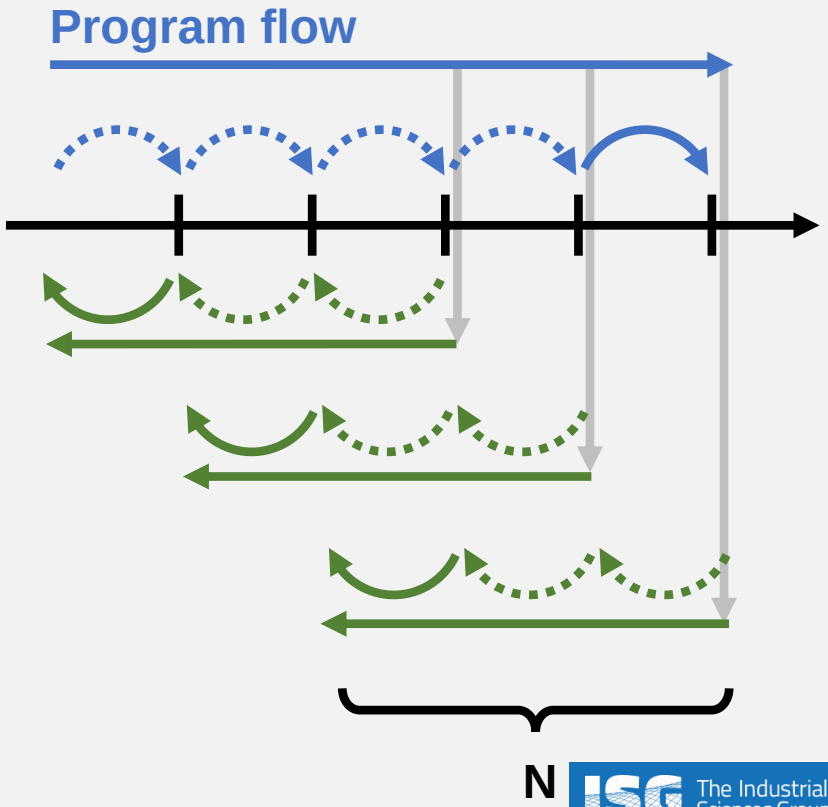
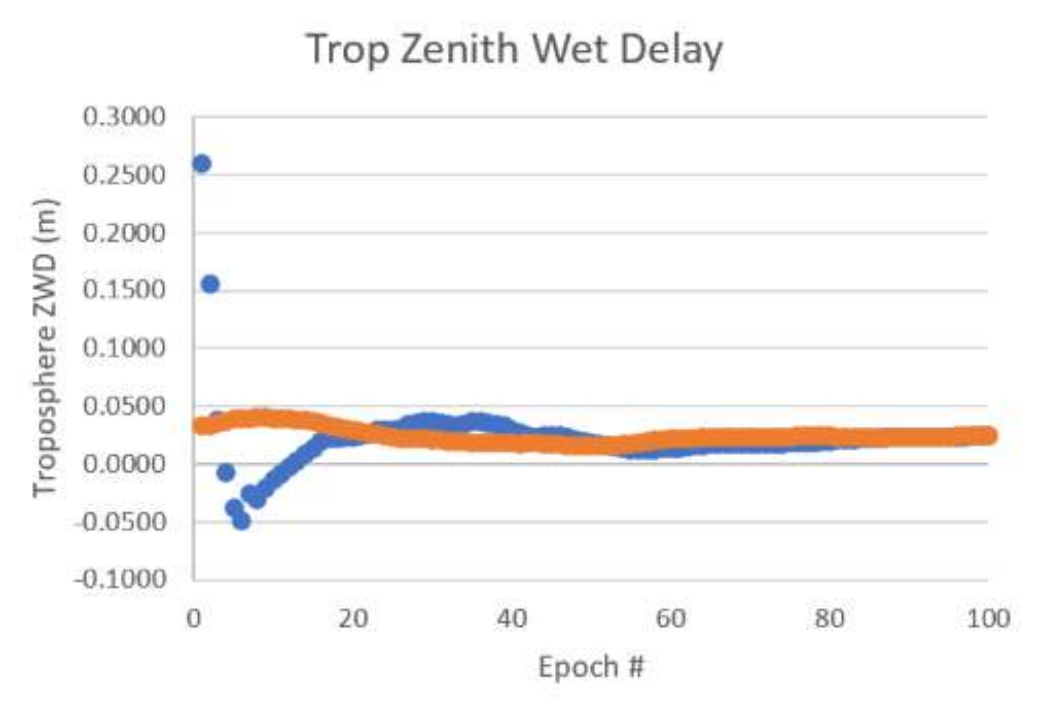


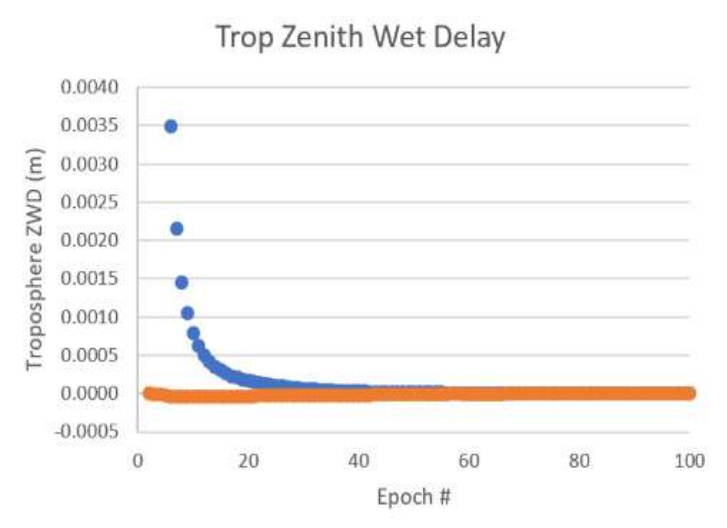
[replace w position?]

Smoothing in Ginan

Forward Pass
Backward Pass



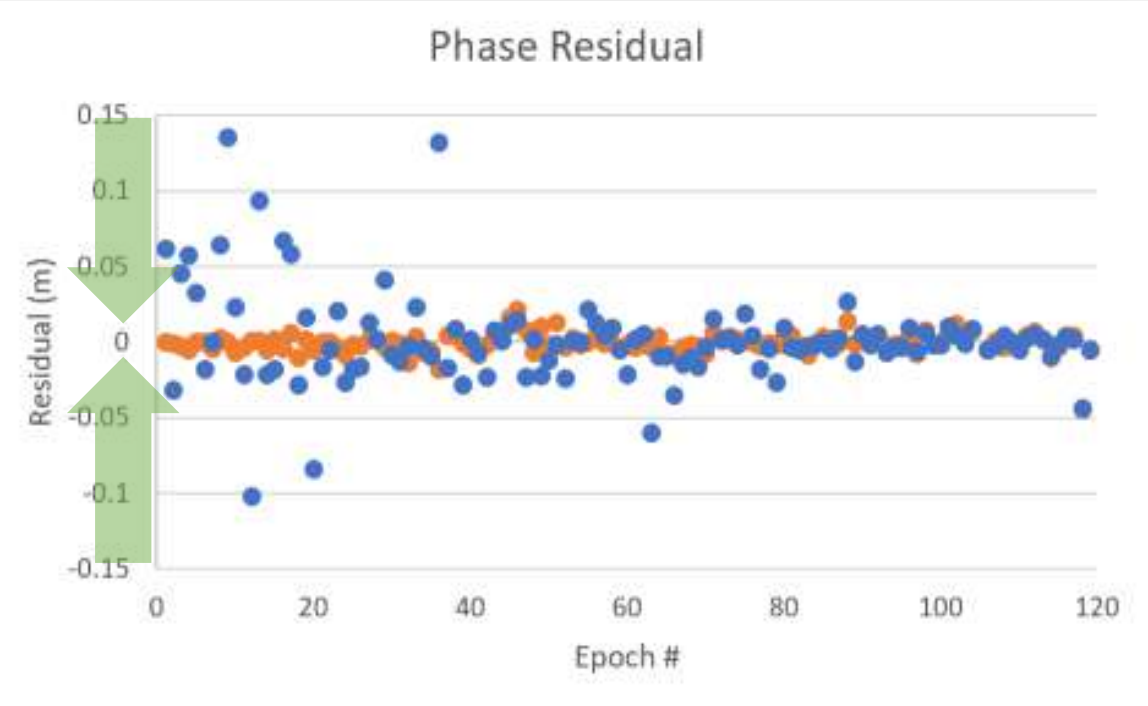
State Estimate



Variance

Smoothing in Ginan

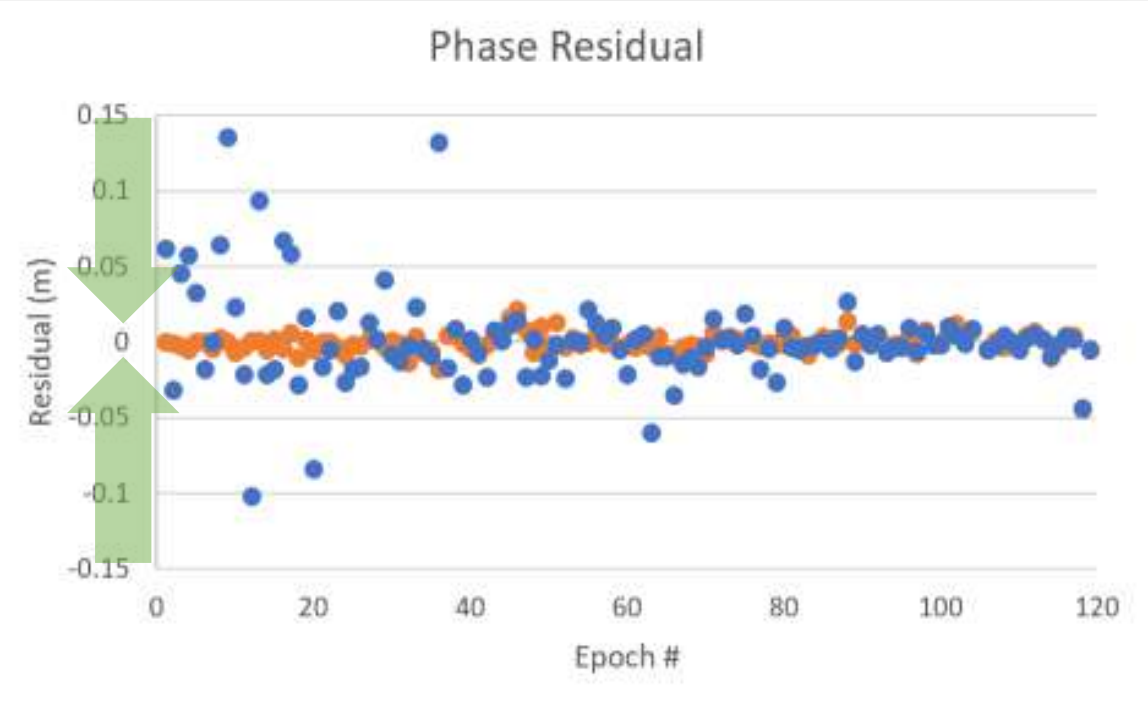
Forward Pass
Backward Pass



Observation Residuals

Smoothing in Ginan

Forward Pass
Backward Pass



Observation Residuals

Better corrections
=
Better positioning