

## Improving the Performance of Geoscience Australia's Ginan with Advanced Kalman Filtering, Statistical Techniques and Satellite Laser Ranging

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Simon McClusky (Geoscience Australia)

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# Industrial Sciences Group

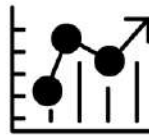
15 years' experience in implementing state-of-the-art research in advanced analytics to deliver commercial outcomes

## 8 Core Capabilities all under 'One Roof'

**Multi-disciplinary** and  
**multi-sector** approach

with skills and expertise in:

Advanced Analytics



Astrodynamics



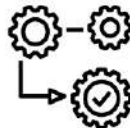
Space Situational  
Awareness



GNSS/Geodesy



Process Optimisation



Simulation



Machine Learning

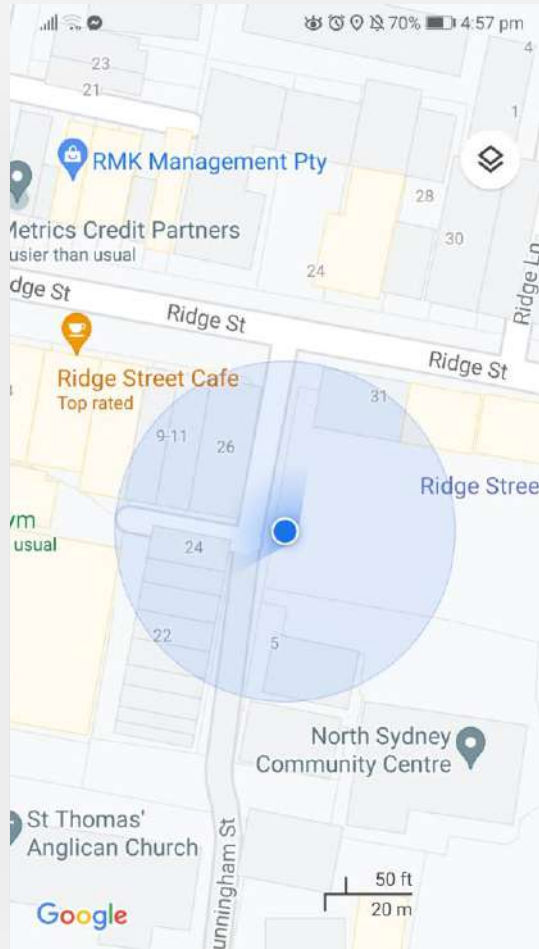


Scientific Programming



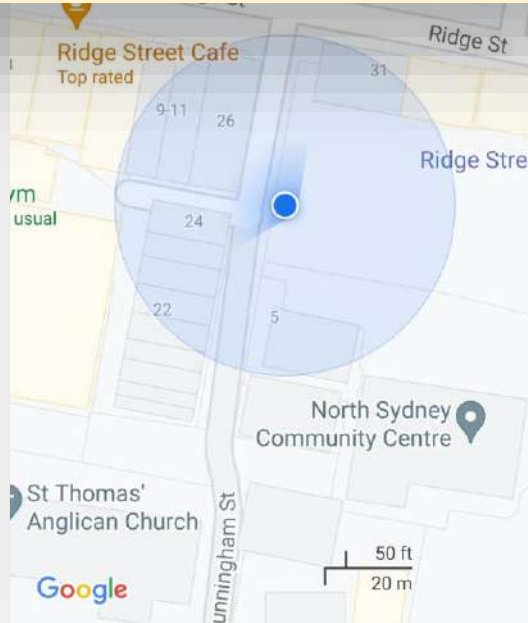
# Outline

<b><i>Section 1</i></b>	<b>The Ginan software toolkit ISG's contributions to Ginan</b>
<b><i>Section 2</i></b>	<b>Smoothing</b>
<b><i>Section 3</i></b>	<b>First-order Gauss Markov modelling</b>
<b><i>Section 4</i></b>	<b>Satellite Laser Ranging</b>





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



01

# The Ginan Software Toolkit

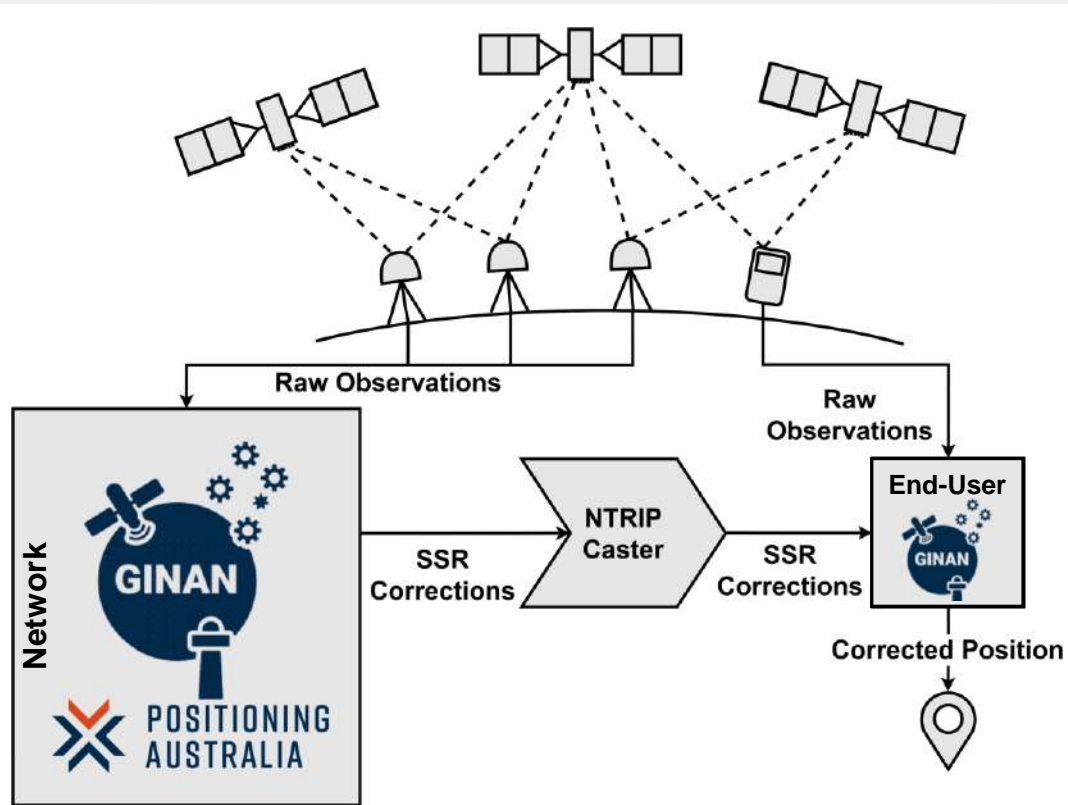
A Brief Overview



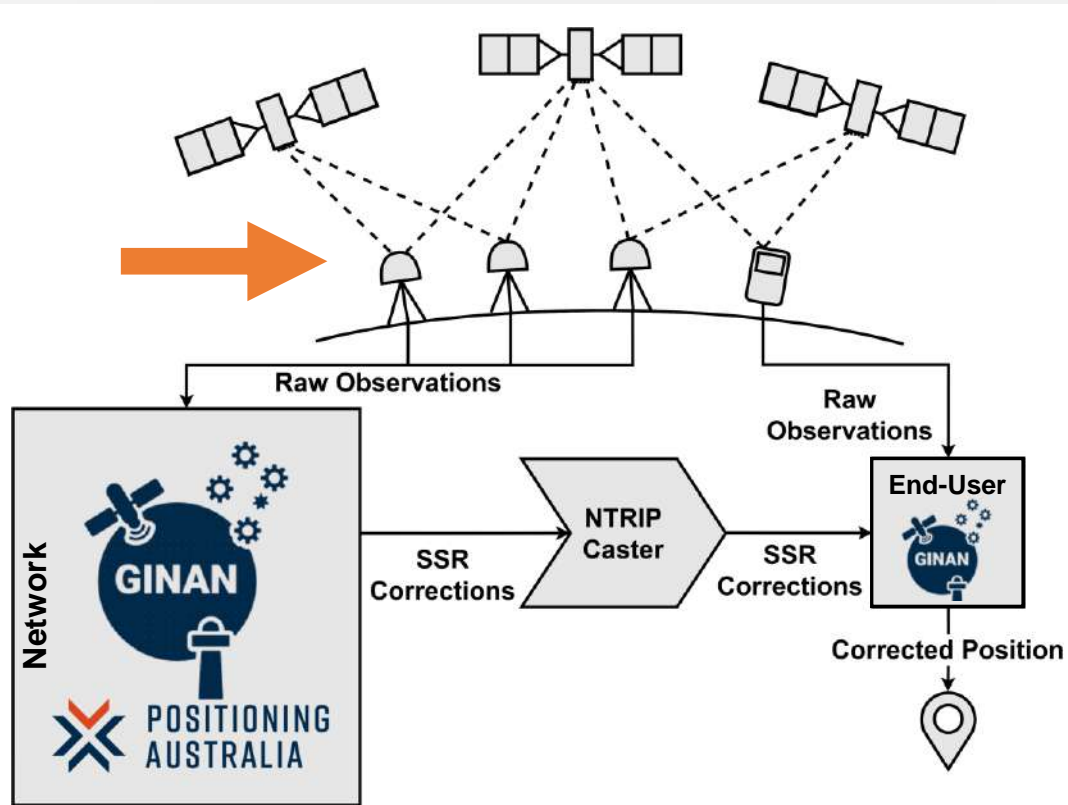
The Industrial  
Sciences Group



# Ginan – Overview

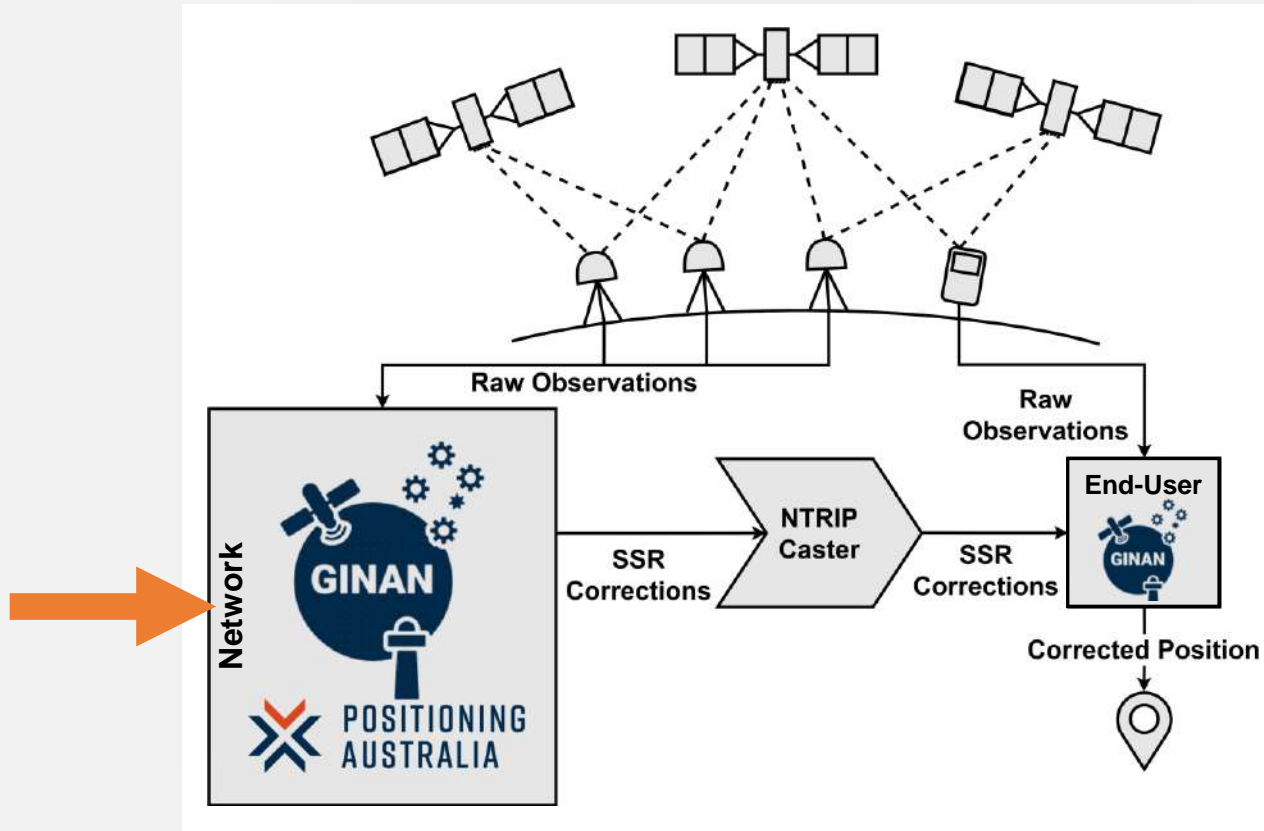


# Ginan – Overview

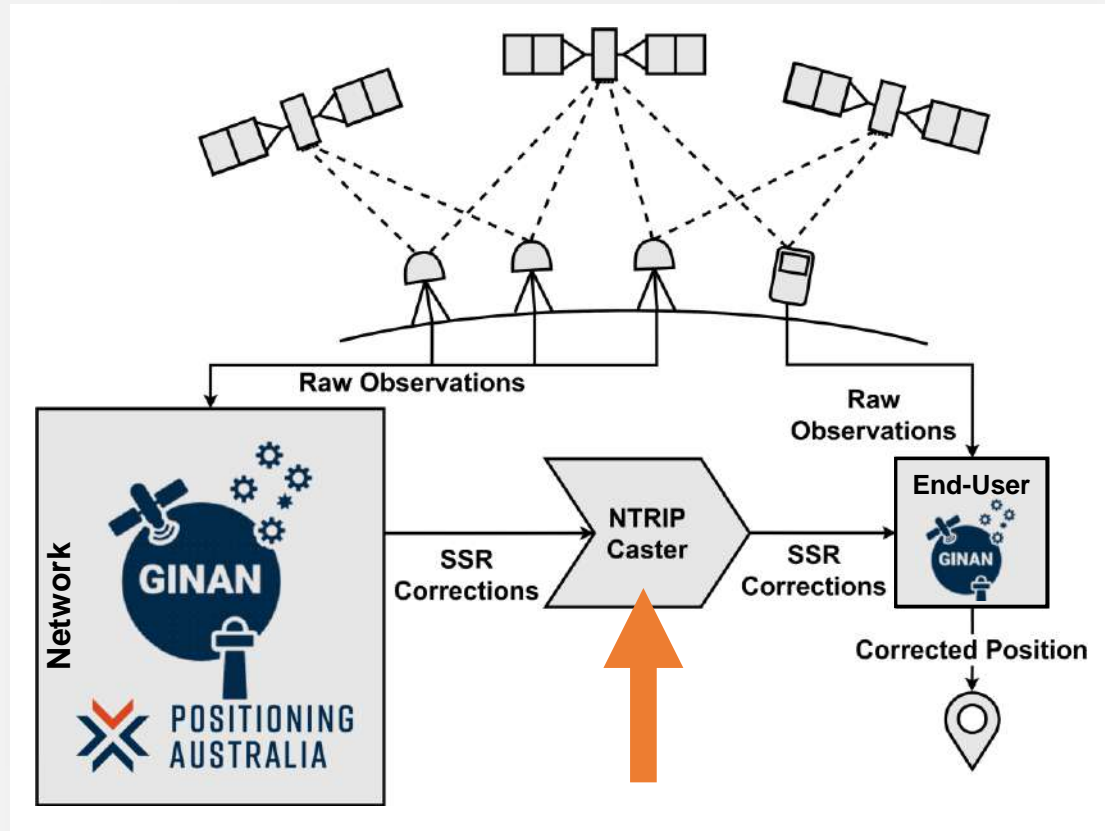




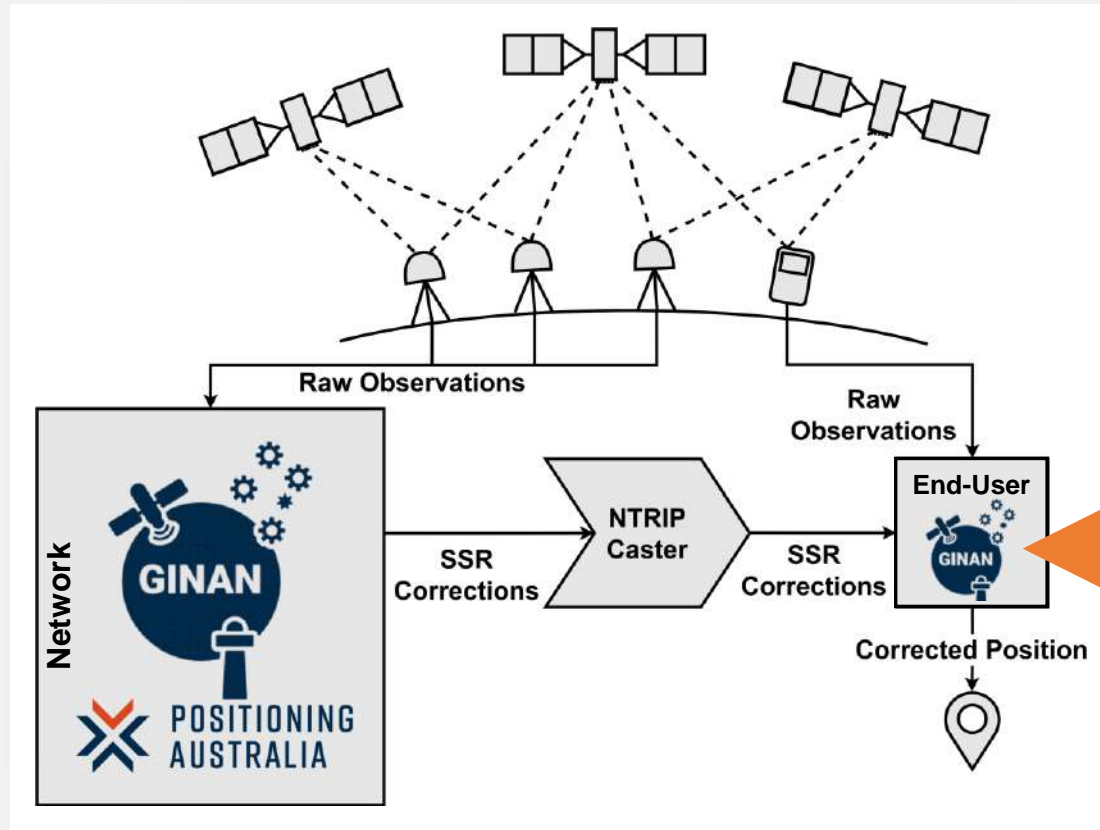
# Ginan – Overview



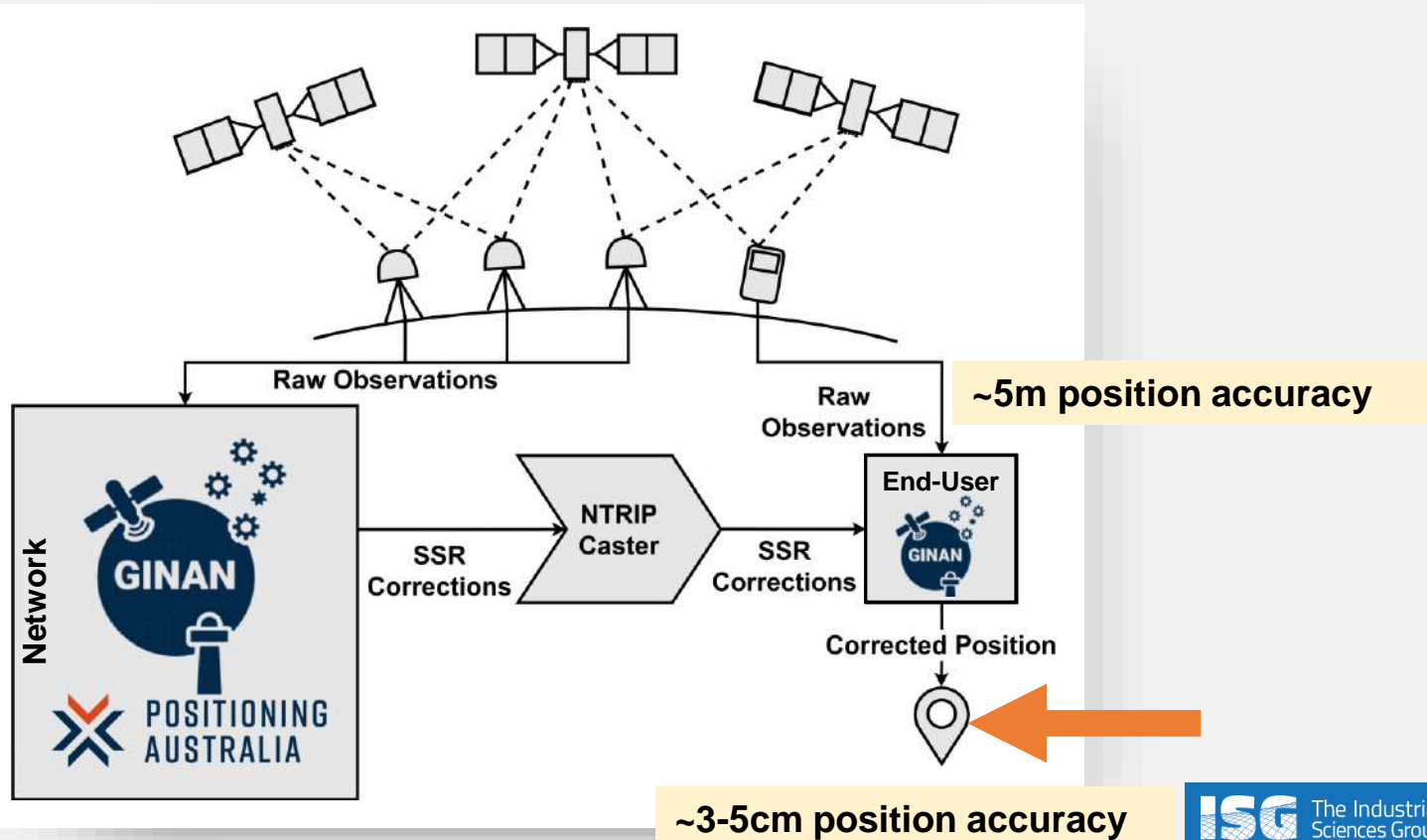
# Ginan – Overview



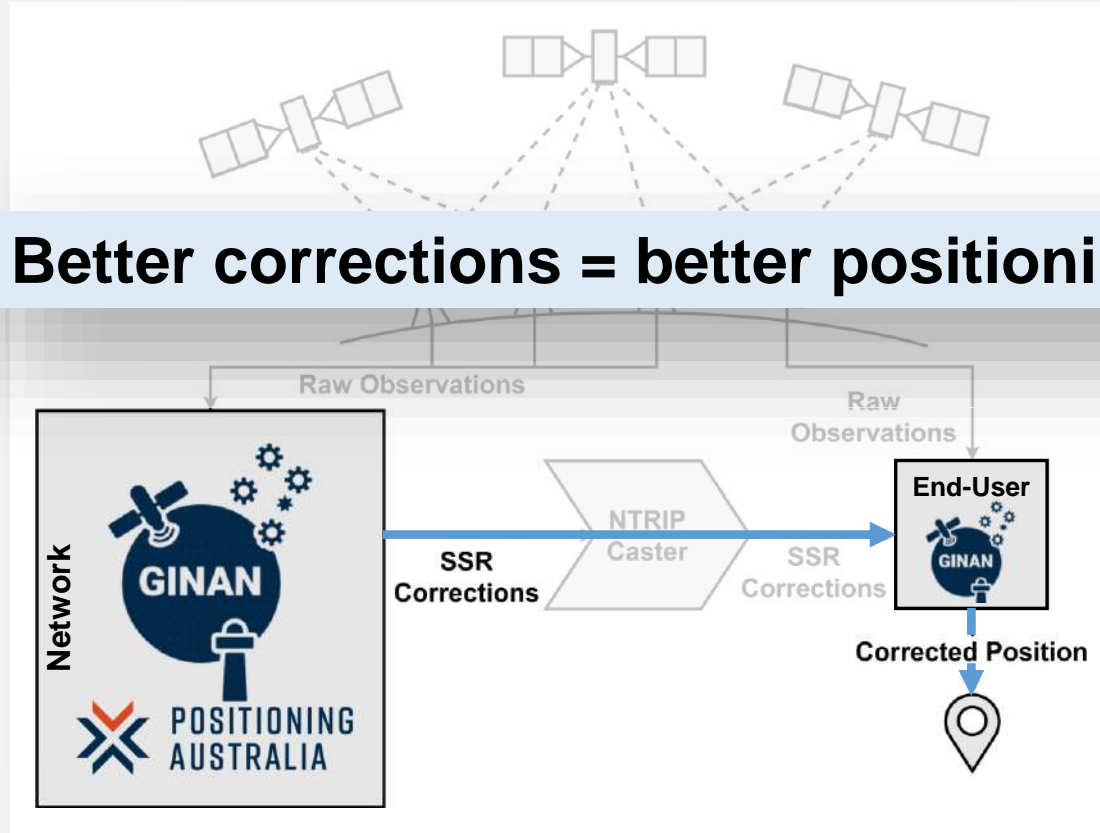
# Ginan – Overview



# Ginan – Overview



# Ginan – Overview



# 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

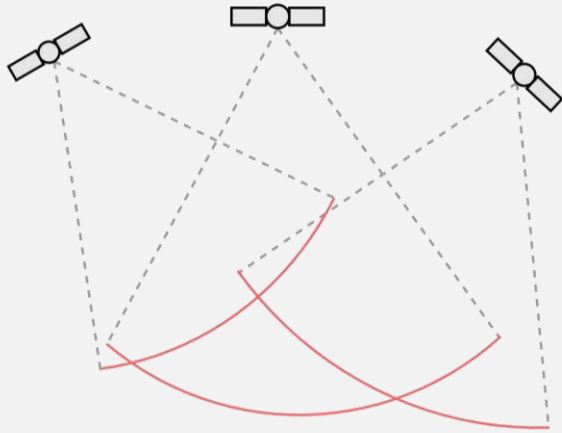
The Benefit of Hindsight



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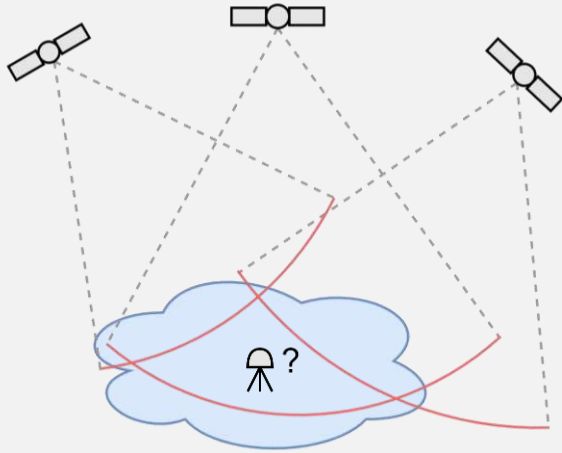
# Smoothing – An Example



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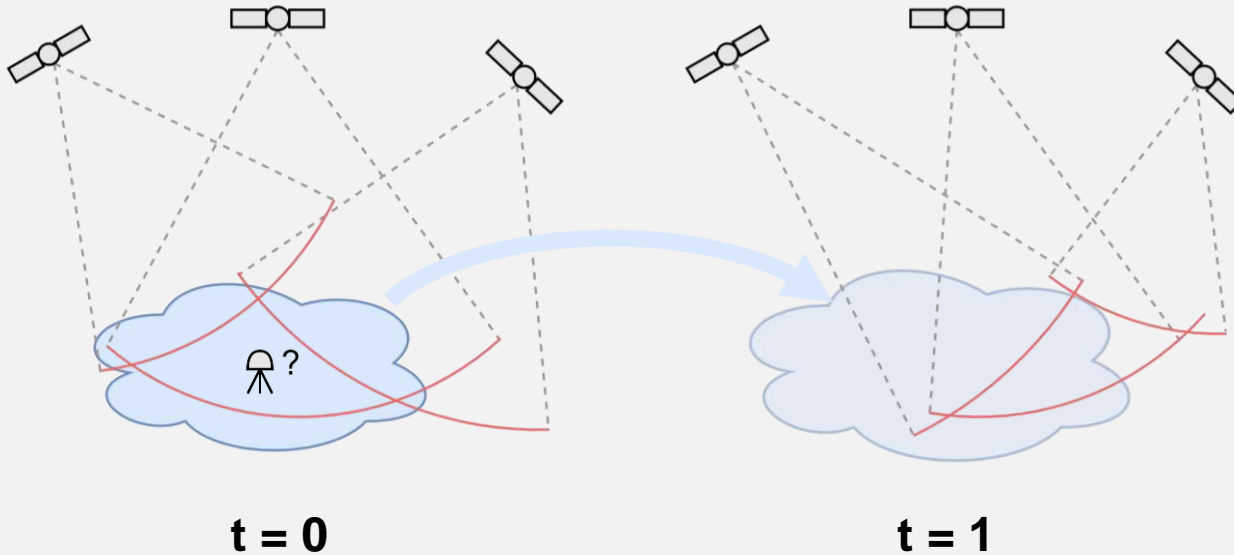


# Smoothing – An Example

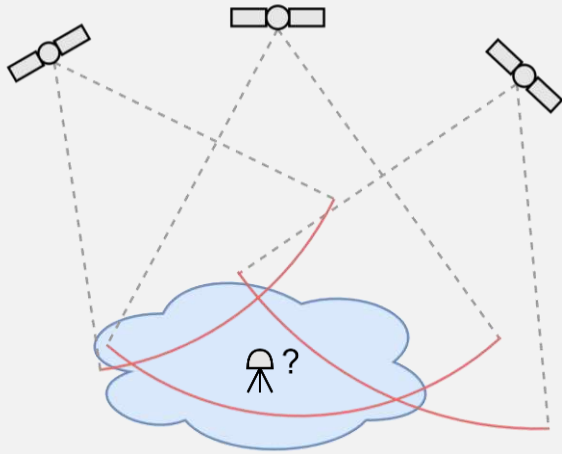


**$t = 0$**

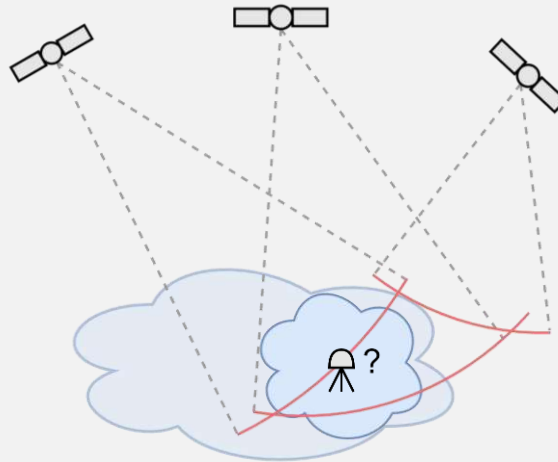
# Smoothing – An Example



# Smoothing – An Example

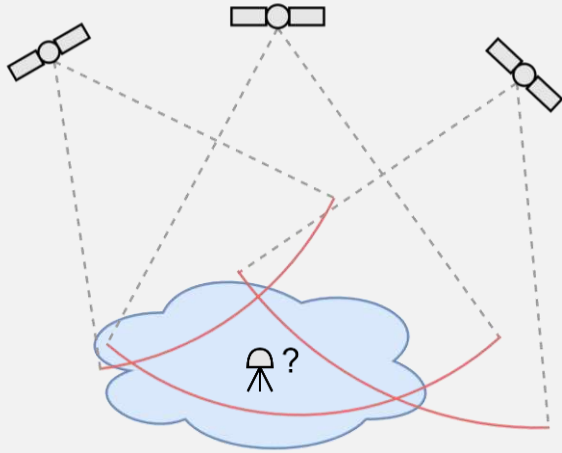


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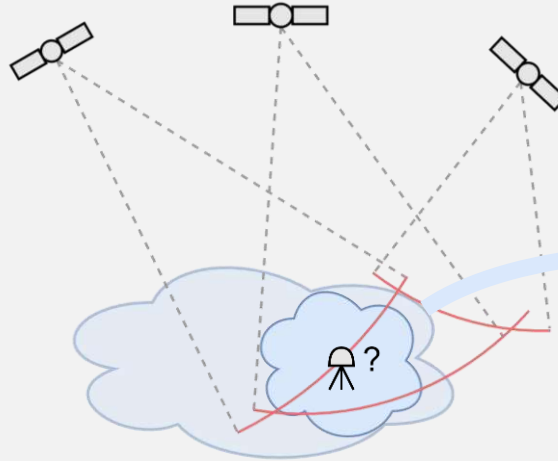


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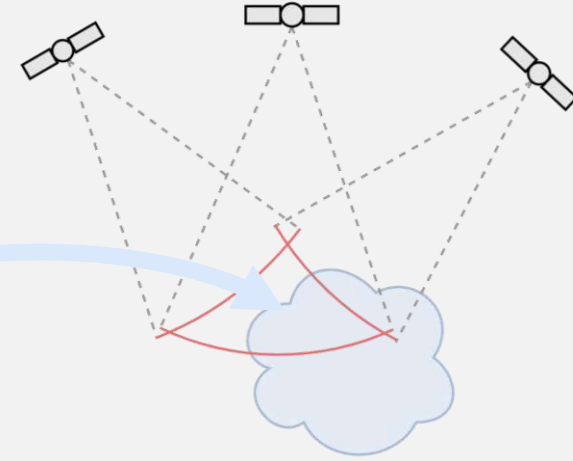
# Smoothing – An Example



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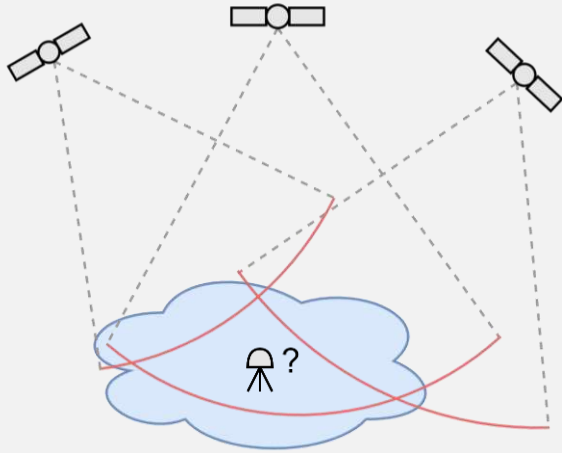


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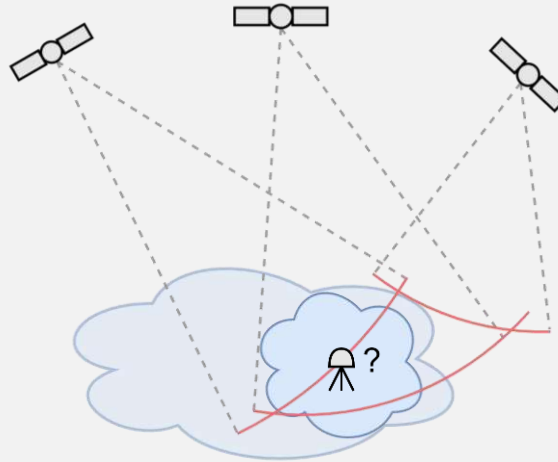


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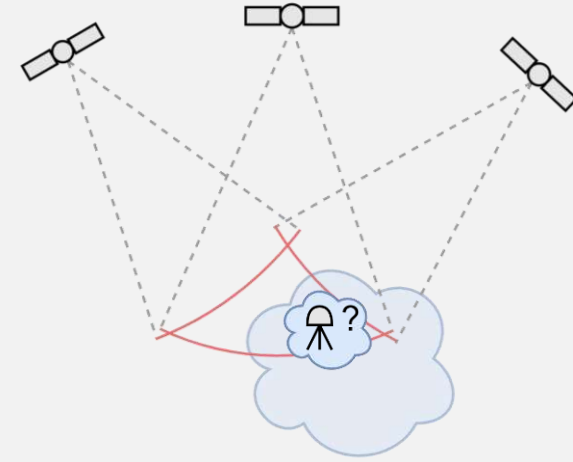
# Smoothing – An Example



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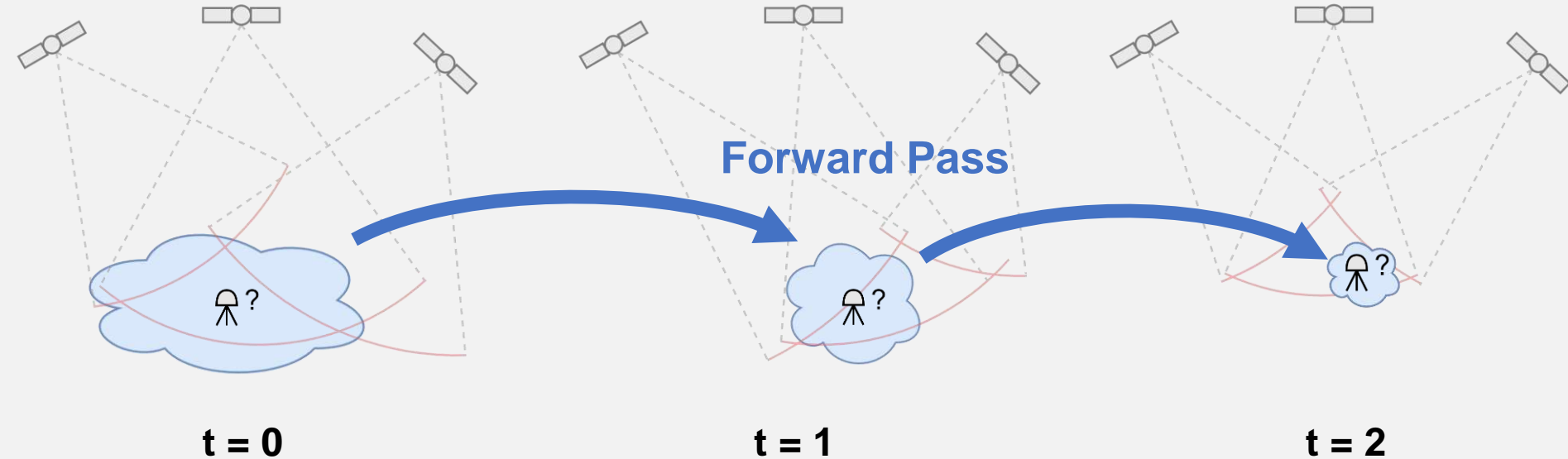


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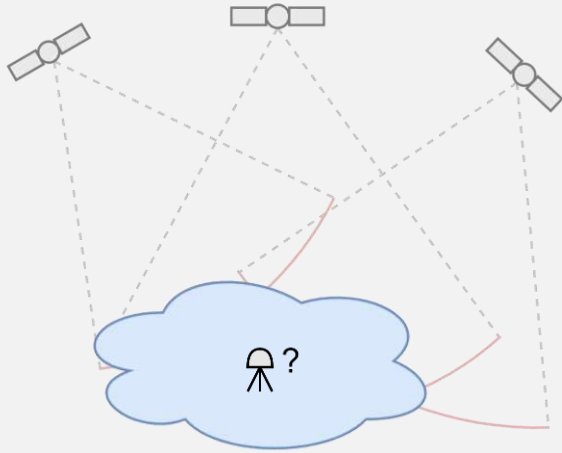


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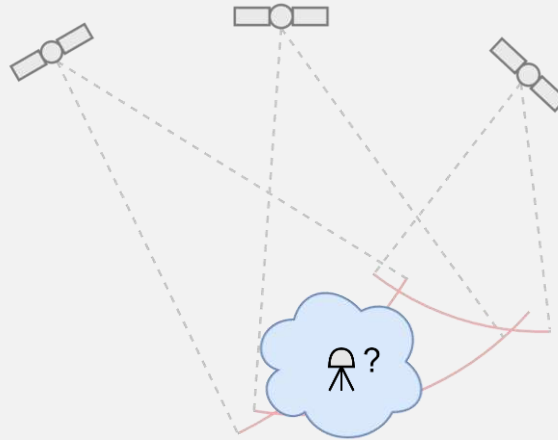
# Smoothing – An Example



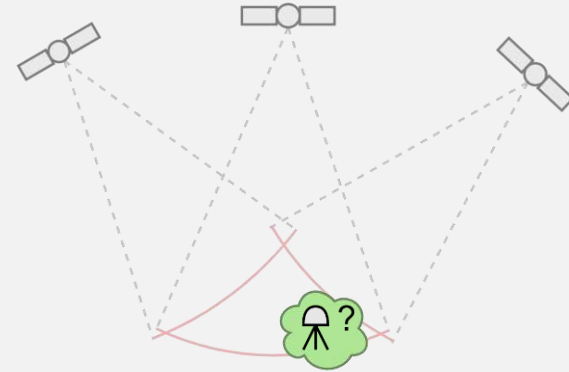
# Smoothing – An Example



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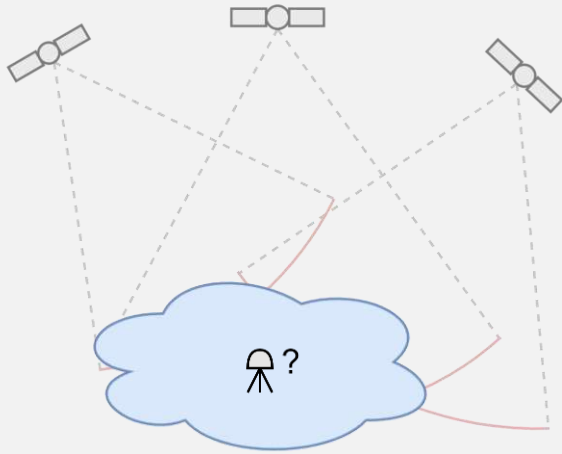


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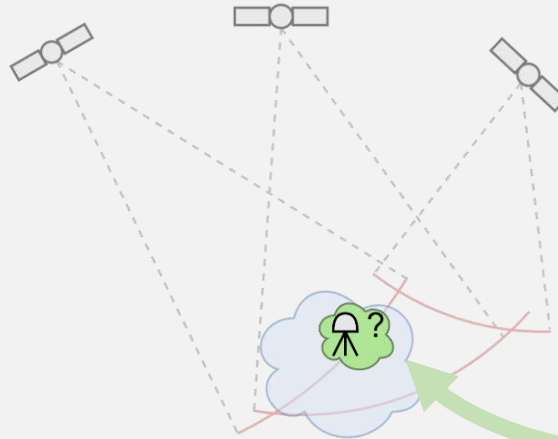


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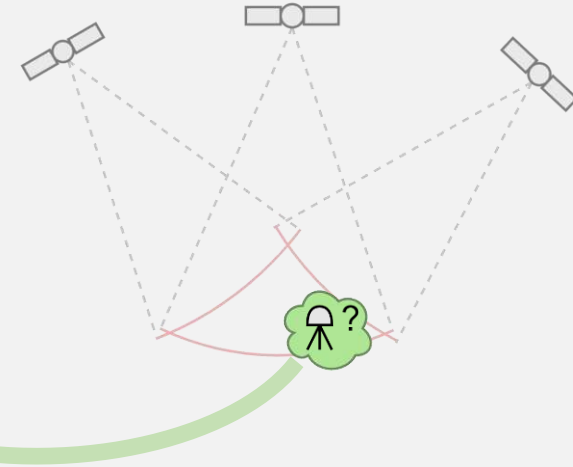
# Smoothing – An Example



$t = 0$



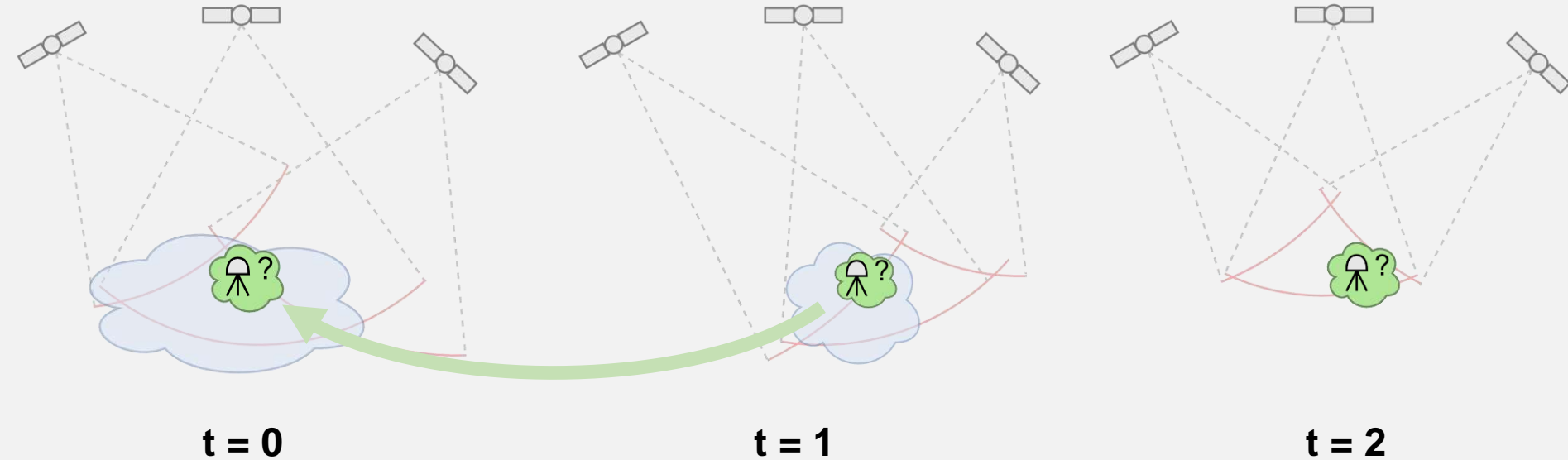
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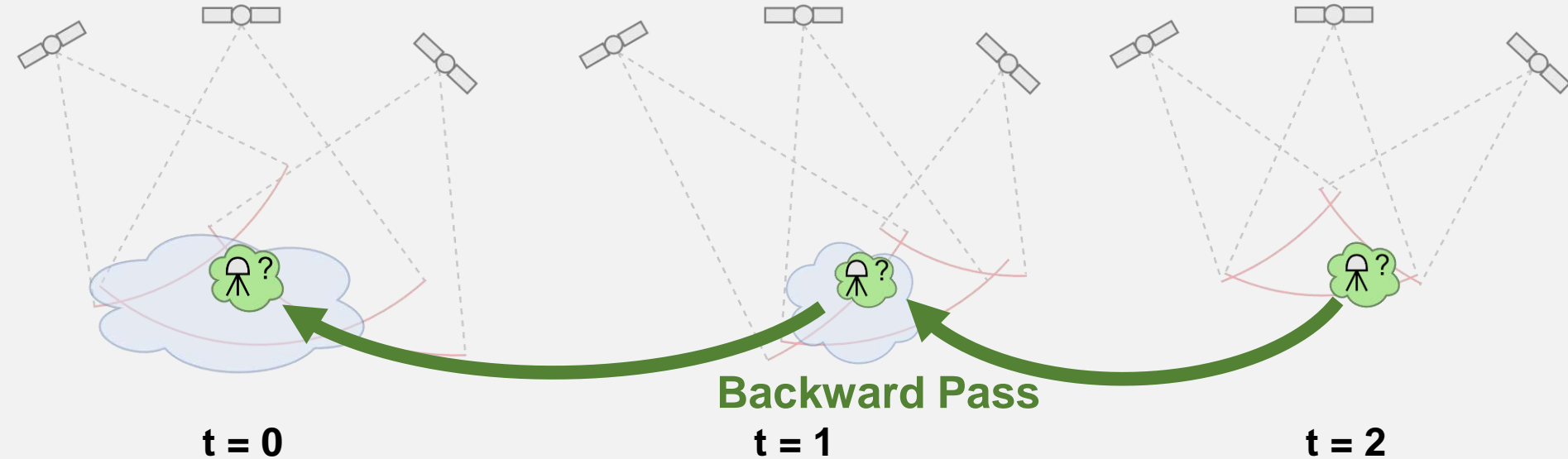
$t = 2$



# Smoothing – An Example



# Smoothing – An Example



# Smoothing – An Example

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

$t = 0$

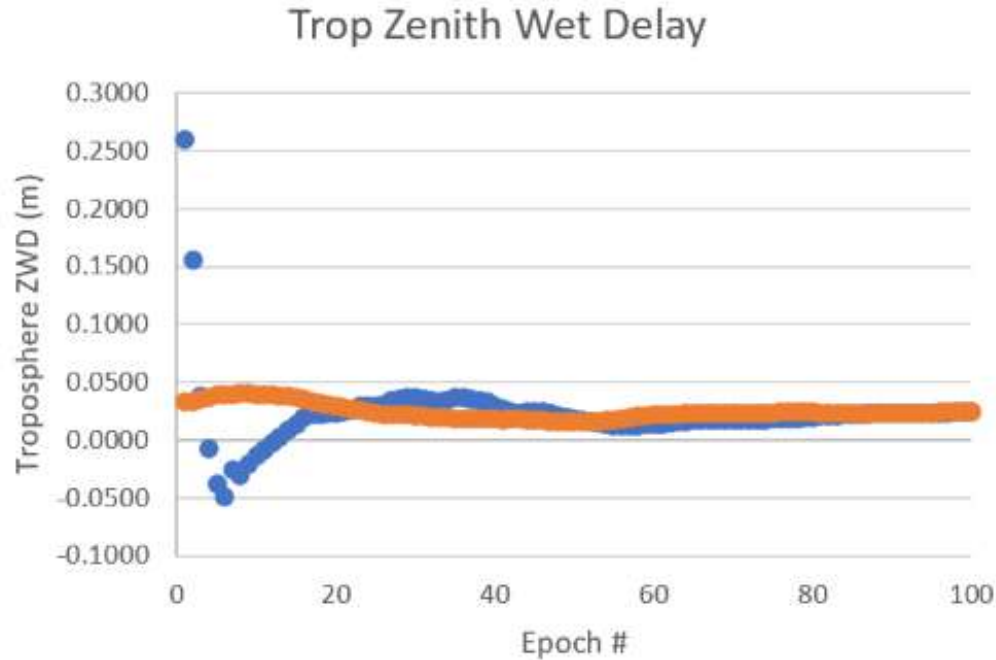
Backward Pass

$t = 1$

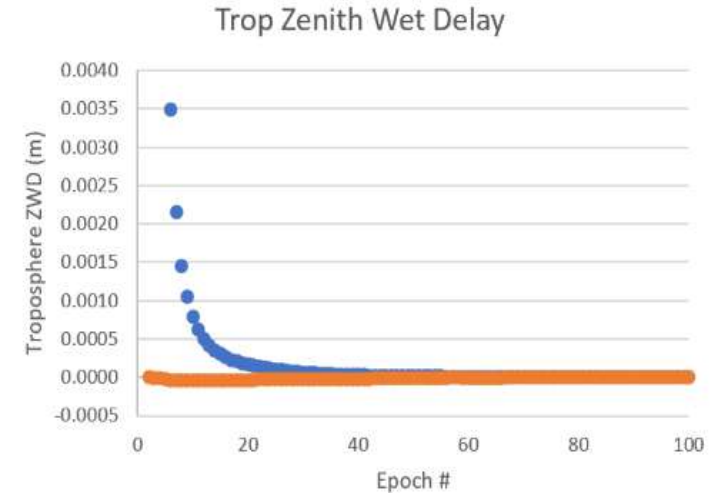
$t = 2$

# Smoothing in Ginan

Forward Pass  
Backward Pass

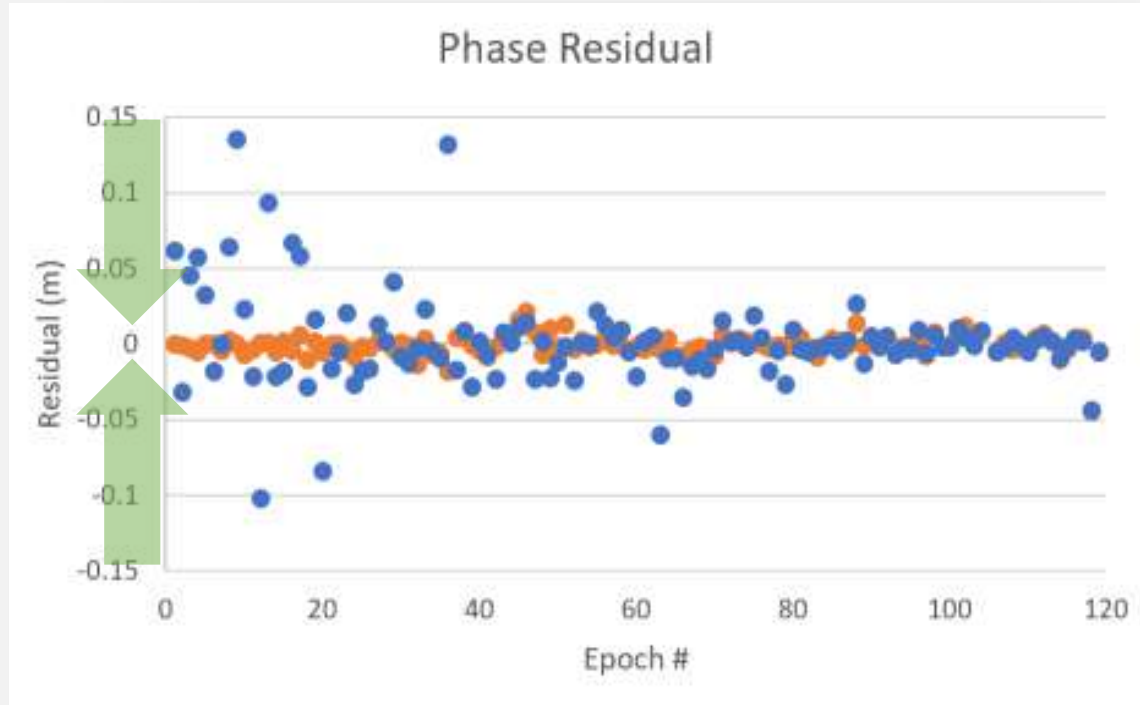


**State Estimate**



**Variance**

# Smoothing in Ginan



**Forward Pass**  
**Backward Pass**

**Observation Residuals**

# Smoothing in Ginan



**Better corrections = better positioning**

Forward Pass  
Backward Pass

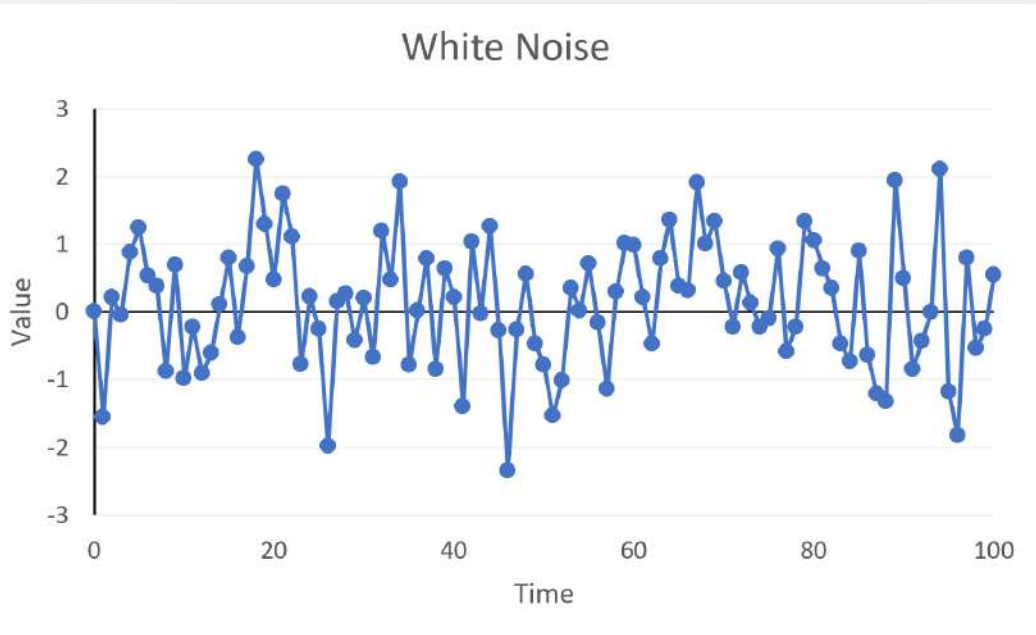
**Observation Residuals**

# 03 First-Order Gauss-Markov Modelling

Using the Right Model



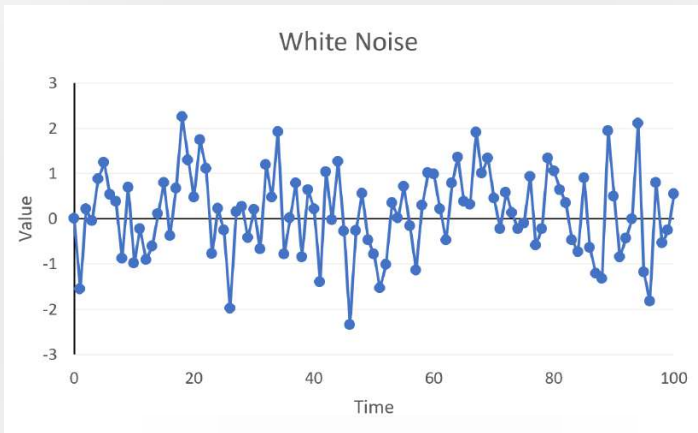
# White Noise to Random Walk



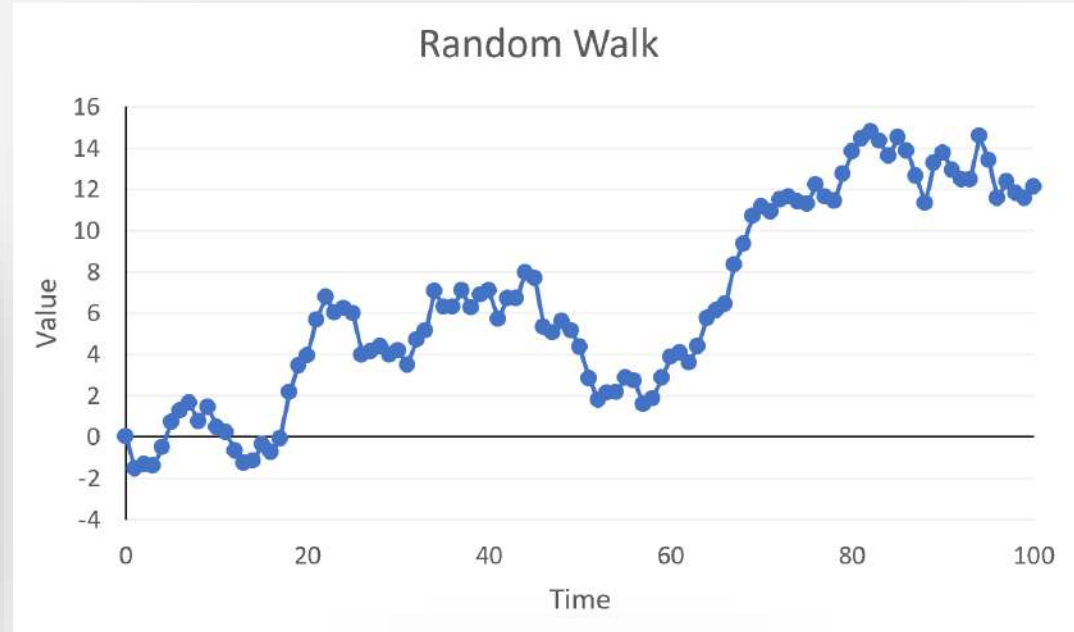
**Independent of previous  
Zero-mean**



# White Noise to Random Walk

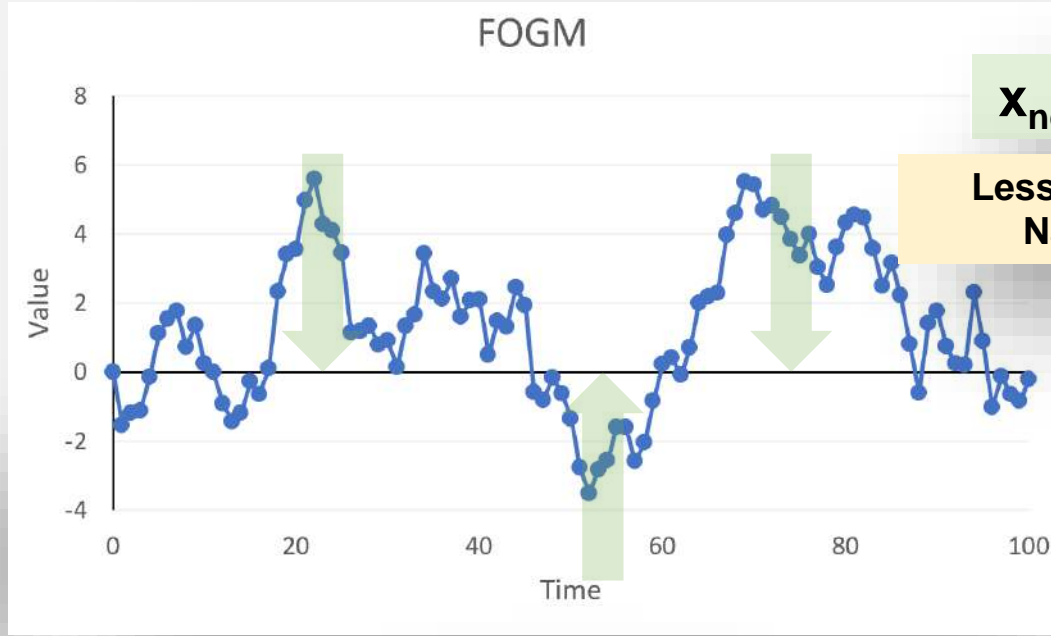
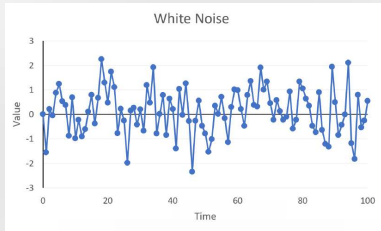


**Independent of previous**  
**Zero-mean**



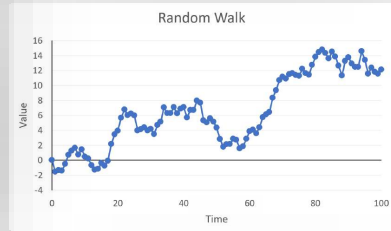
**Dependent on previous**  
**No mean**

# White Noise to Random Walk



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

Less uncertainty growth  
Naturally bounded

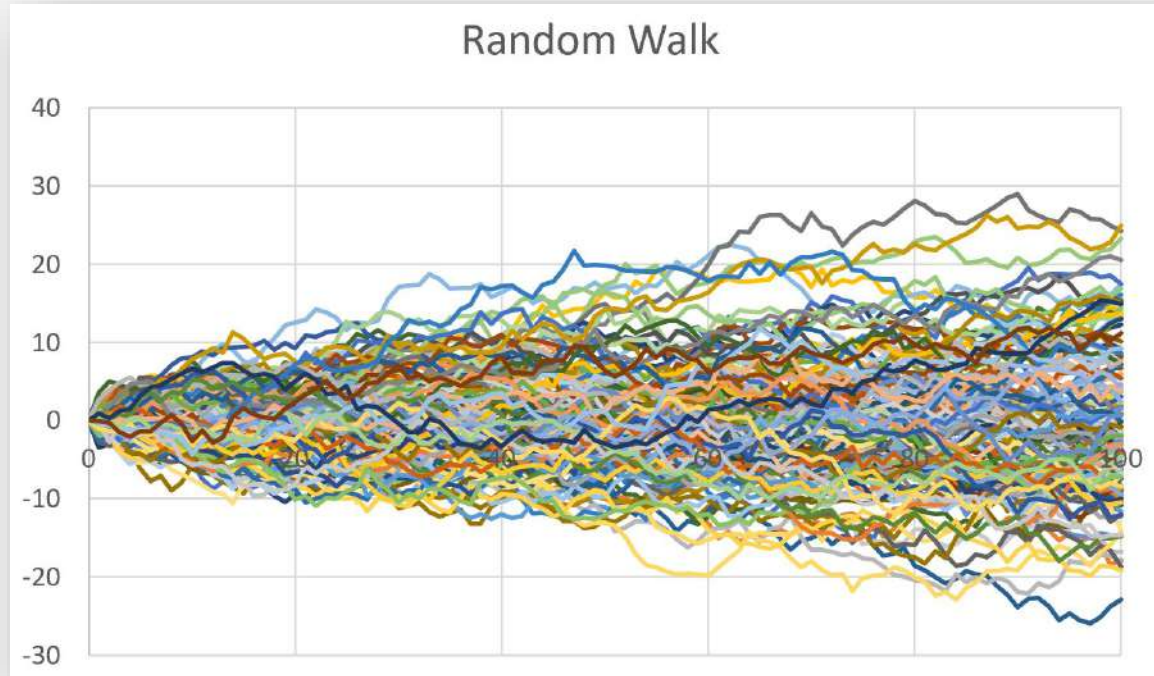


Indep. of prev.  
Zero-mean

Dependent on prev.  
Zero-mean

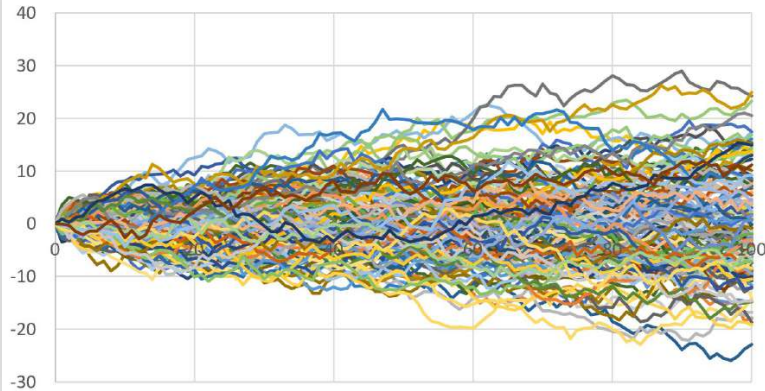
Dep. on prev.  
No mean

# White Noise to Random Walk

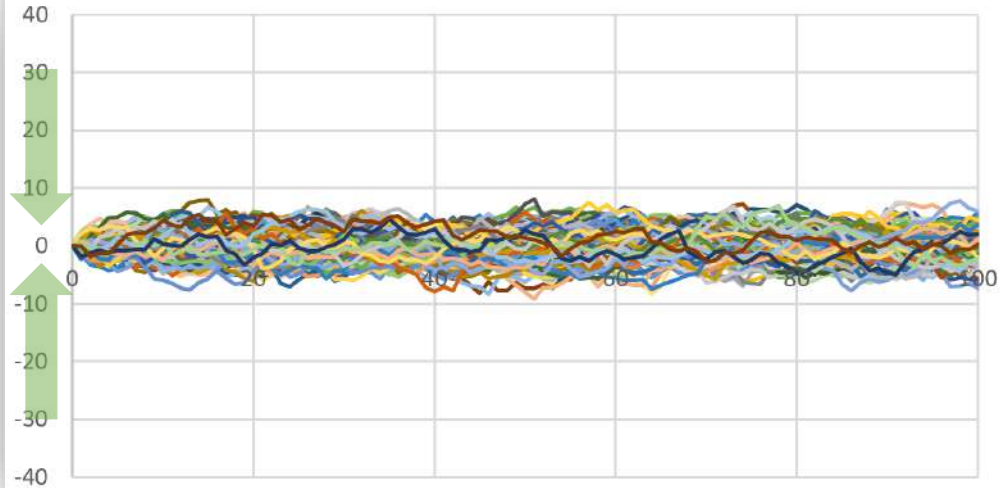


# White Noise to Random Walk

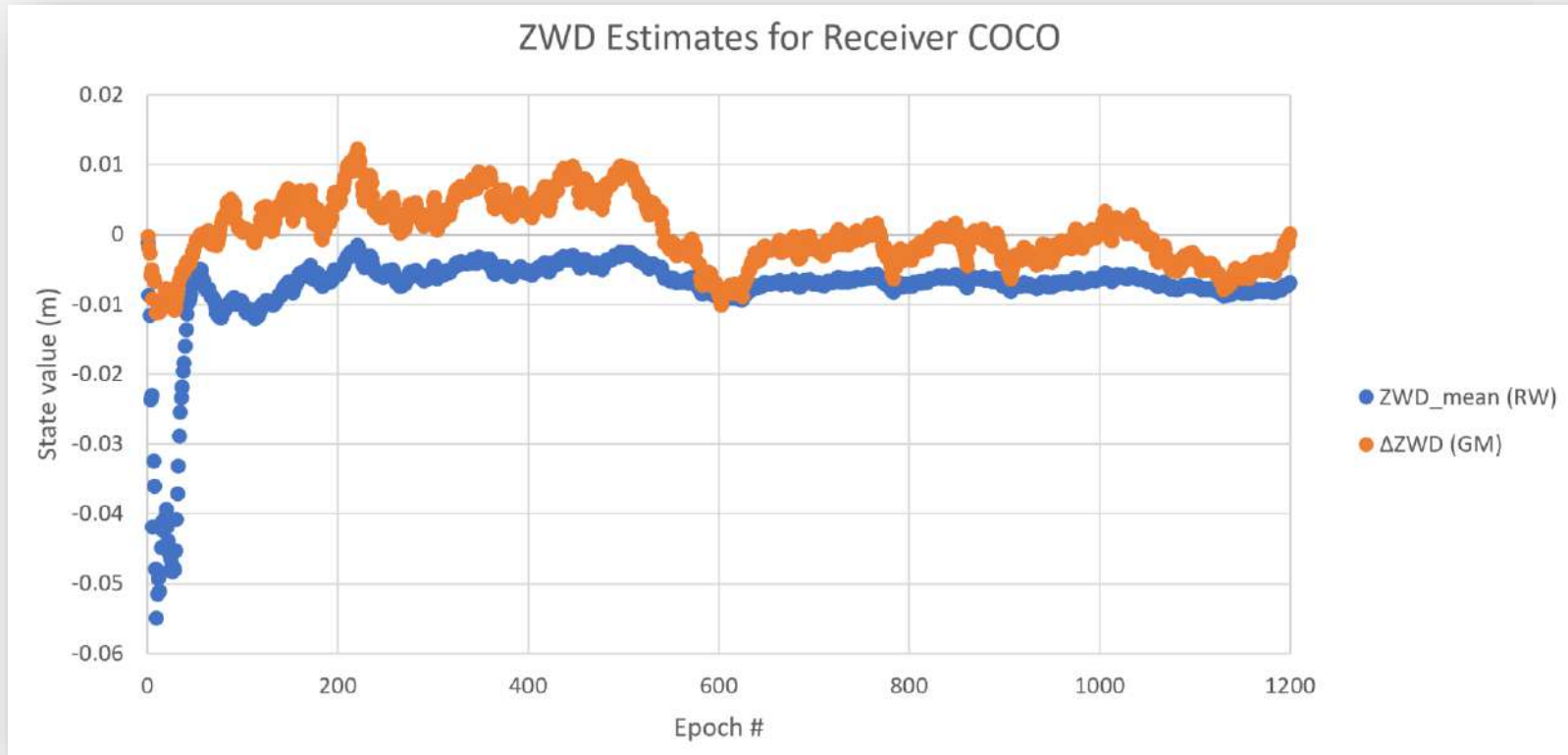
Random Walk



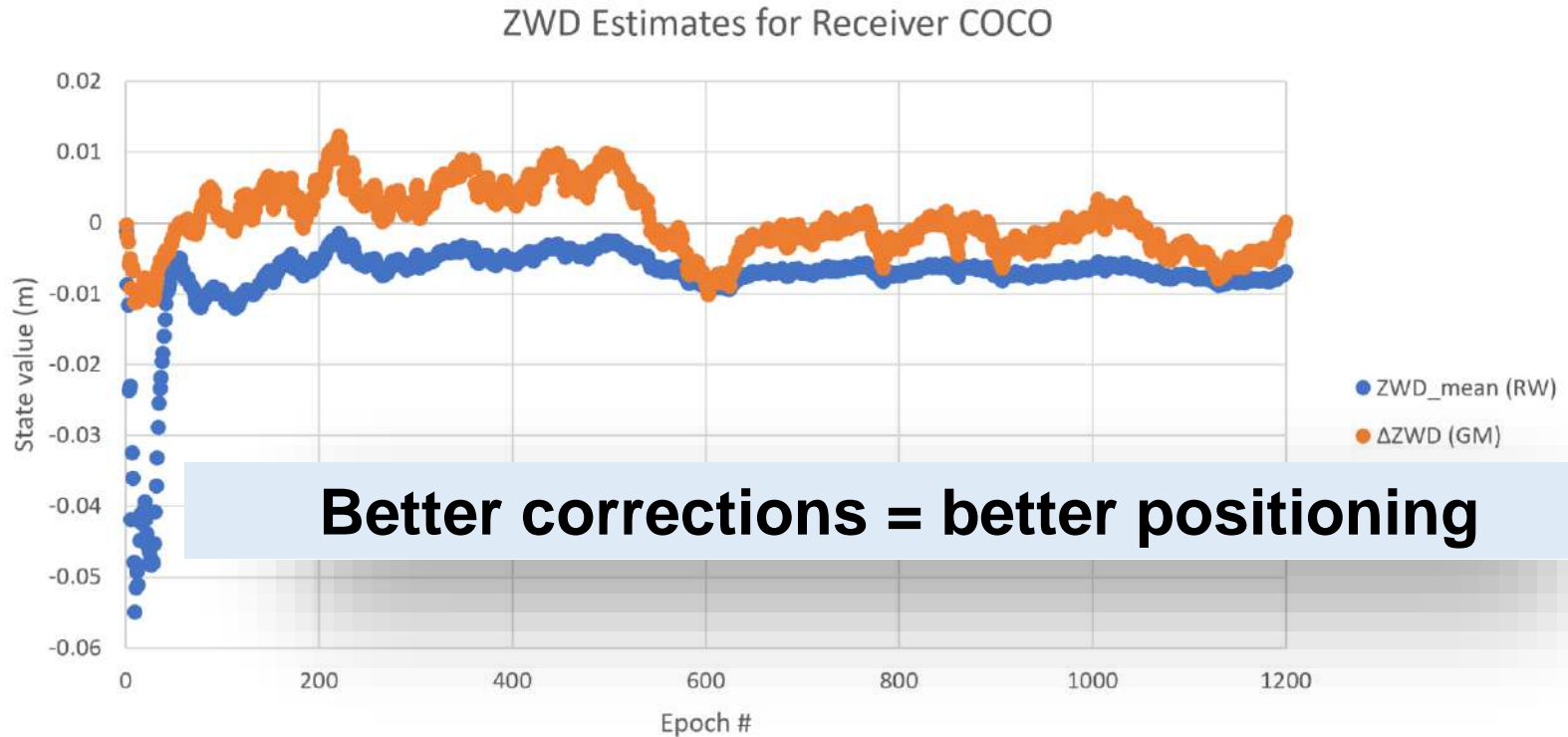
FOGM



# FOGM modelling in Ginan



# FOGM modelling in Ginan



04

# Satellite Laser Ranging

The Benefit of a Second Opinion

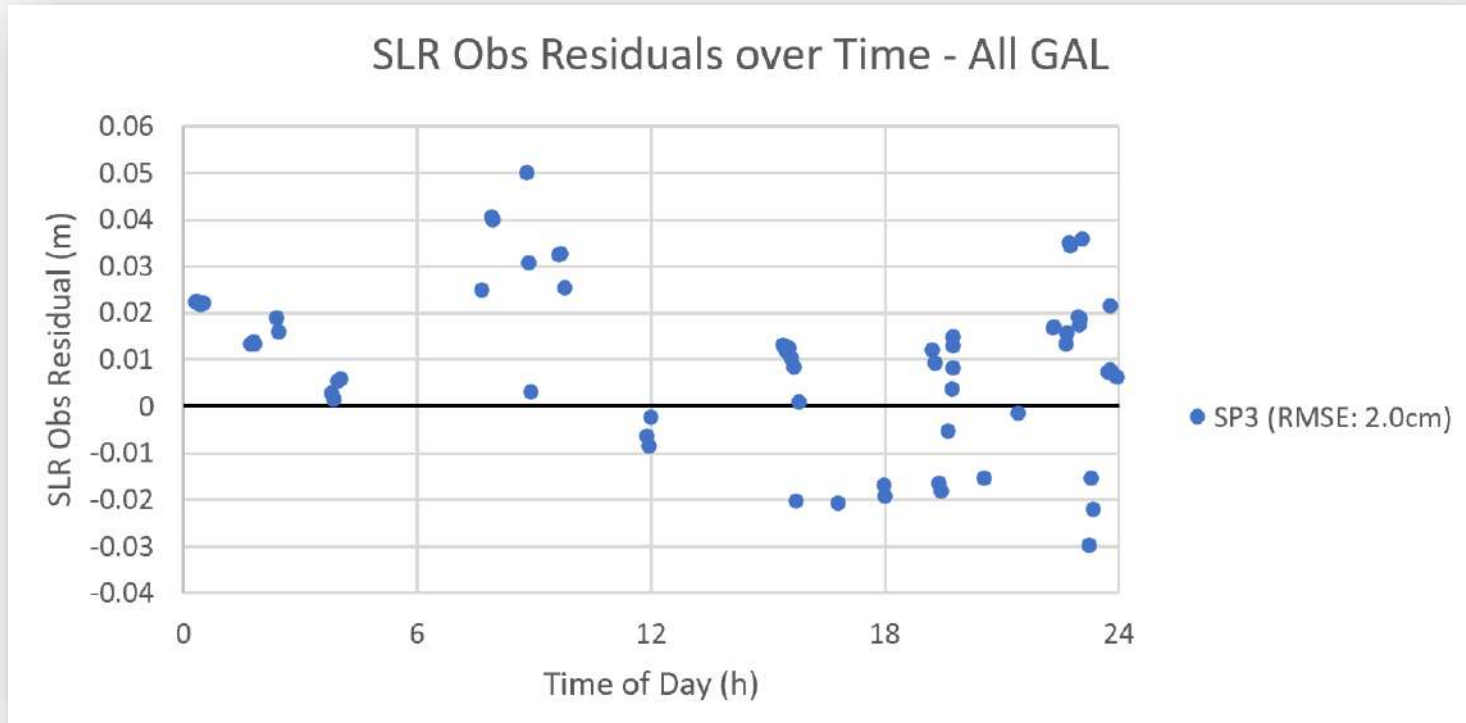


# Satellite Laser Ranging

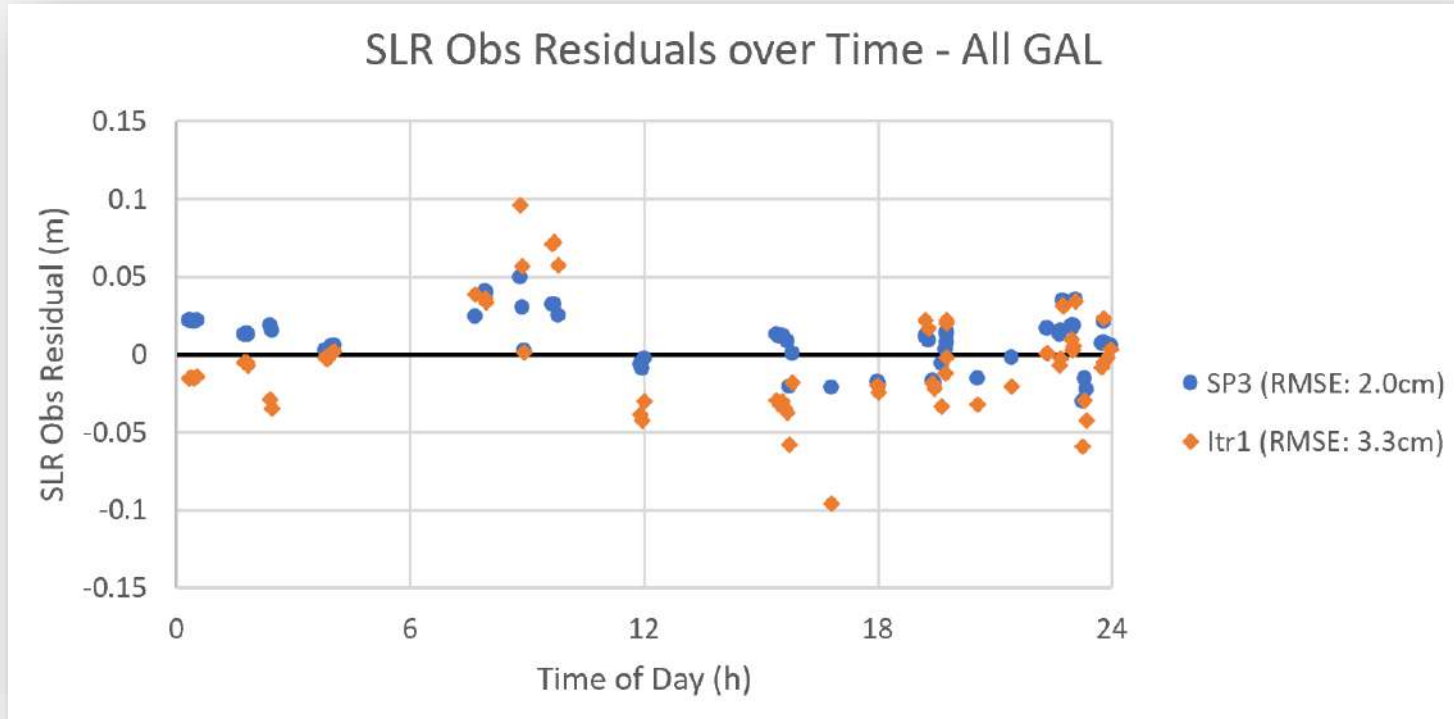
- Originally used for establishing global geodetic parameters
- Benefits for GNSS positioning:
  - No satellite clocks!
  - Data fusion – improves accuracy of GNSS products
  - External verification of GNSS orbits



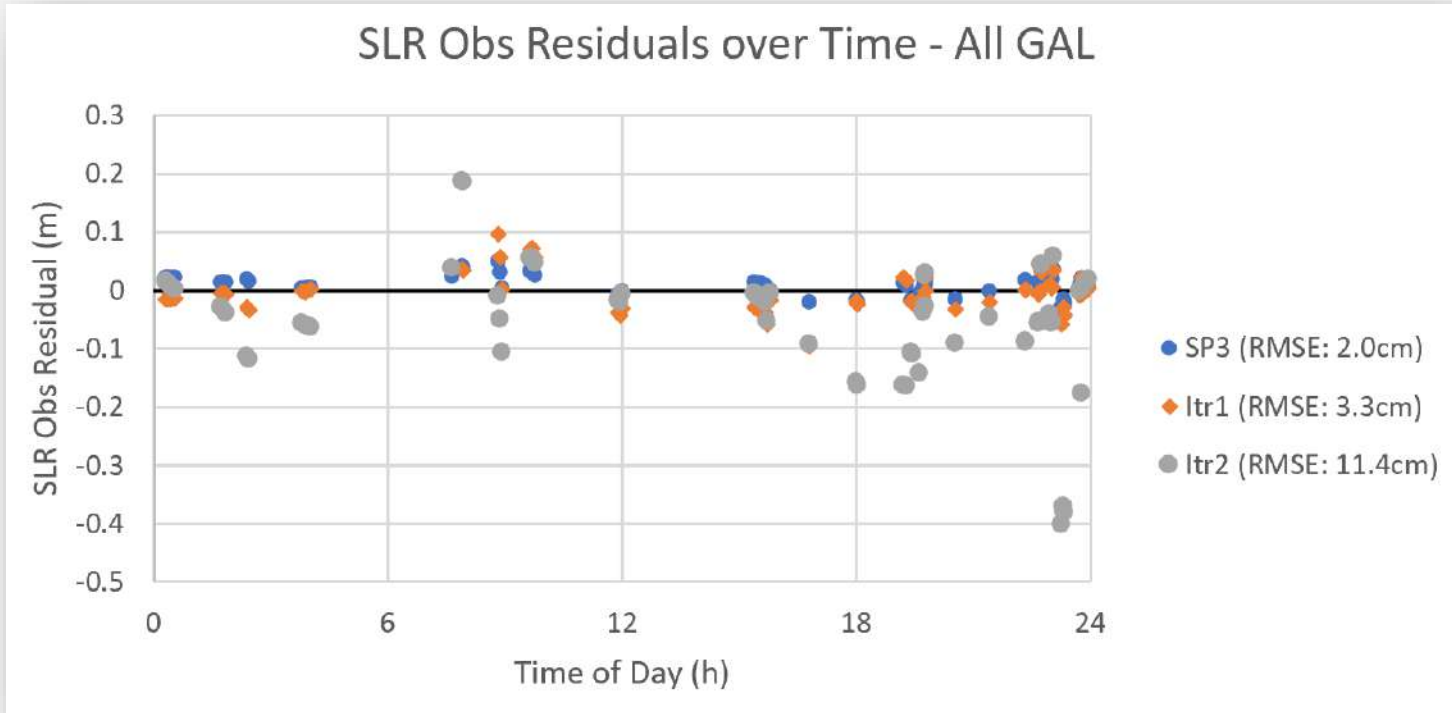
# Orbit verification using SLR



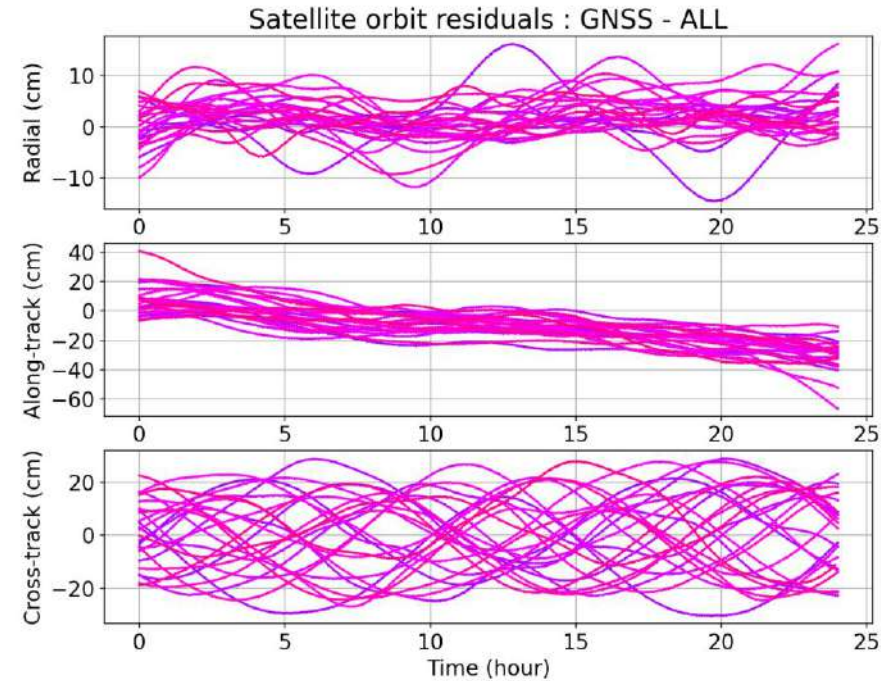
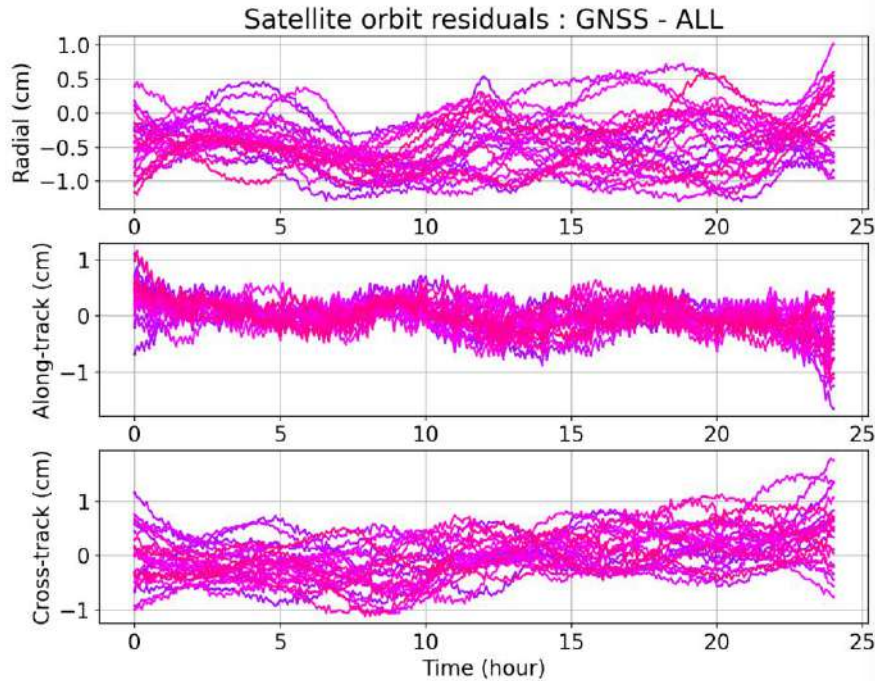
# Orbit verification using SLR



# Orbit verification using SLR



# Orbit verification using SLR



# Conclusions

**Better corrections = Better positioning**

# Conclusions

**Ginan – improves GNSS positioning via SSR corrections**

**ISG contributions improve Ginan's corrections  
→ Better corrected GPS position**

# Questions





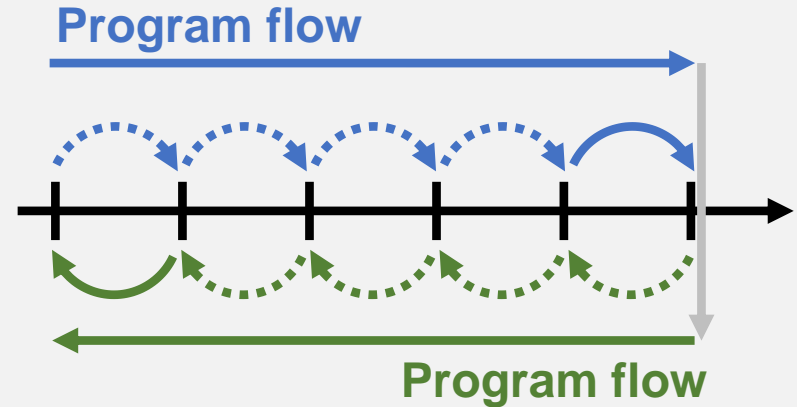


# Future work

- LEO precise orbits
- LEO positioning – using SOP & LEO PNT sats
- Troposphere modelling

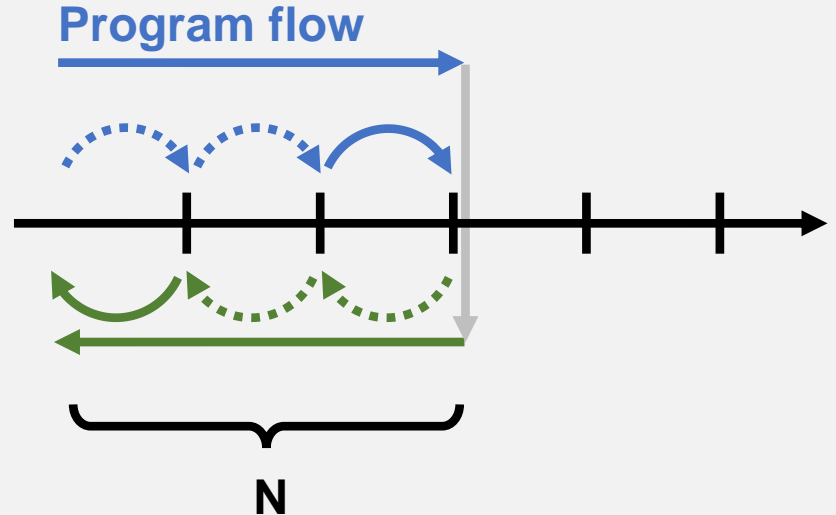
# Fixed-Interval Smoothing (RTS)

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



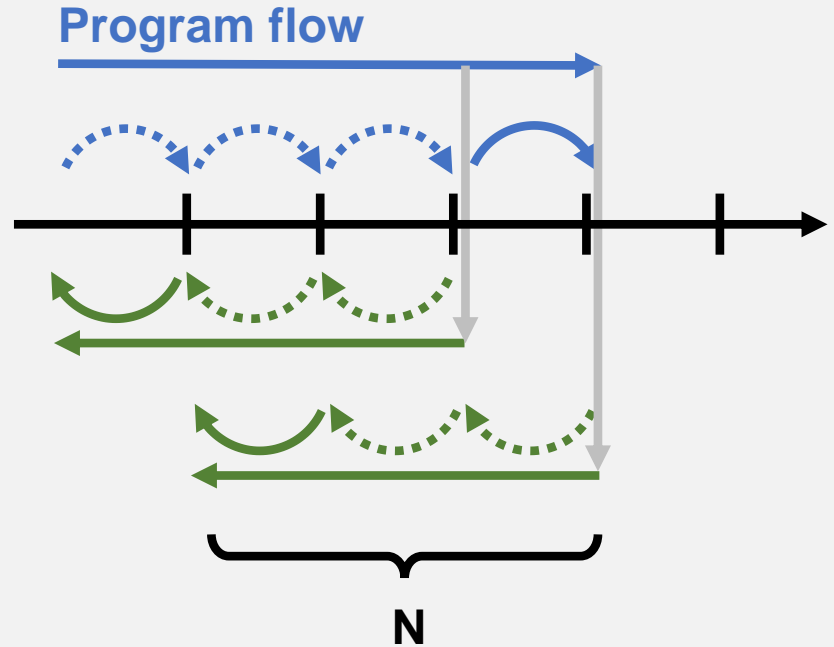
# Fixed-lag Smoothing

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



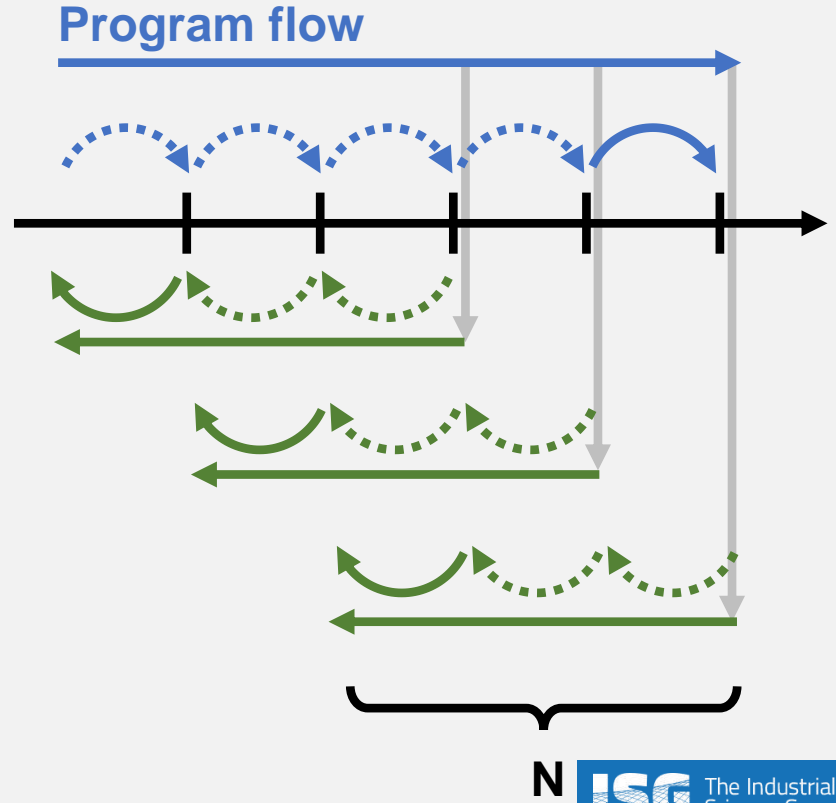
# Fixed-lag Smoothing

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



# Fixed-lag Smoothing

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



# RTS Smoothing Equations

$$\begin{aligned}\hat{\mathbf{x}}_{k|n} &= \hat{\mathbf{x}}_{k|k} + \mathbf{C}_k (\hat{\mathbf{x}}_{k+1|n} - \hat{\mathbf{x}}_{k+1|k}) \\ \mathbf{P}_{k|n} &= \mathbf{P}_{k|k} + \mathbf{C}_k (\mathbf{P}_{k+1|n} - \mathbf{P}_{k+1|k}) \mathbf{C}_k^T\end{aligned}$$

where

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

# RTS Smoothing Equations

$$\begin{aligned}\hat{\mathbf{x}}_{k|n} &= \hat{\mathbf{x}}_{k|k} + \mathbf{C}_k (\hat{\mathbf{x}}_{k+1|n} - \hat{\mathbf{x}}_{k+1|k}) \\ \mathbf{P}_{k|n} &= \mathbf{P}_{k|k} + \mathbf{C}_k (\mathbf{P}_{k+1|n} - \mathbf{P}_{k+1|k}) \mathbf{C}_k^T\end{aligned}$$

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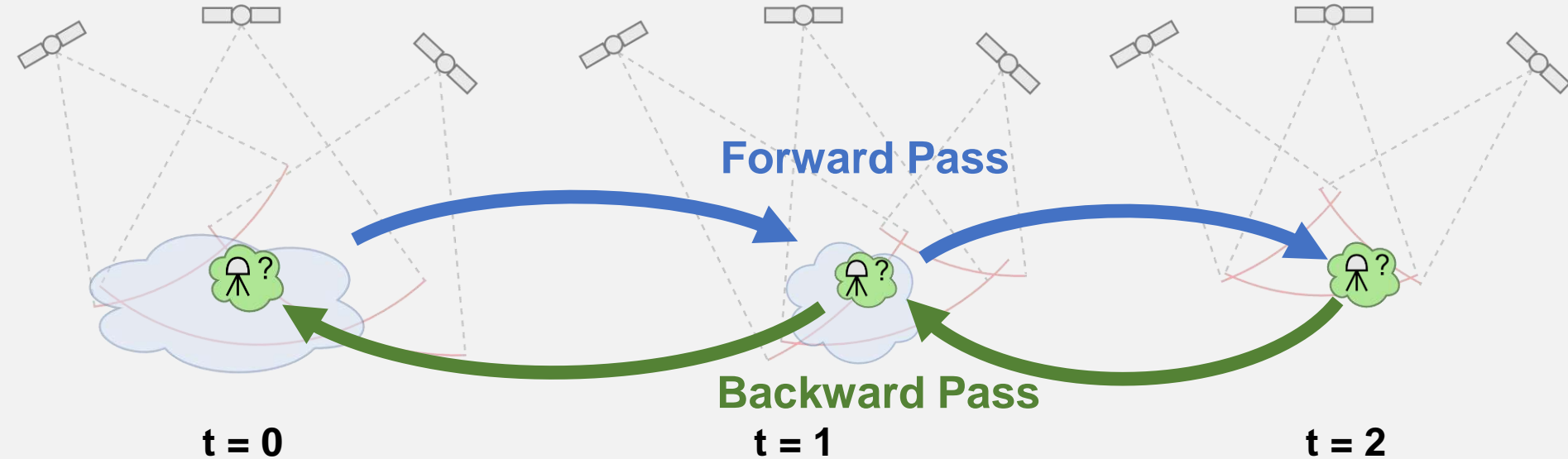
$$\mathbf{C}_k = \mathbf{P}_{k|k} \mathbf{F}_{k+1}^T \mathbf{P}_{k+1|k}^{-1}$$

More process noise =

- Larger  $\mathbf{P}_{k+1|k}$
- Smaller  $\mathbf{P}_{k+1|k}^{-1}$
- Smaller  $\mathbf{C}_k$
- Smaller impact of future states

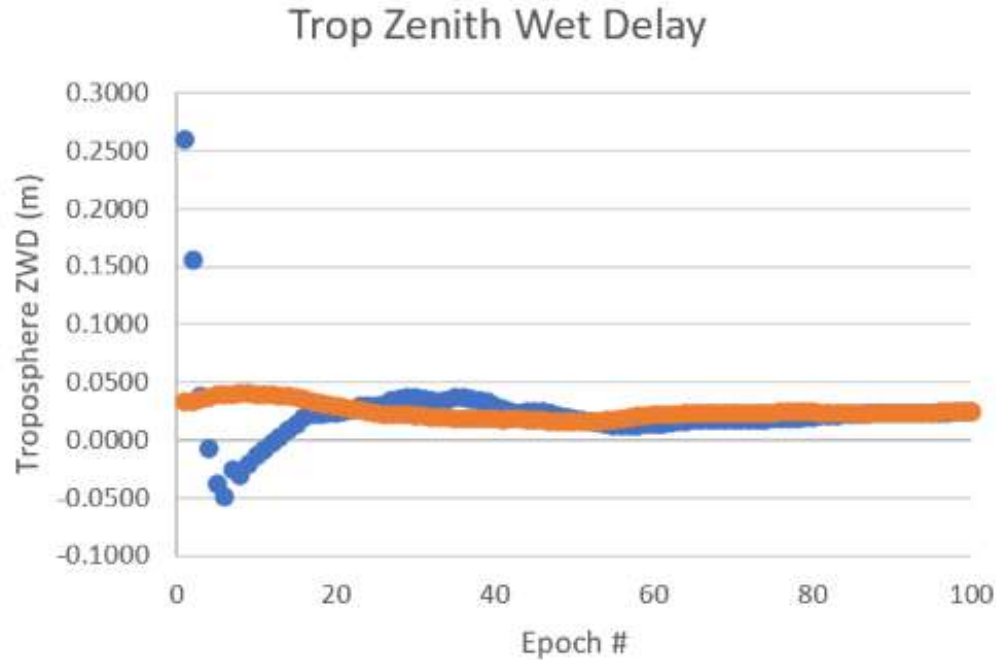


# Smoothing – An Example

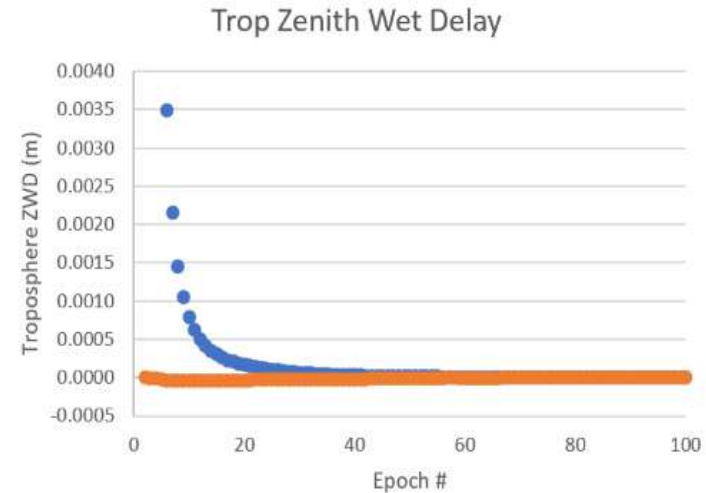


# Smoothing in Ginan

Forward Pass  
Backward Pass



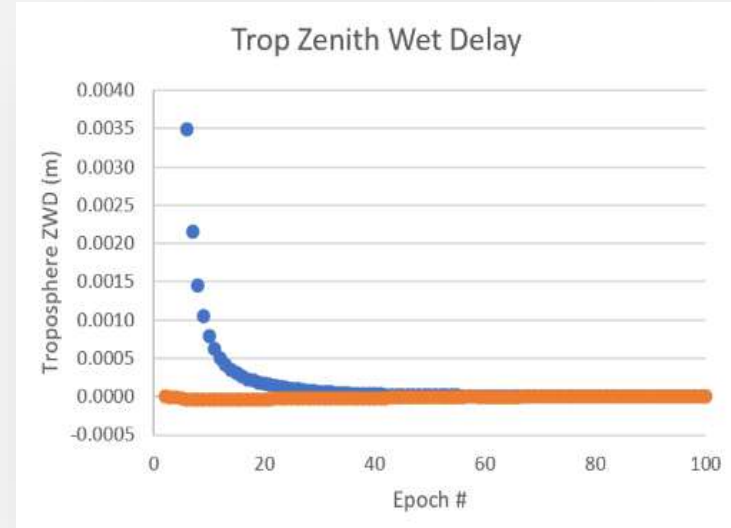
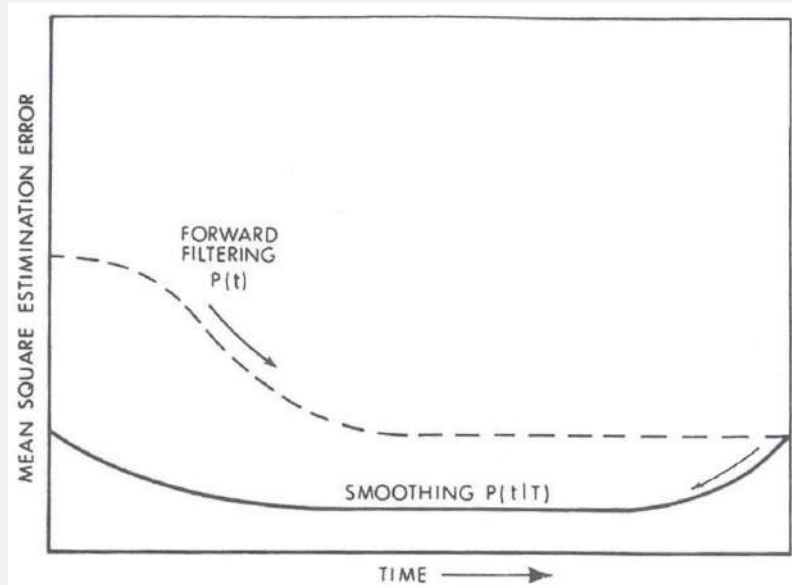
**State Estimate**



**Variance**

# Smoothing in GINAN

Forward Pass  
Backward Pass



Variance