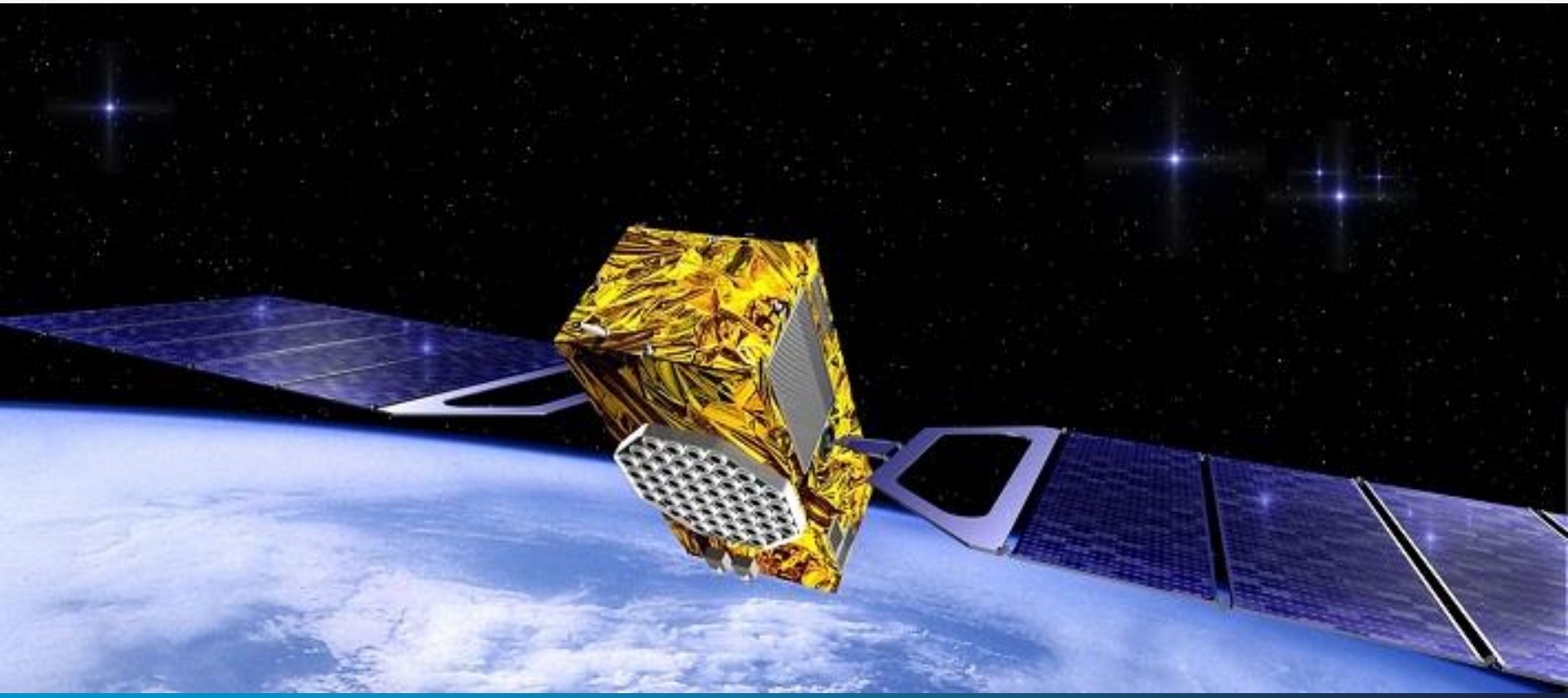
GNSS orbit monitoring with Where

Kartverket

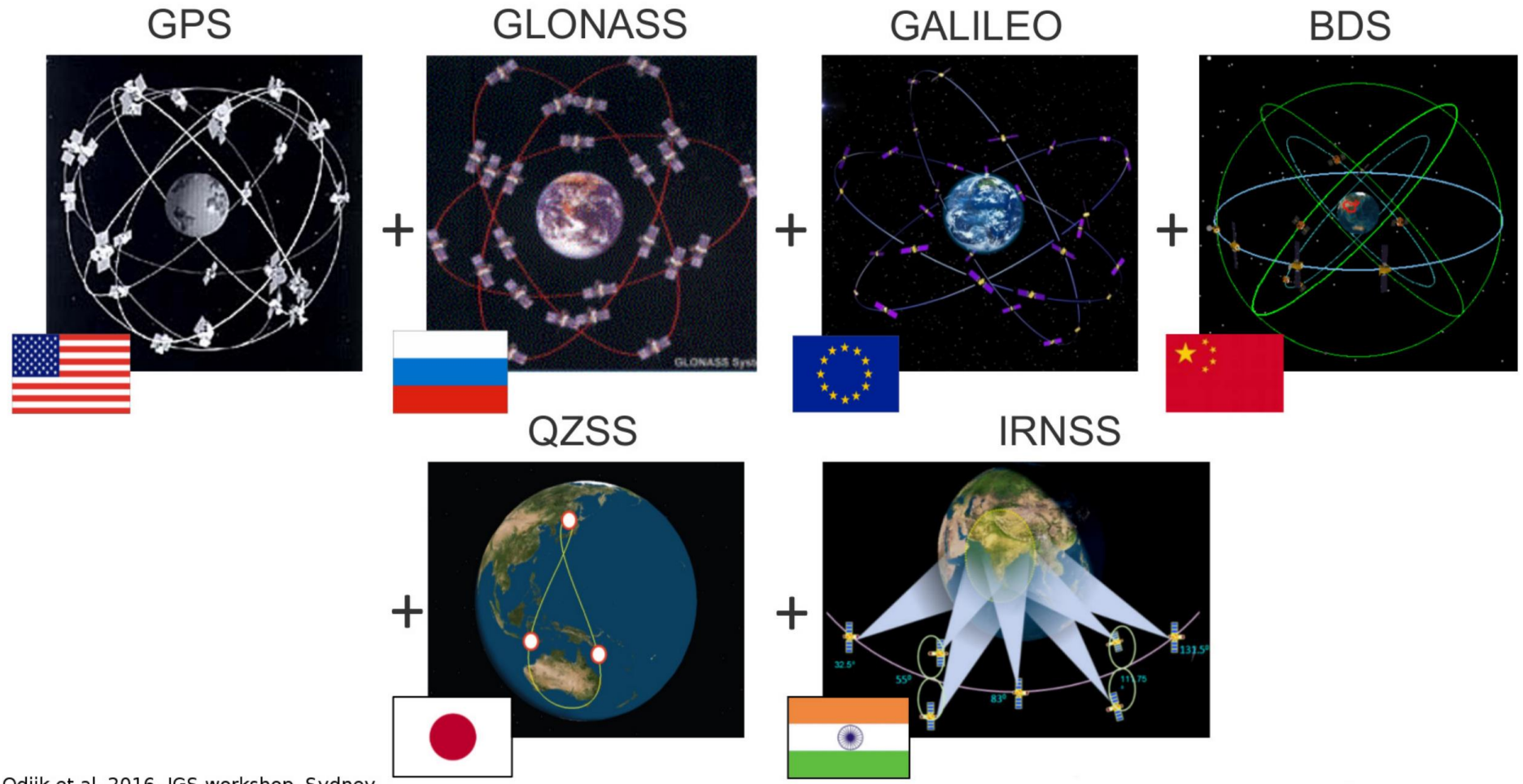
M. Dähnn, G. A. Hjelle, A.-S. Kirkvik, I. Fausk, M. Ouassou, A. M. Solberg

Where workshop, Oslo, 6. November 2018

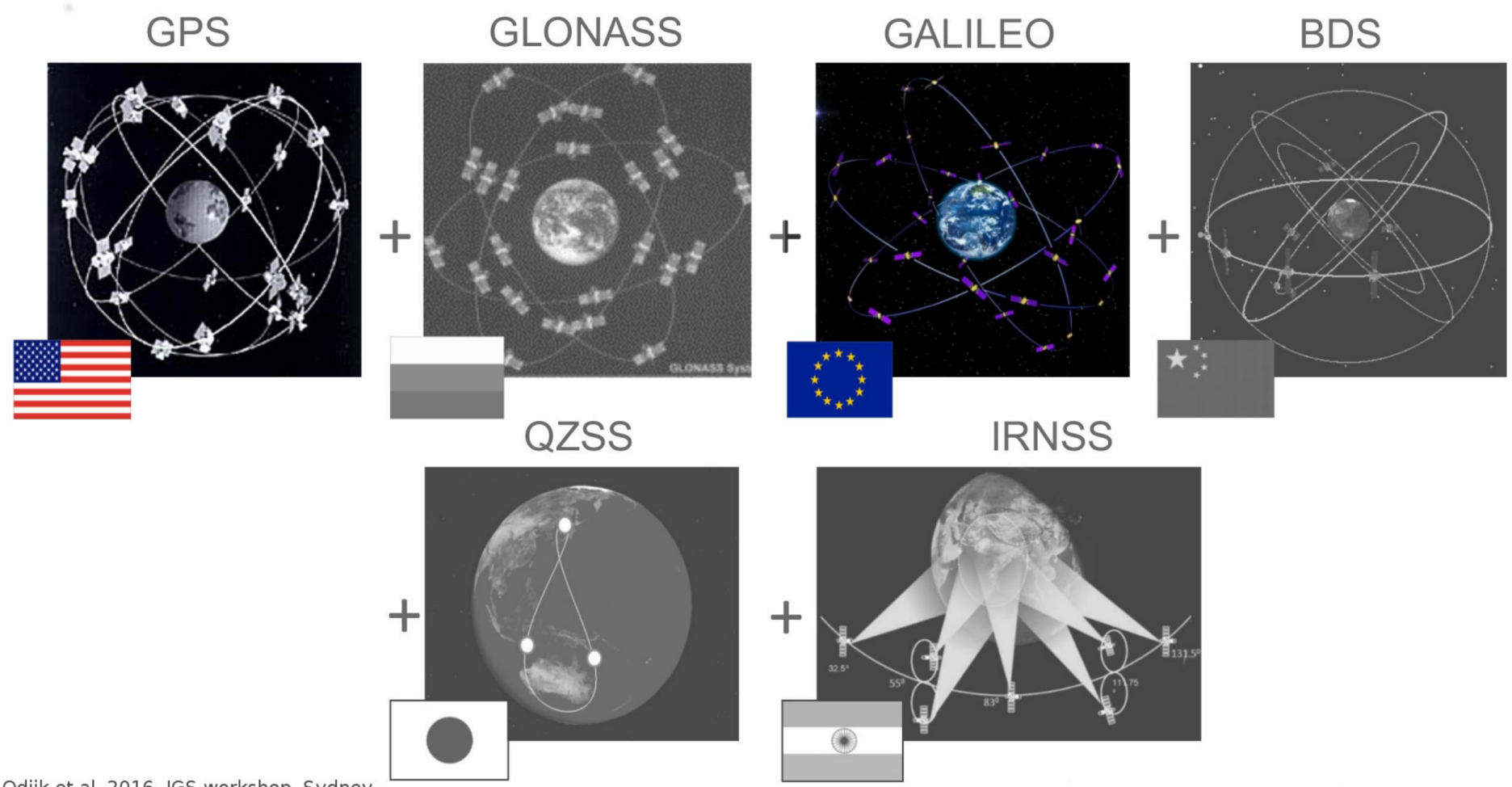


Part I

Background



Odijk et al. 2016, IGS workshop, Sydney



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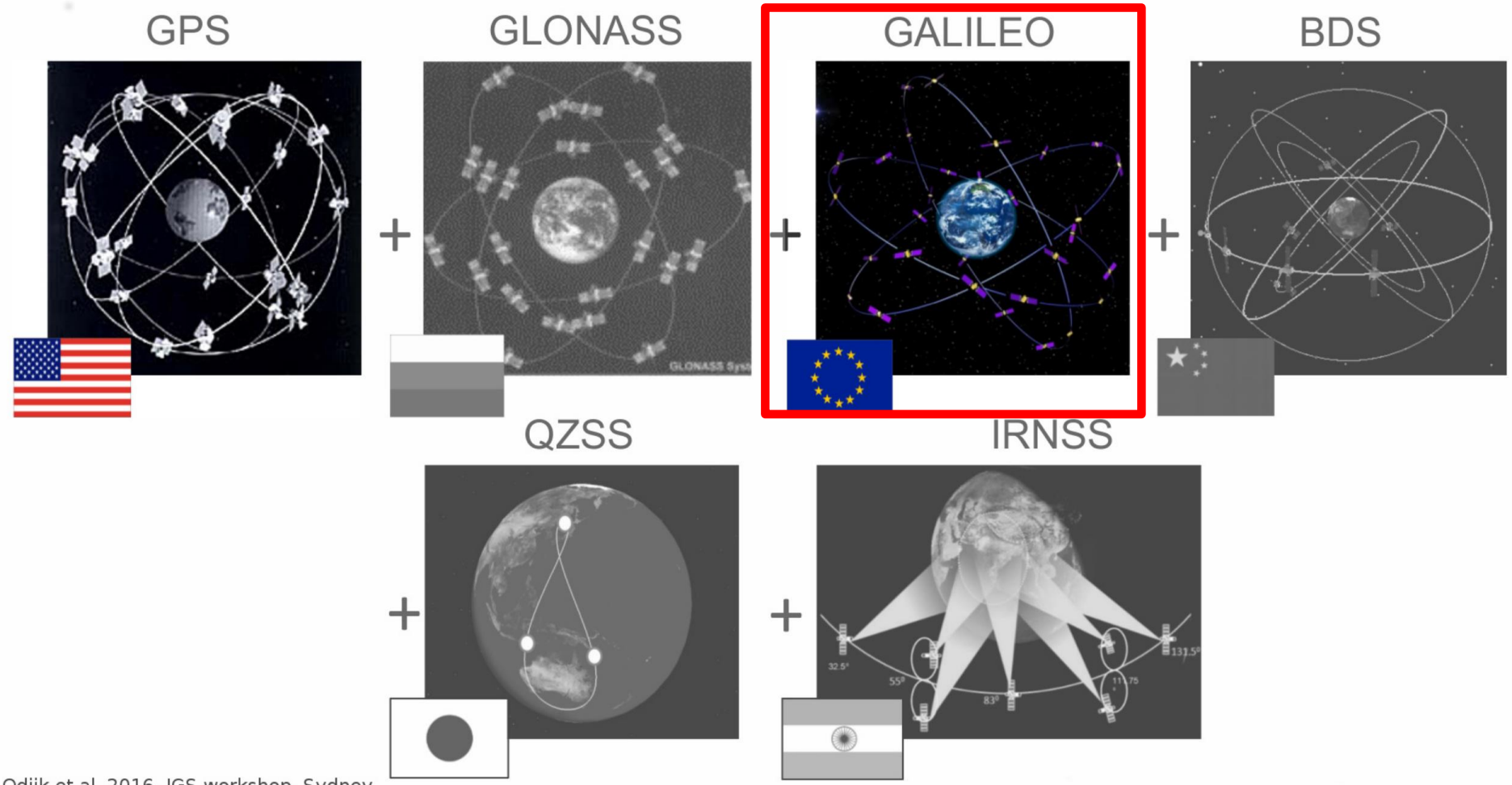


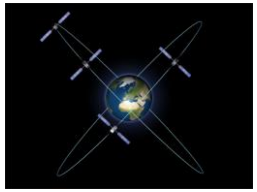
Odijk et al. 2016, IGS workshop, Sydney

Galileo deployment

Development
GIOVE A & B

2005/2008

In-Orbit Validation



2011-2013

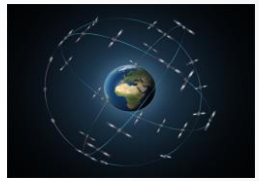
Initial Services

2016

Exploitation Phase

2017

Full Operational Capability



2020

Kartverket

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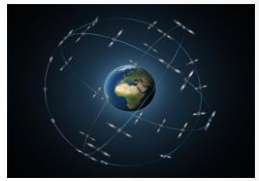

2020

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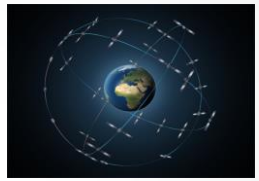

2020

Kartverket

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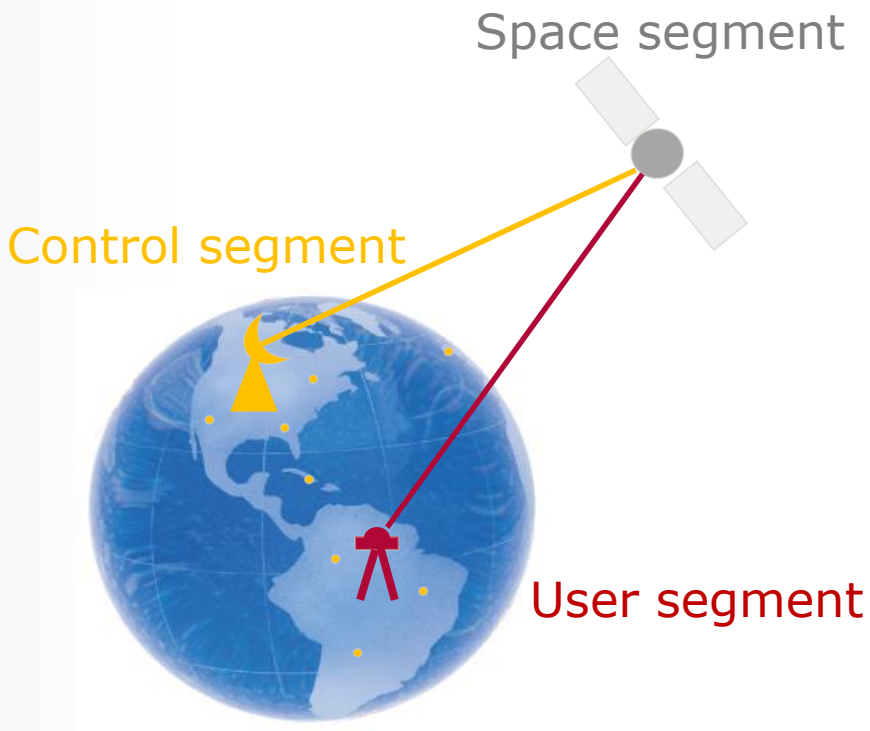
Kartverket

Motivation – Galileo performance monitoring



- testing and verifying the initial services
- detecting anomalies (satellite faults)
- ensure the provision of high quality satellite data to users
- signal-in-space range error is a key performance indicator used from all GNSS

Part II

What is signal-in-space range error (SISRE)?

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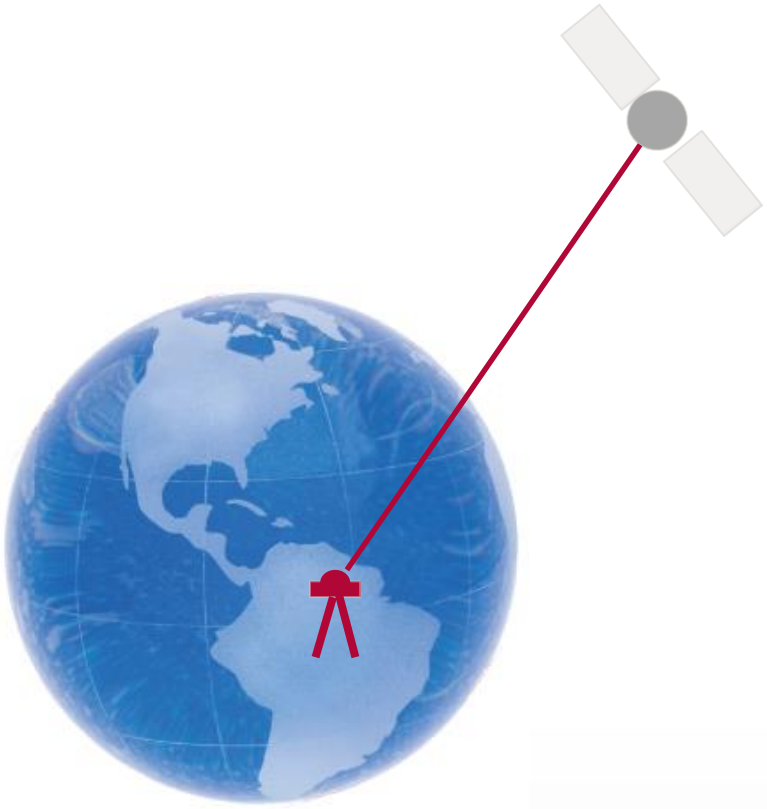
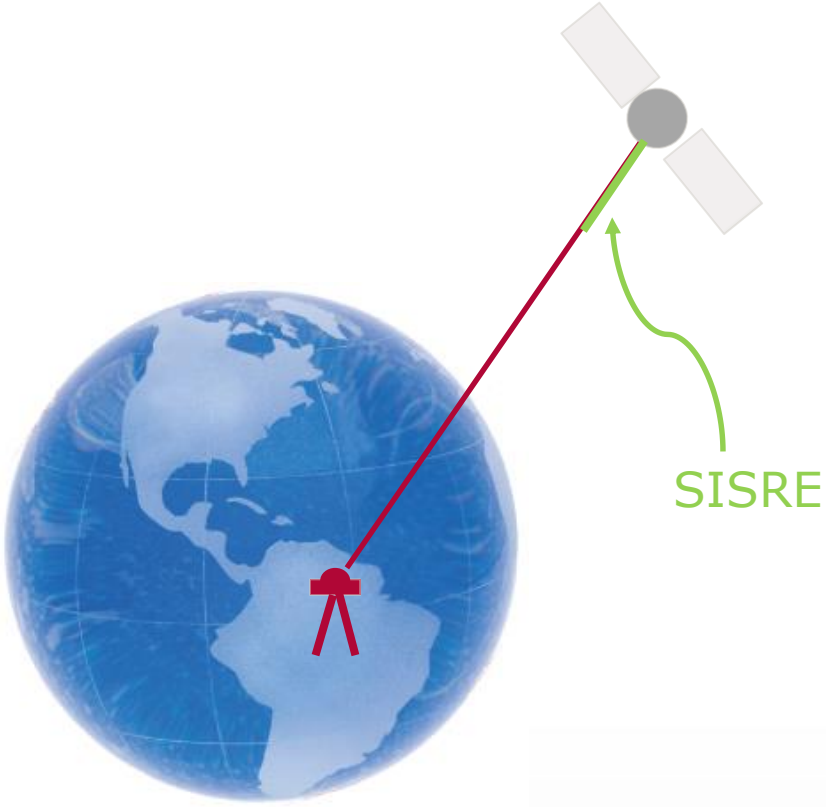


Kartverket

What is signal-in-space range error (SISRE)?

SISRE: Statistical uncertainty of the modeled pseudorange related to errors in the broadcast orbit and clock information.



Kartverket

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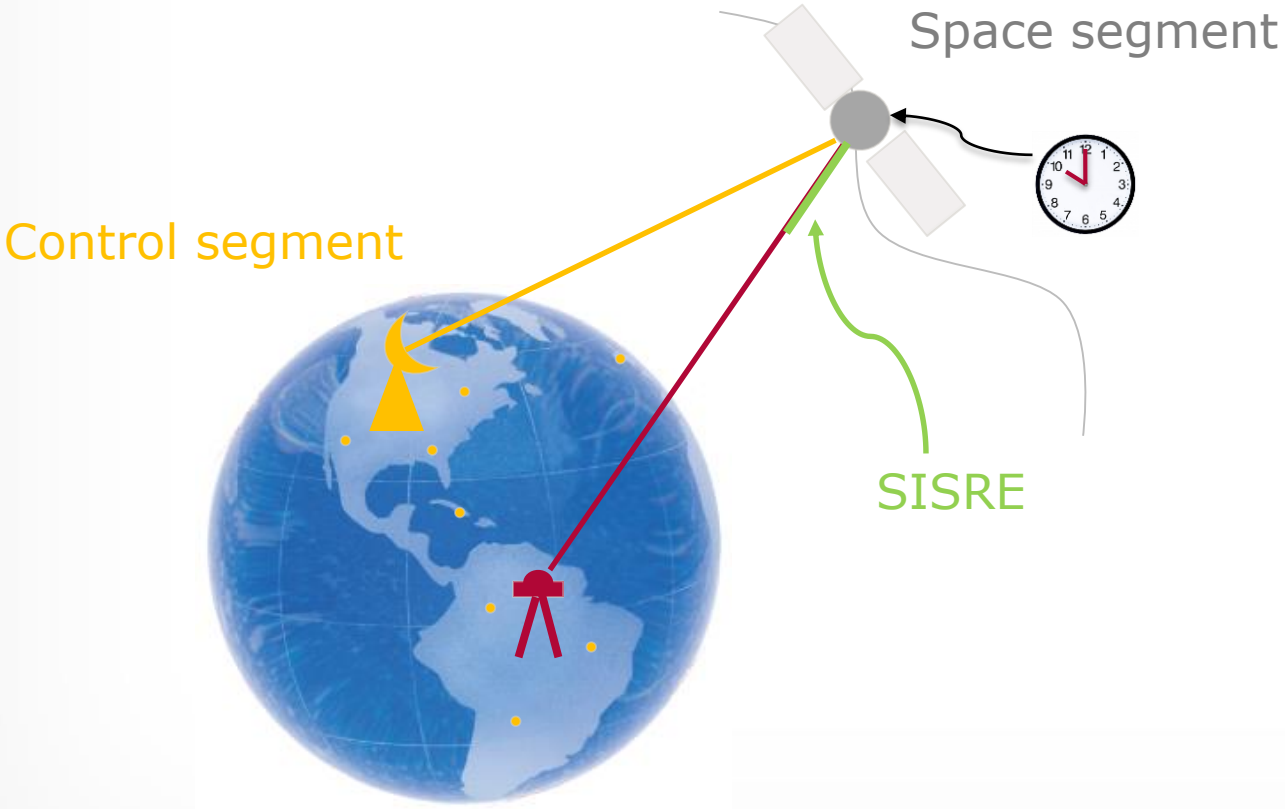

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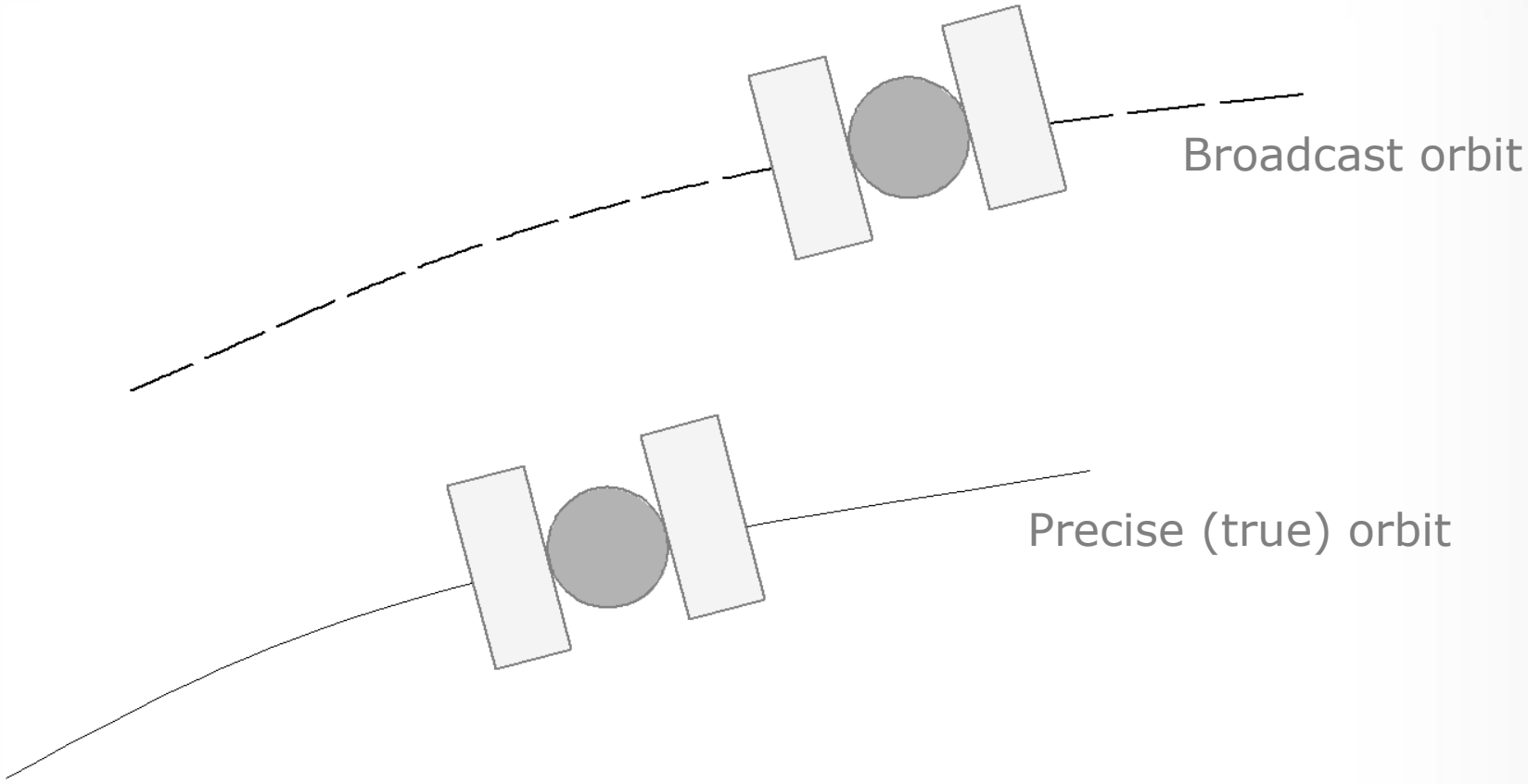
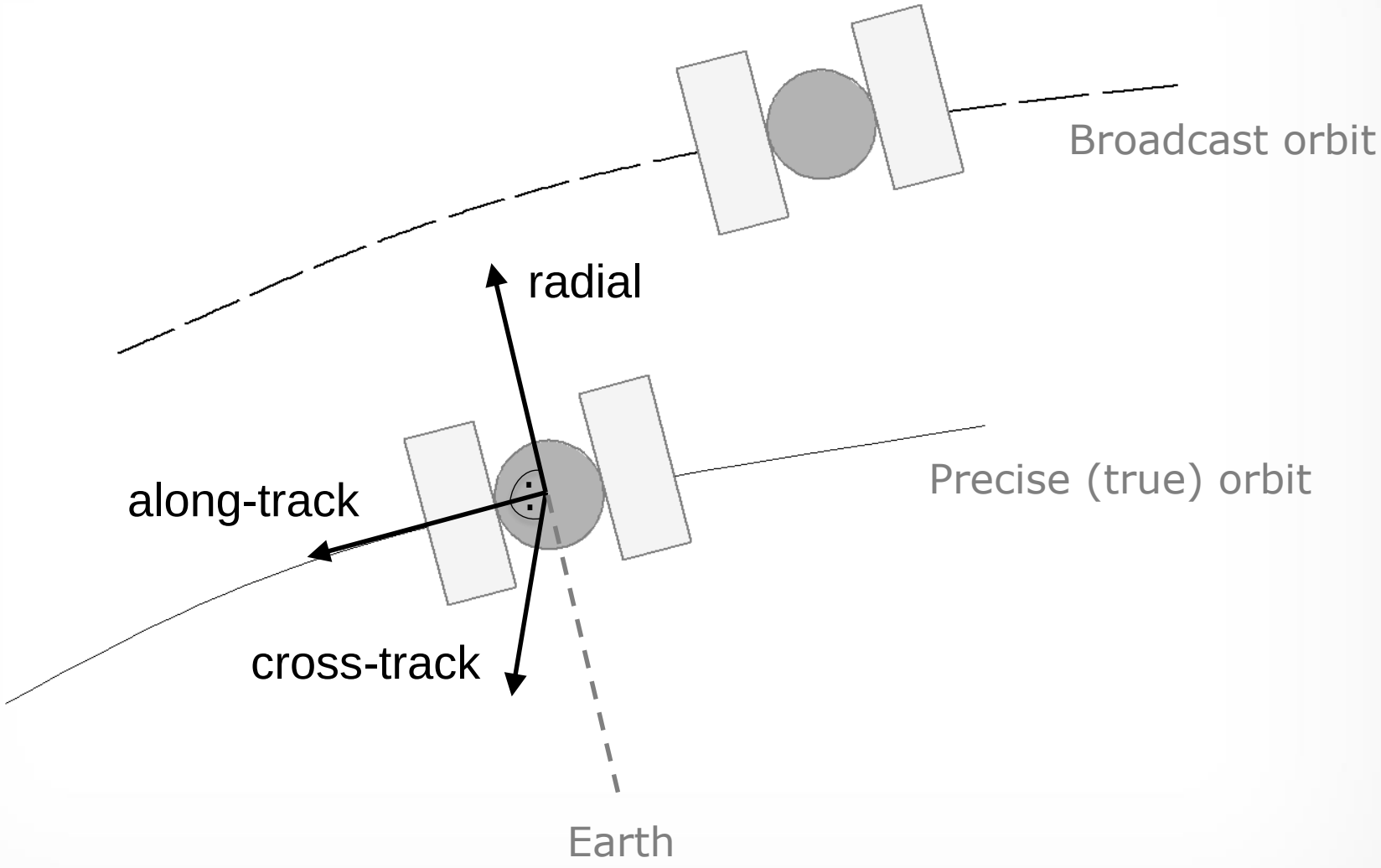
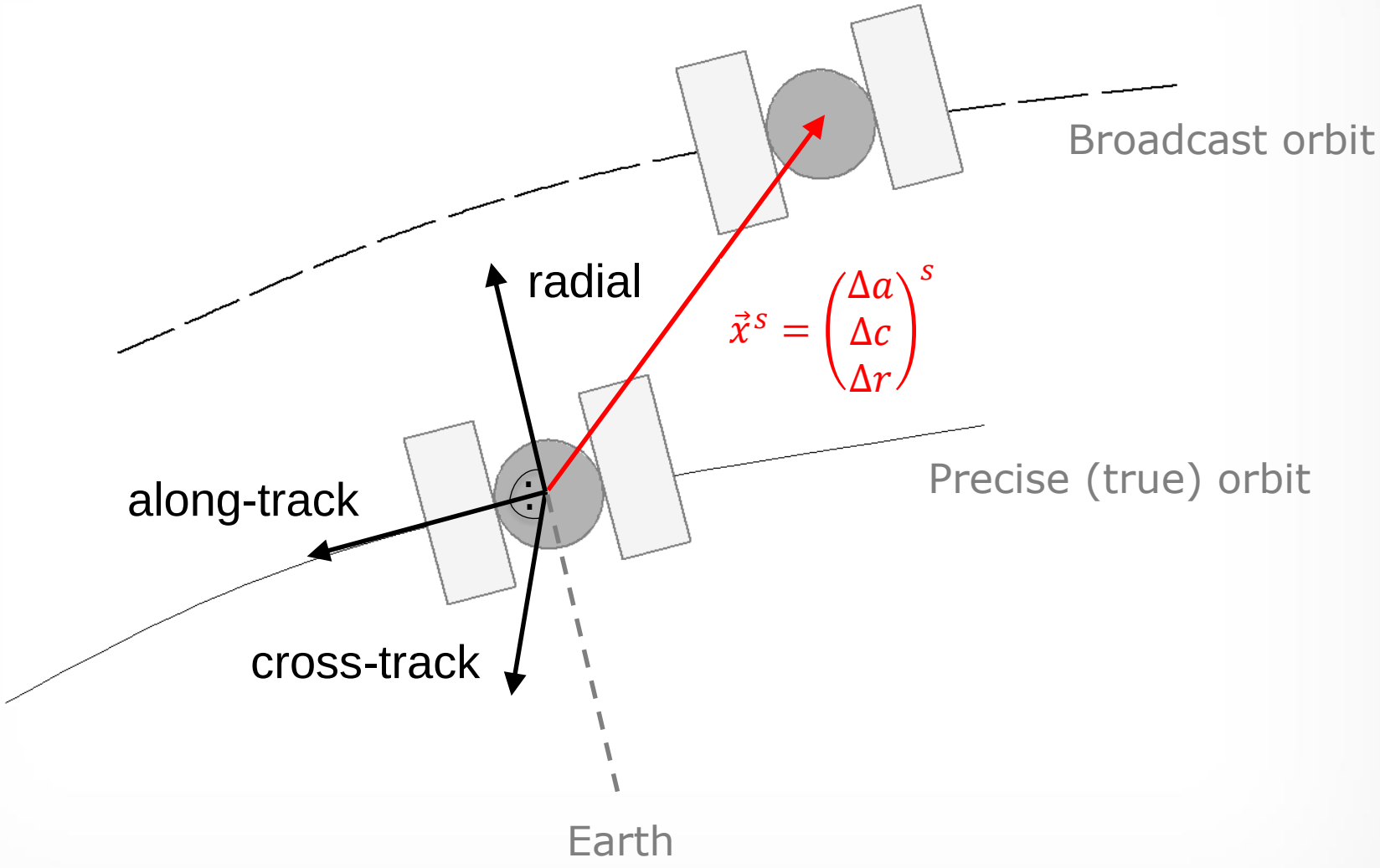
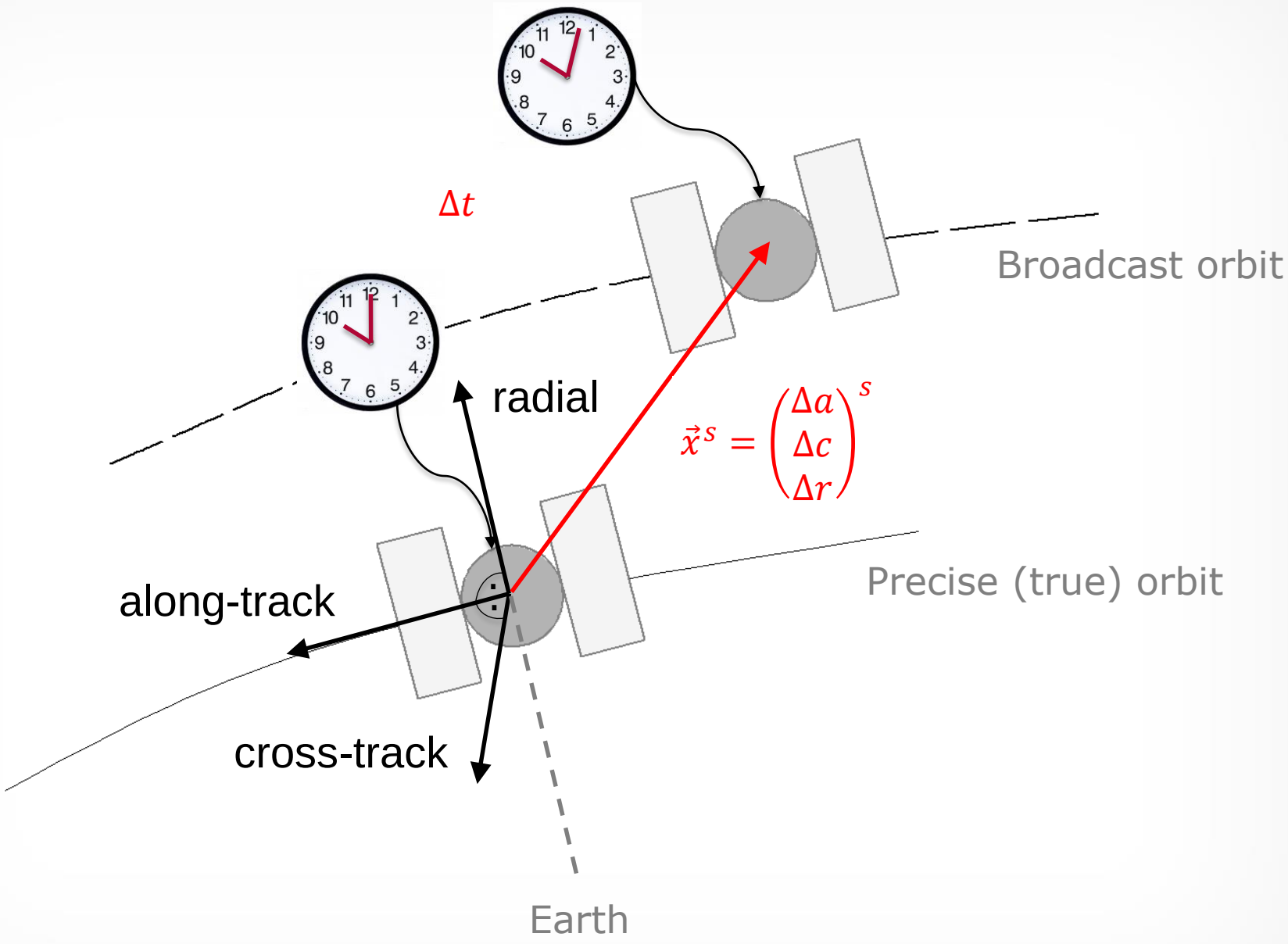

Broadcast orbit
Precise (true) orbit


Broadcast orbit
radial
along-track
Precise (true) orbit
cross-track
Earth

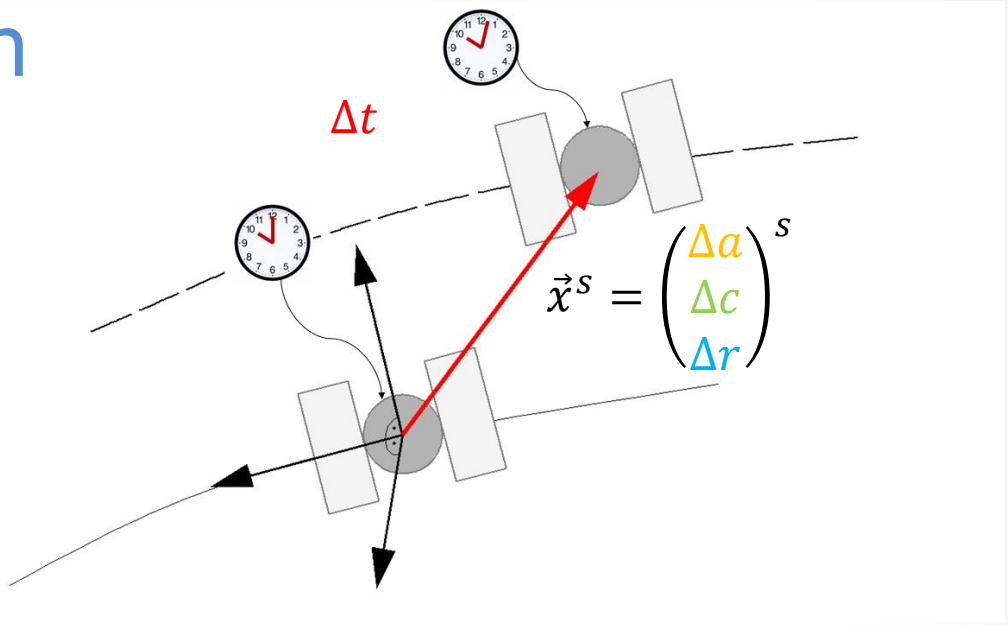

Broadcast orbit
radial
$\vec{x}^s = \begin{pmatrix} \Delta a \\ \Delta c \\ \Delta r \end{pmatrix}^s$
along-track
Precise (true) orbit
cross-track
Earth

Kartverket

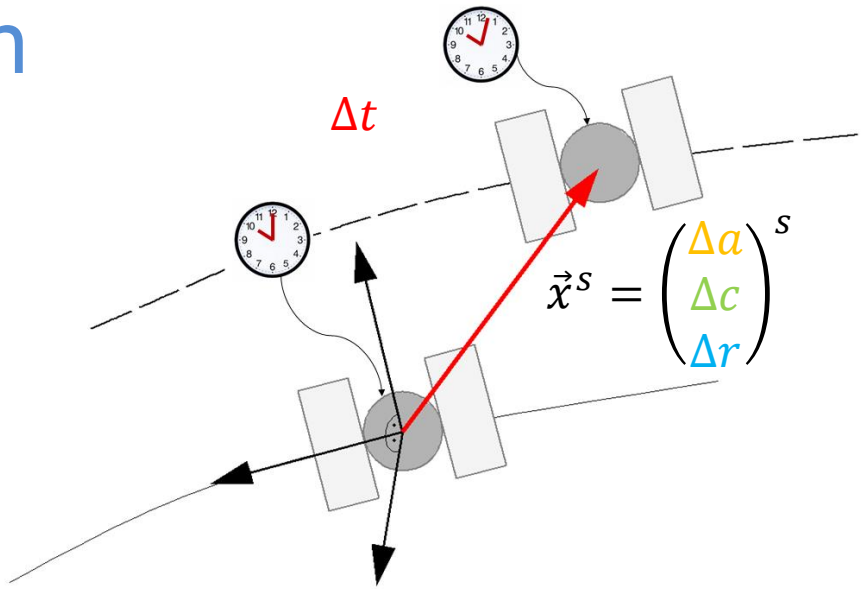

Δt
Broadcast orbit
radial
$\vec{x}^s = \begin{pmatrix} \Delta a \\ \Delta c \\ \Delta r \end{pmatrix}^s$
along-track
Precise (true) orbit
cross-track
Earth

Kartverket

SISRE computation

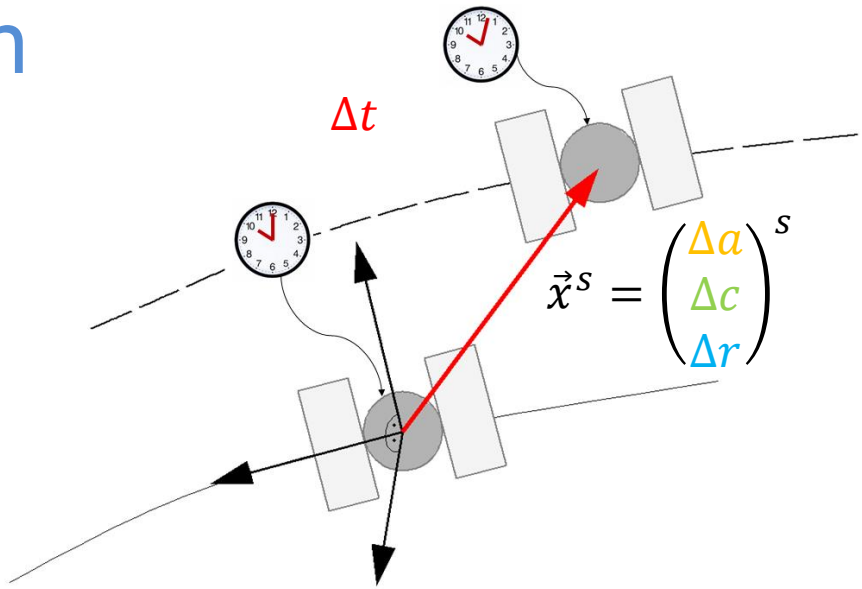


SISRE computation



$$SISRE = \sqrt{(w_r \cdot \Delta r - \Delta t)^2 + w_{a,c}^2 \cdot (\Delta a^2 + \Delta c^2)}$$

SISRE computation



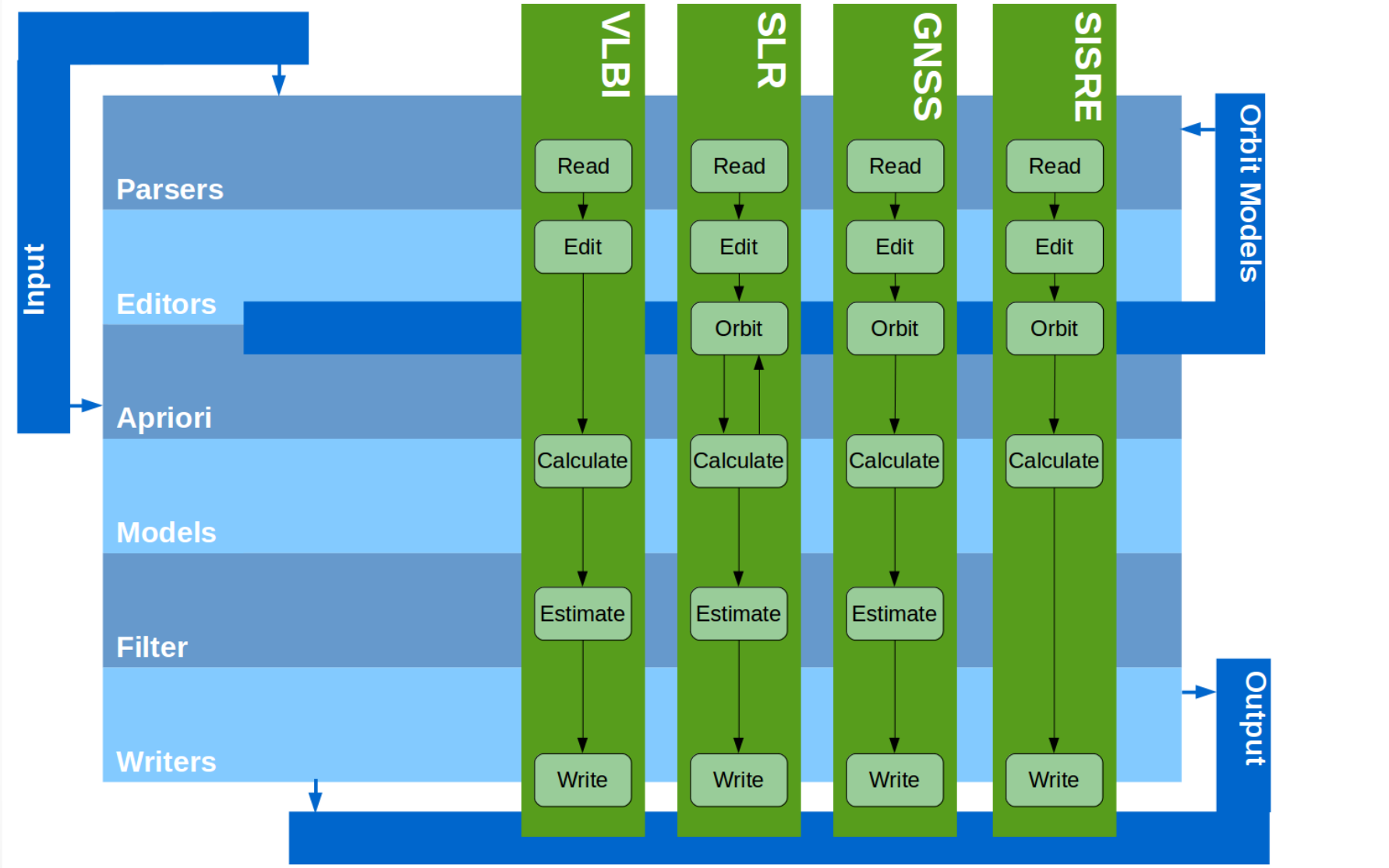
$$SISRE = \sqrt{(w_r \cdot \Delta r - \Delta t)^2 + w_{a,c}^2 \cdot (\Delta a^2 + \Delta c^2)}$$

weight factors

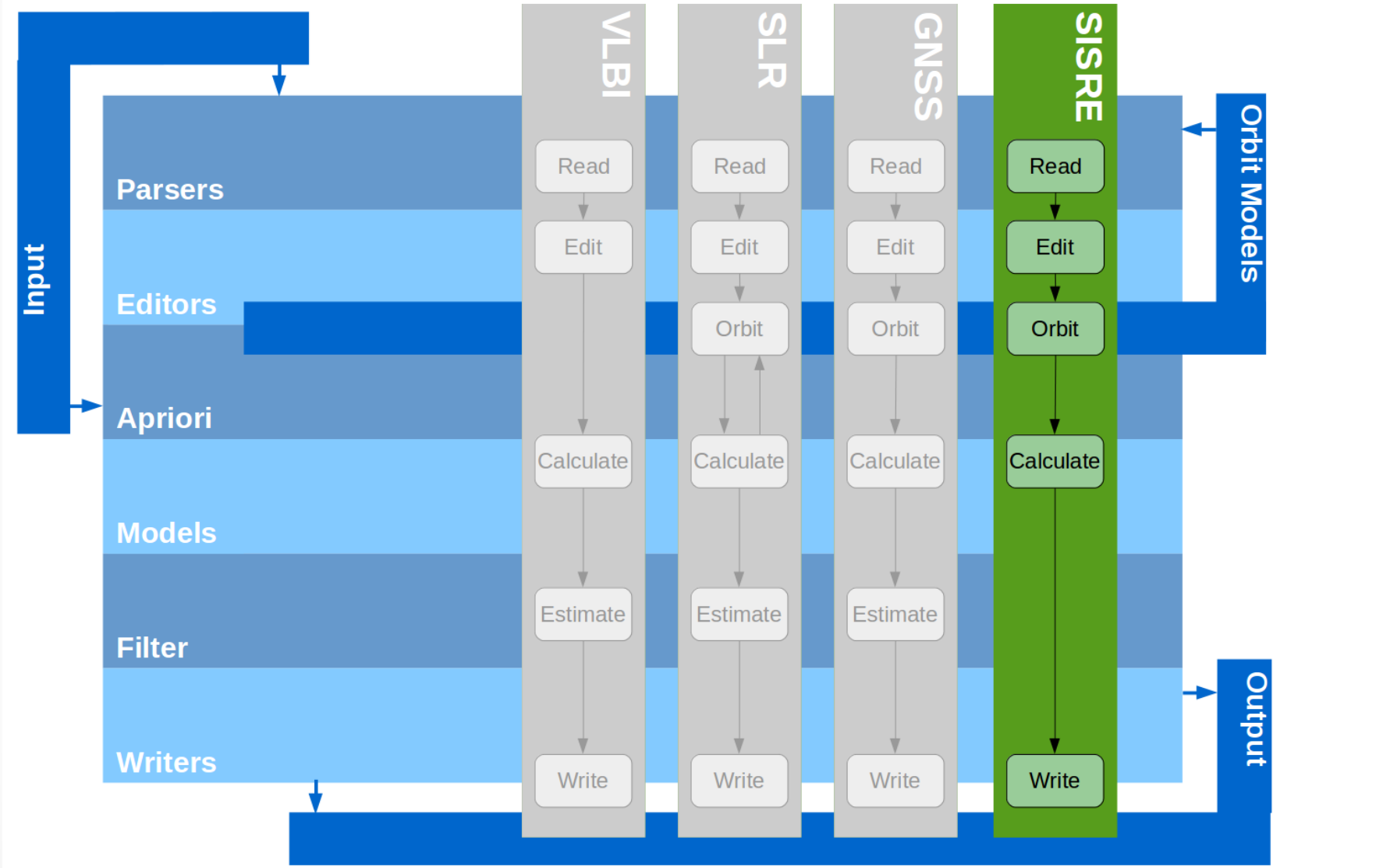
Part III

SISRE implementation in Where

SISRE implementation in Where



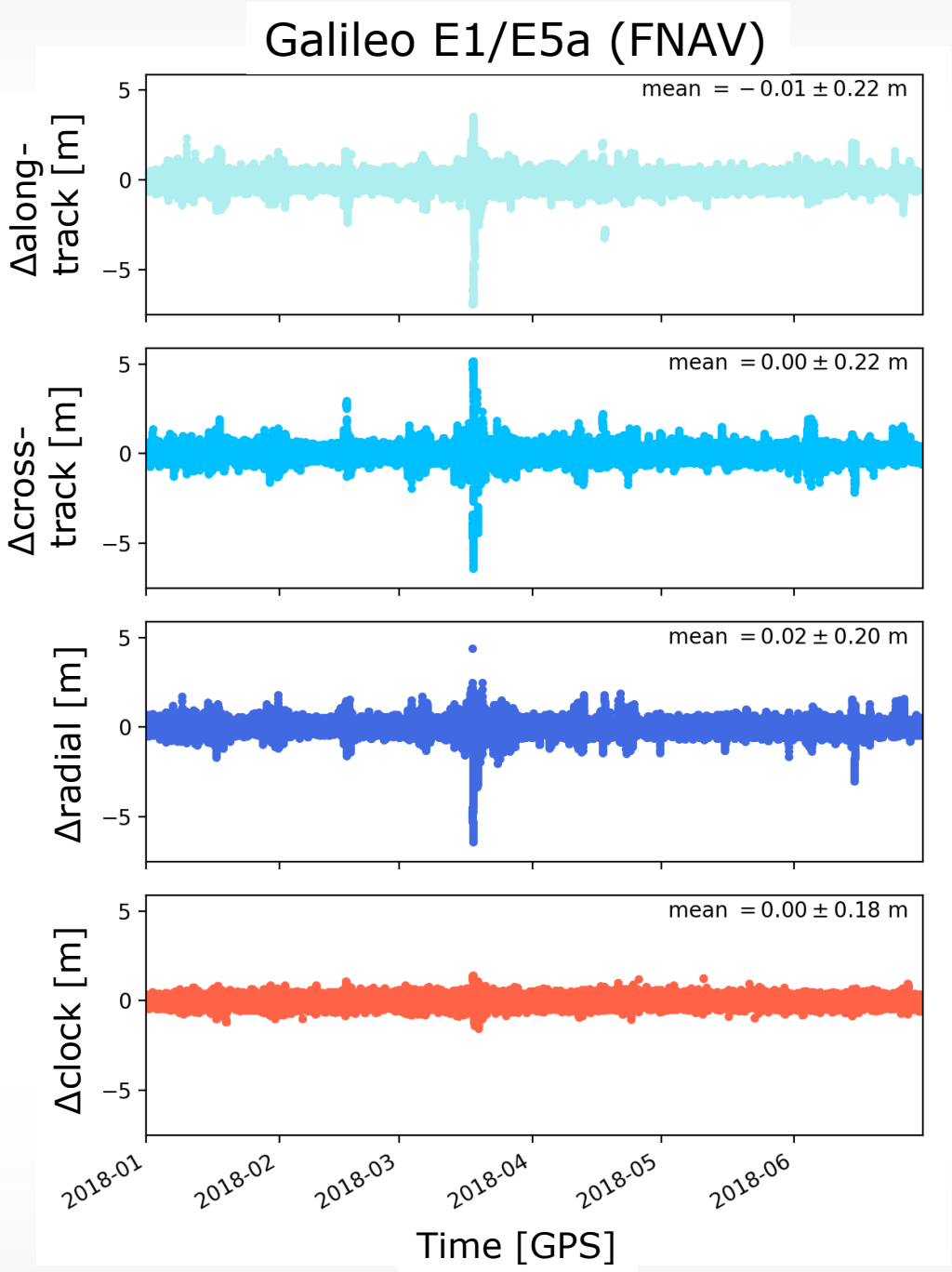
SISRE implementation in Where

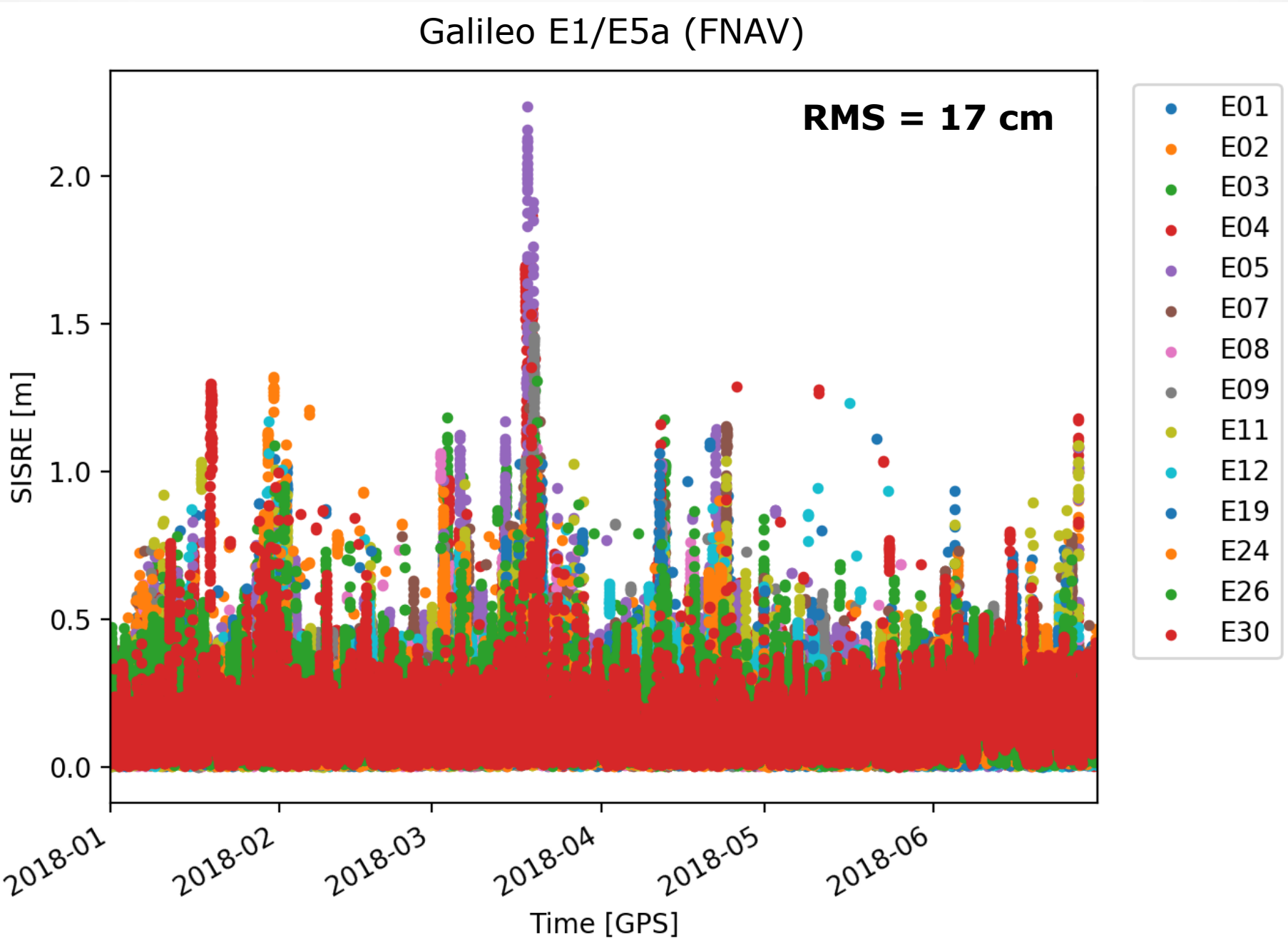


Kartverket

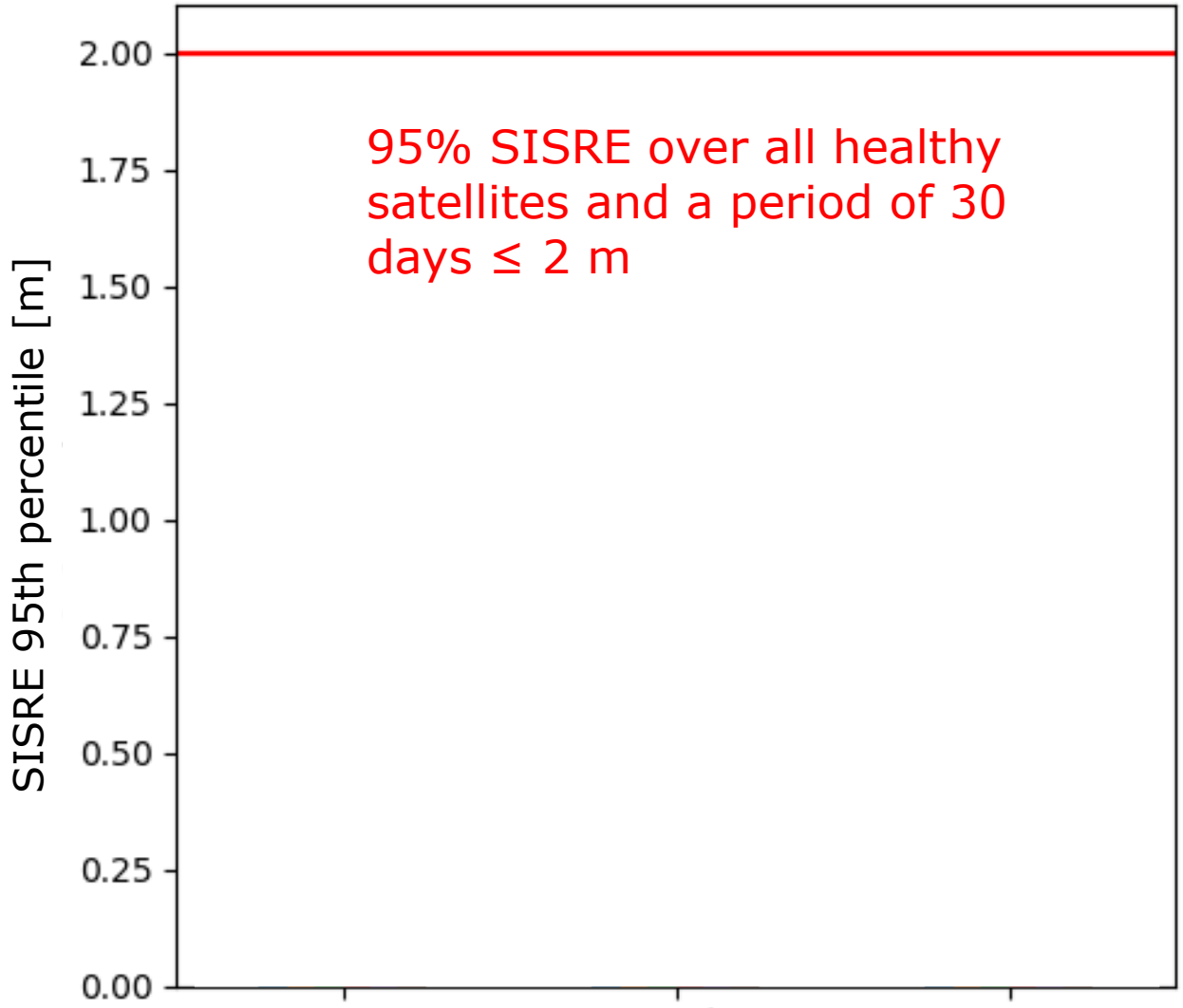
Part IV

Results

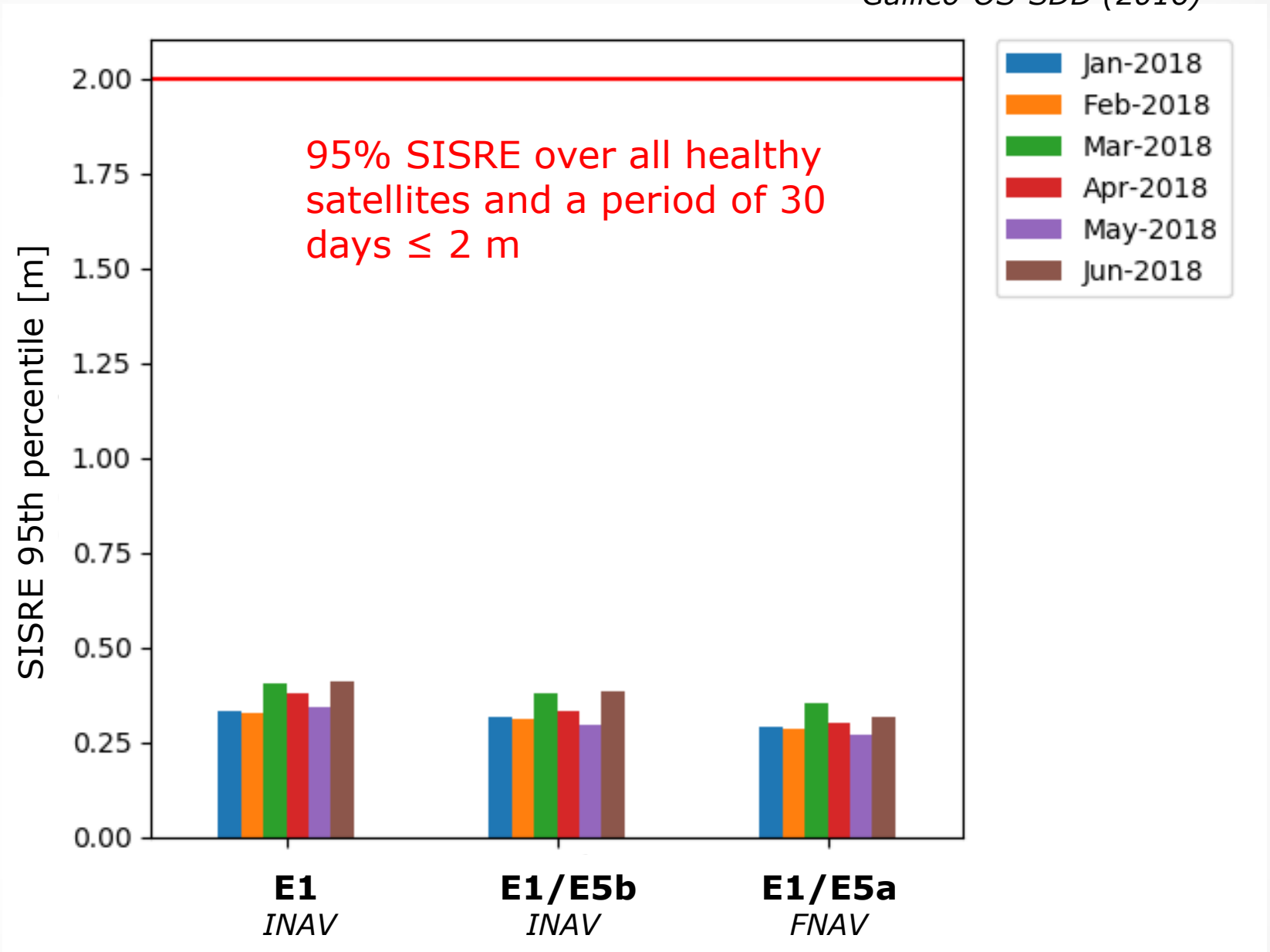

Galileo E1/E5a (FNAV)
Δalong-track [m]
mean = −0.01 ± 0.22 m
Δcross-track [m]
mean = 0.00 ± 0.22 m
Δradial [m]
mean = 0.02 ± 0.20 m
Δclock [m]
mean = 0.00 ± 0.18 m
5
0
−5
2018-01
2018-02
2018-03
2018-04
2018-05
2018-06
Time [GPS]

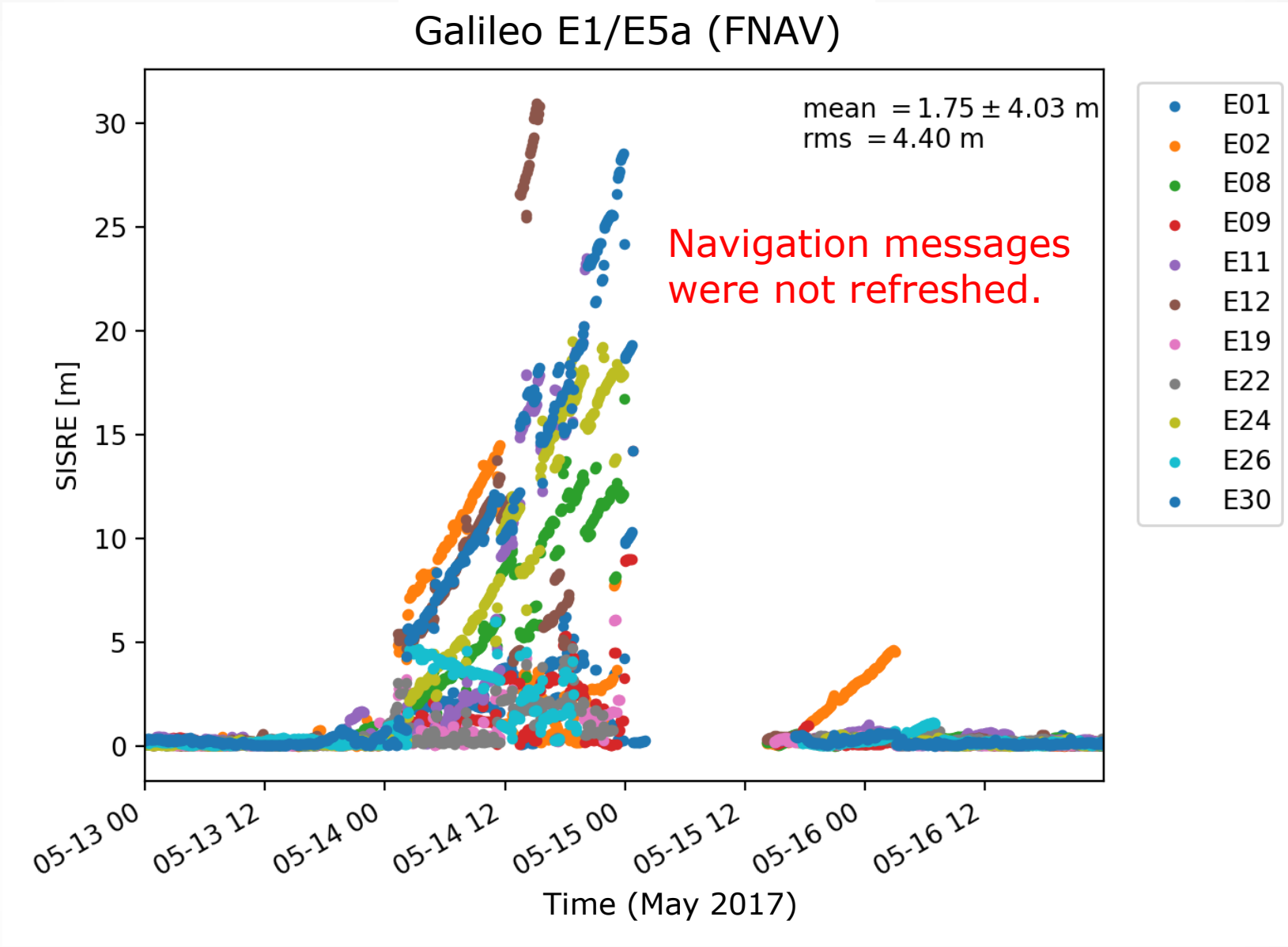

Galileo E1/E5a (FNAV)
RMS = 17 cm
SISRE [m]
2.0
1.5
1.0
0.5
0.0
2018-01
2018-02
2018-03
2018-04
2018-05
2018-06
Time [GPS]
E01
E02
E03
E04
E05
E07
E08
E09
E11
E12
E19
E24
E26
E30

Galileo-OS-SDD (2016)



Galileo-OS-SDD (2016)




Galileo E1/E5a (FNAV)
mean = 1.75 ± 4.03 m
rms = 4.40 m
Navigation messages were not refreshed.
SISRE [m]
30
25
20
15
10
5
0
05-13 00
05-13 12
05-14 00
05-14 12
05-15 00
05-15 12
05-16 00
05-16 12
Time (May 2017)
E01
E02
E08
E09
E11
E12
E19
E22
E24
E26
E30

Part V

Conclusion and outlook

Conclusion and outlook

- Galileo system fulfills SISRE minimum performance level for January to June 2018
- Where SISRE solution shows comparable results to other studies (e.g. Montenbruck et. al (2018) or Galileo-IS-OS (2018)) with SISRE RMS of 17 cm and monthly 95th percentile of 25-40 cm
- Further validation of Where SISRE analysis needed
- Improvement of SISRE analysis by quality checking of input data

Literature

Galileo-IS-OS (2018): *European GNSS (Galileo) inital services – Open service quarterly performance report*. January-March 2018.

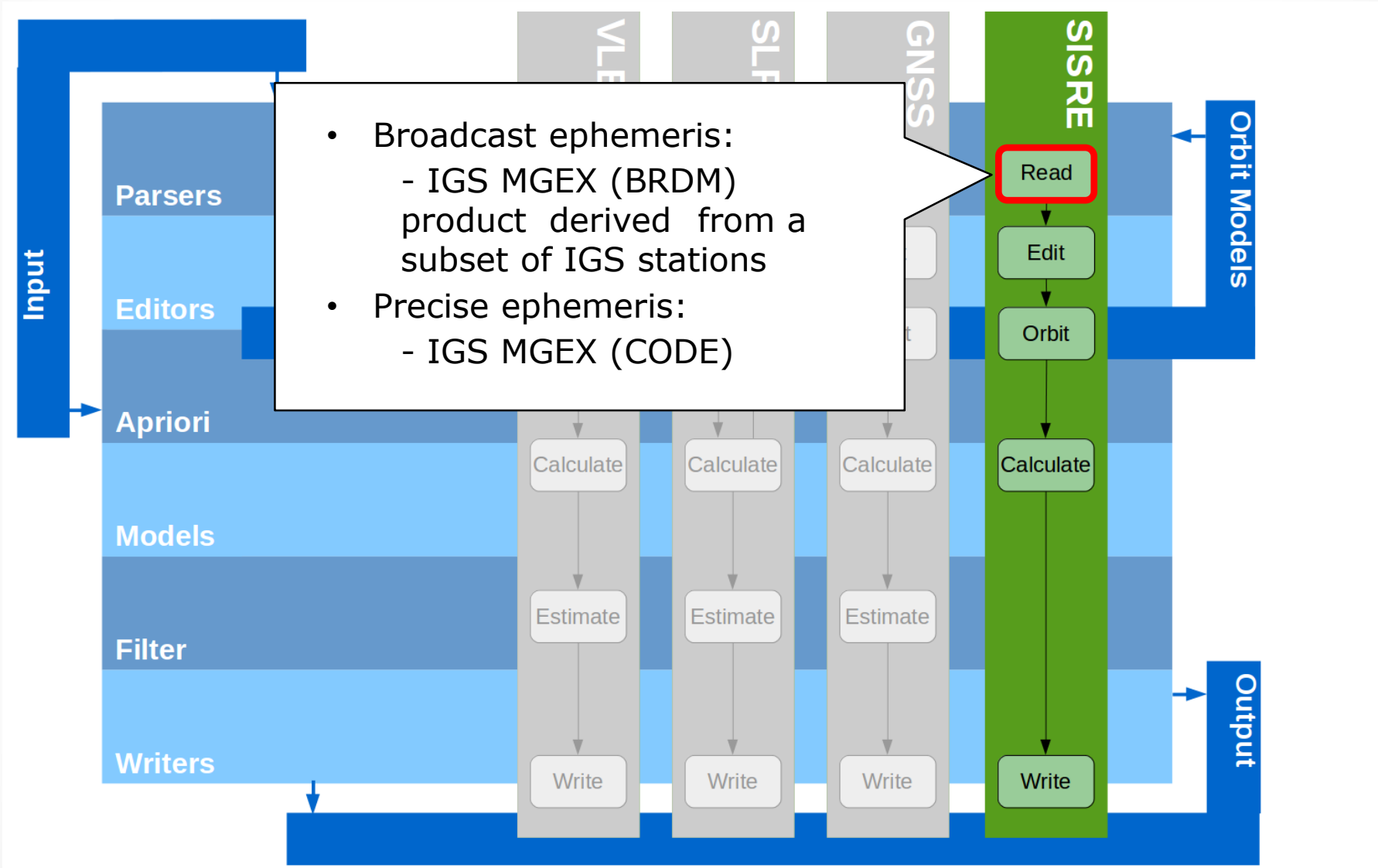
Galileo-OS-SDD (2016): *European GNSS (Galileo) inital services – Open service definition document*. Issue 1.0, December 2016.

Galileo-OS-SIS-ICD (2015): *European GNSS (Galileo) Open service – Signal in space inferface control document*. Issue 1.2, November 2015.

Montenbruck, O., Steigenberger, P., and Hauschild, A. (2018): *Multi-GNSS signal-in-space range error assessment – methodology and results.* Advances in Space Research, 61(12):3020-3038. DOI 10.1016/j.asr.2018.03.041.

Thank you for your attention!

SISRE implementation in Where



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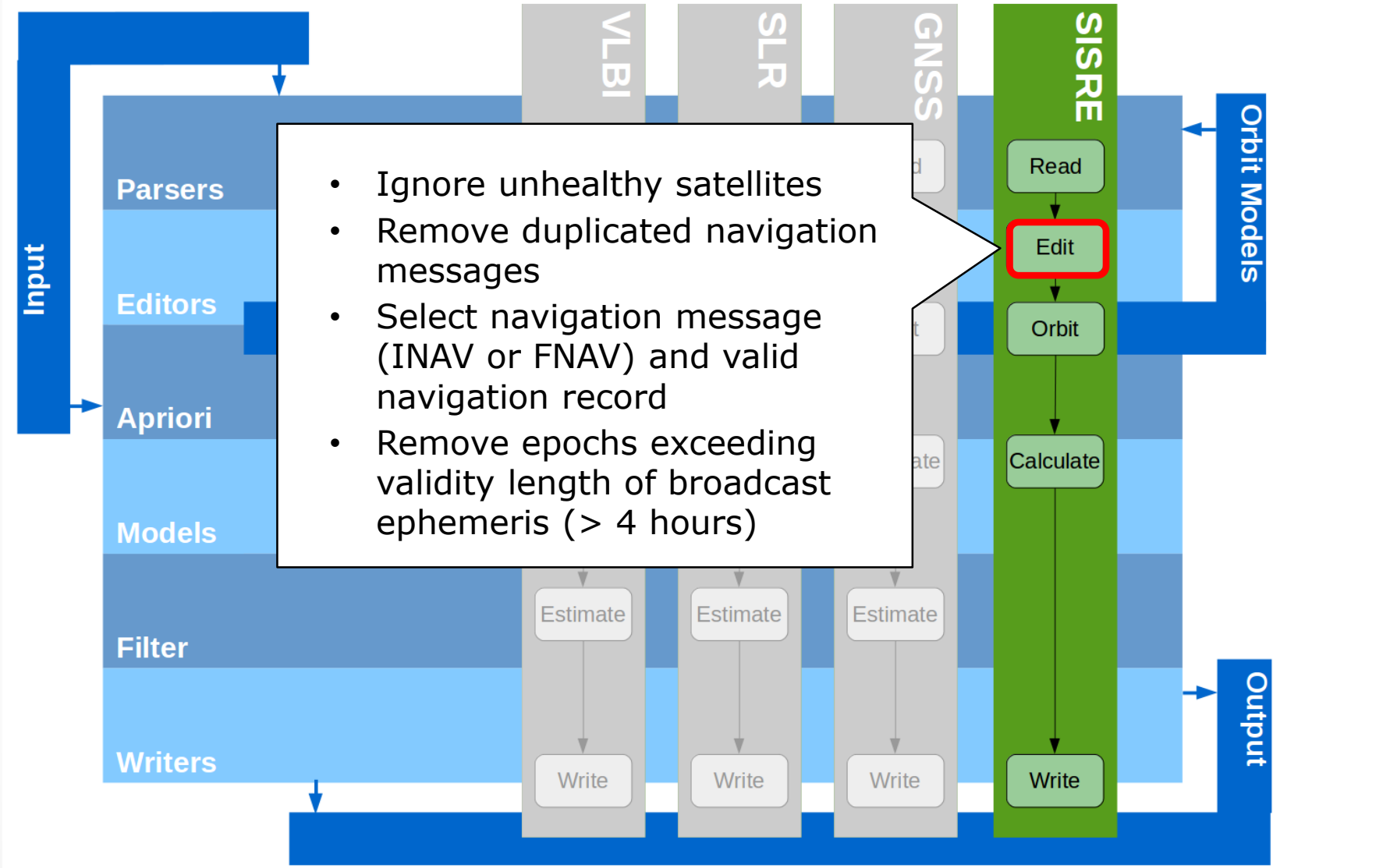
SISRE implementation in Where



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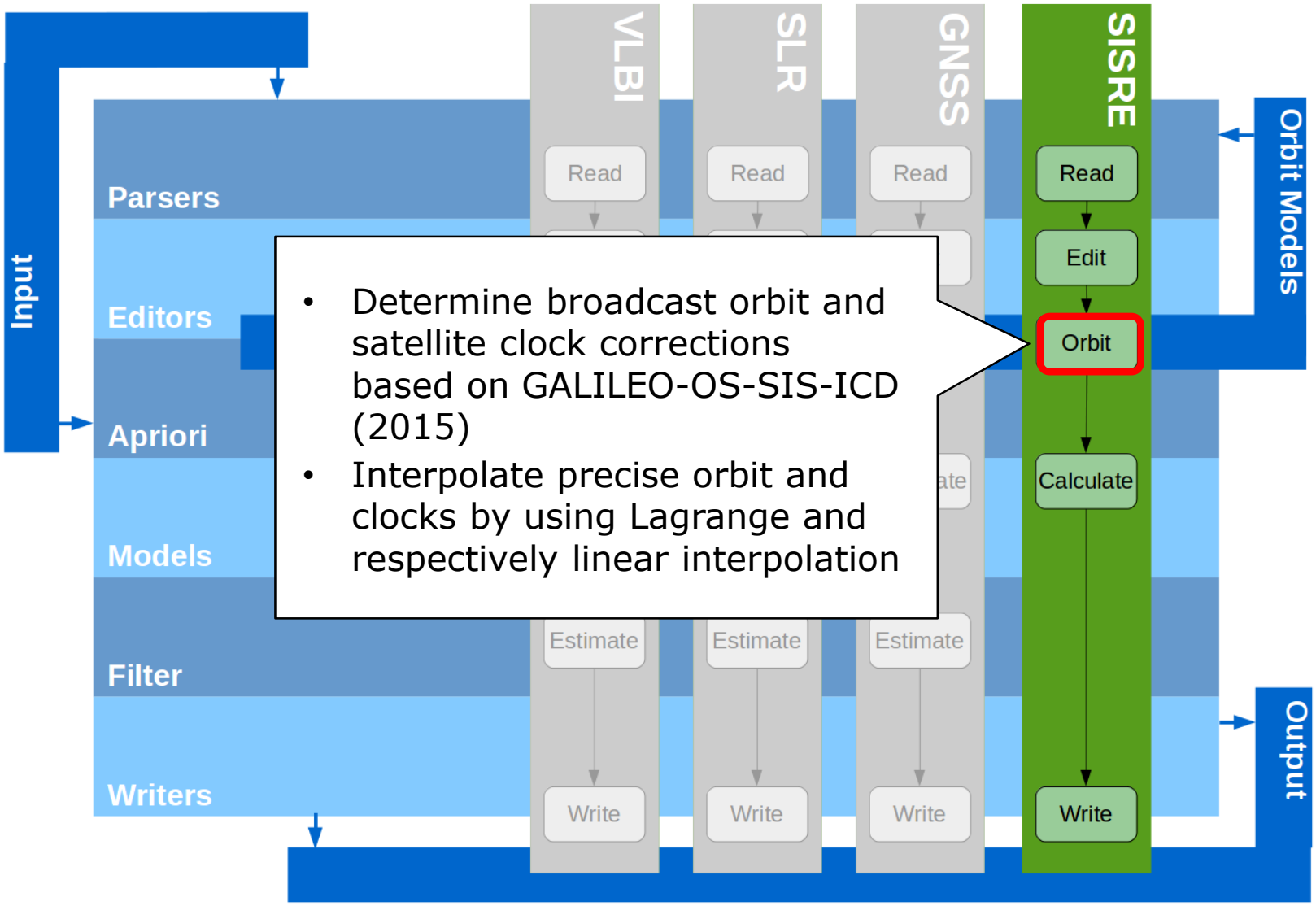
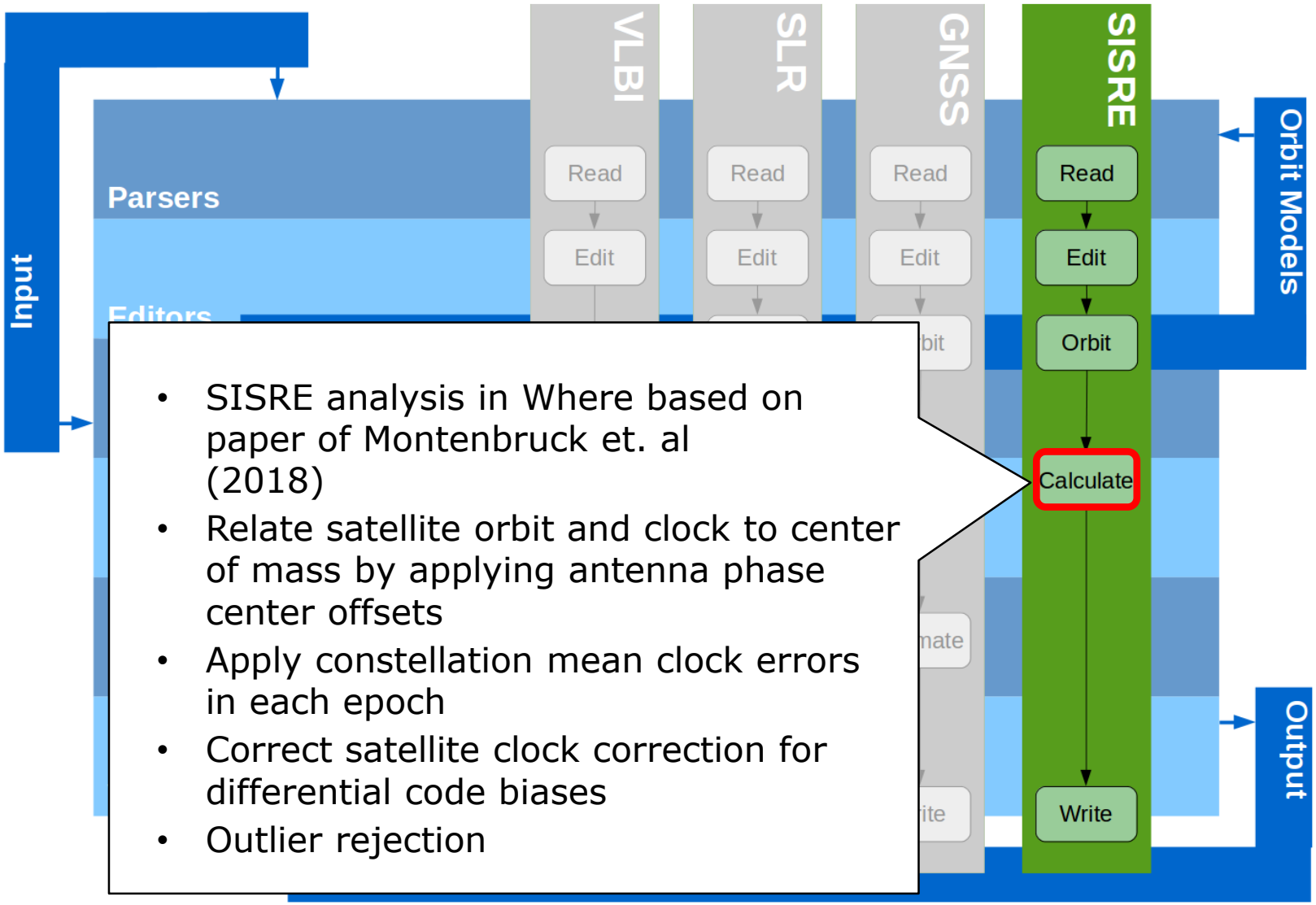
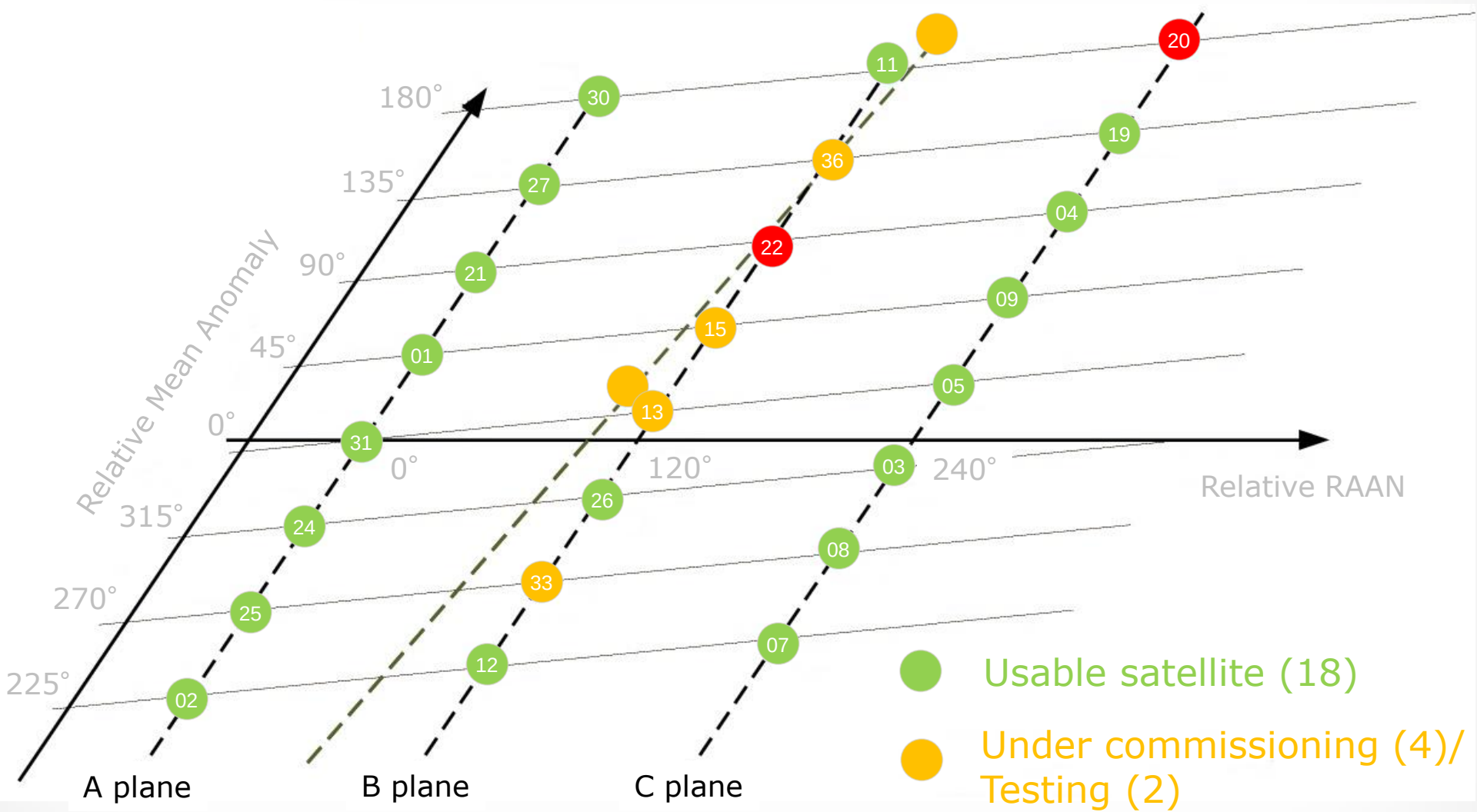


SISRE implementation in Where



- SISRE analysis in Where based on paper of Montenbruck et. al (2018)
- Relate satellite orbit and clock to center of mass by applying antenna phase center offsets
- Apply constellation mean clock errors in each epoch
- Correct satellite clock correction for differential code biases
- Outlier rejection

Galileo satellite constellation



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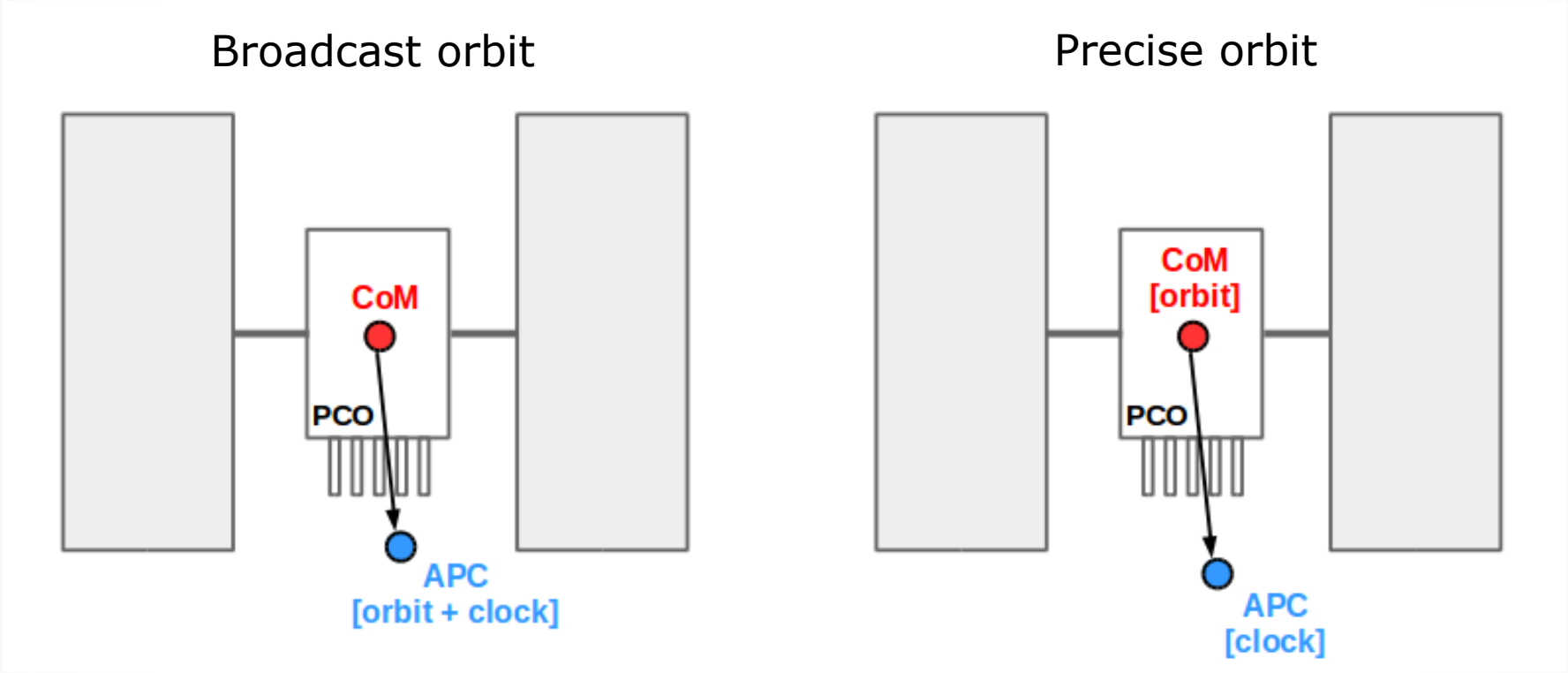
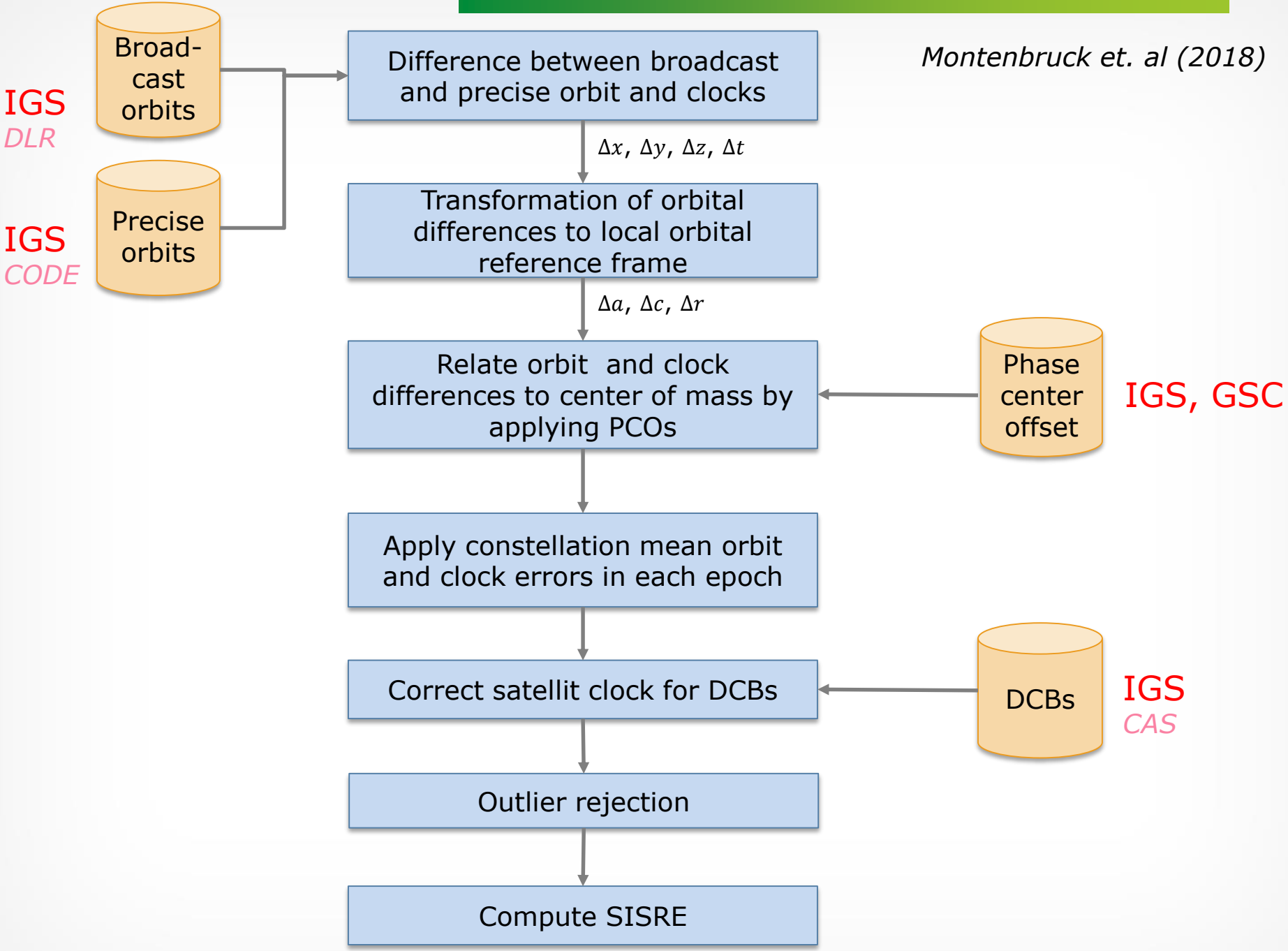
Satellite antenna relation



- Relate orbit and clock differences to center of mass by applying PCOs given by GSC and IGS (igs14.atx)


Broad-cast orbits
IGS
DLR
Precise orbits
IGS
CODE
Difference between broadcast and precise orbit and clocks
$\Delta x, \Delta y, \Delta z, \Delta t$
Transformation of orbital differences to local orbital reference frame
$\Delta a, \Delta c, \Delta r$
Relate orbit and clock differences to center of mass by applying PCOs
Phase center offset
IGS, GSC
Apply constellation mean orbit and clock errors in each epoch
Correct satellit clock for DCBs
DCBs
IGS
CAS
Outlier rejection
Compute SISRE
Montenbruck et. al (2018)