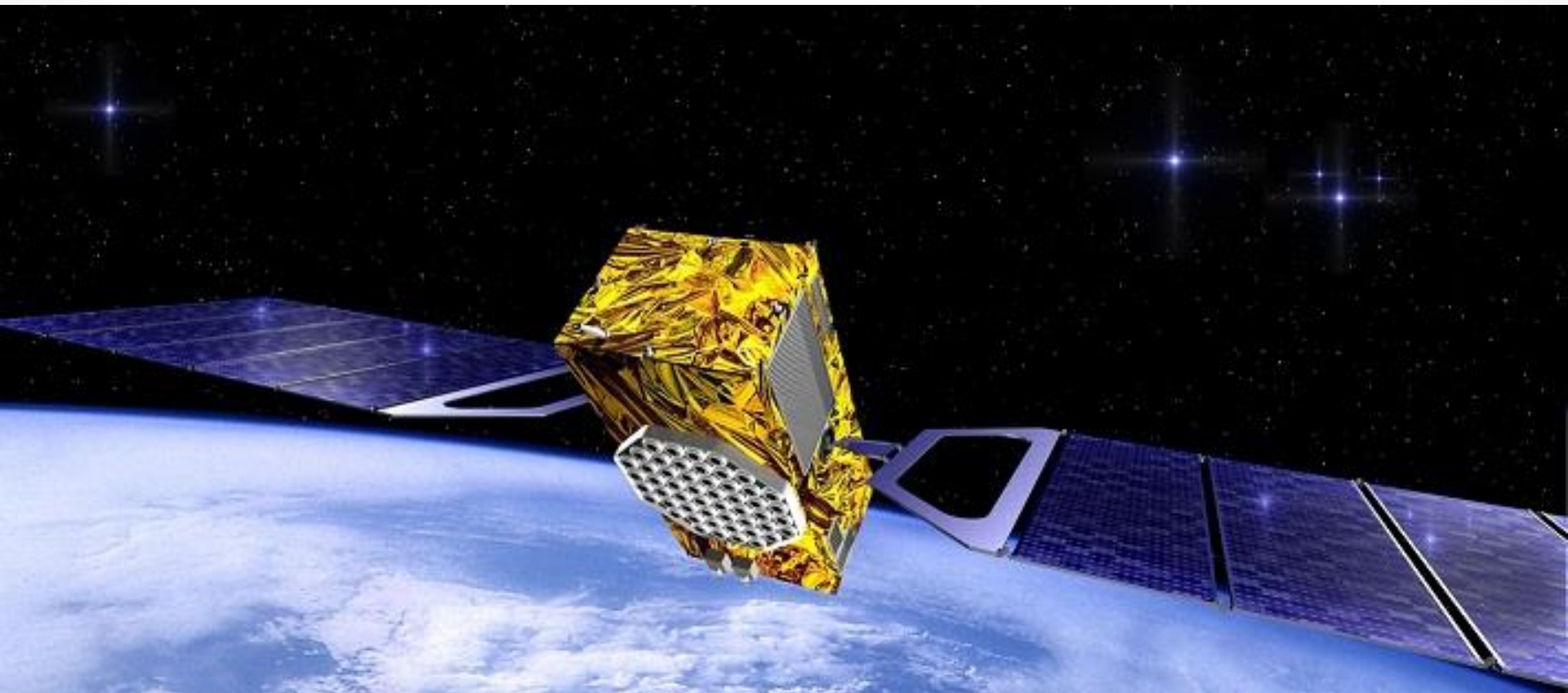# Galileo orbit performance monitoring with Where

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

NKG General Assembly, Helsinki, 6. September 2018

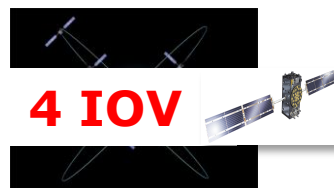Kartverket

Part I

Background

Galileo deployment

Full Operational Capability

24

2020

Exploitation Phase

2017

Initial Services

2016

In-Orbit Validation

4 IOV

2011-2013

Development GIOVE A & B

2005/2008

Kartverket

Motivation – Galileo performance monitoring

Space segment
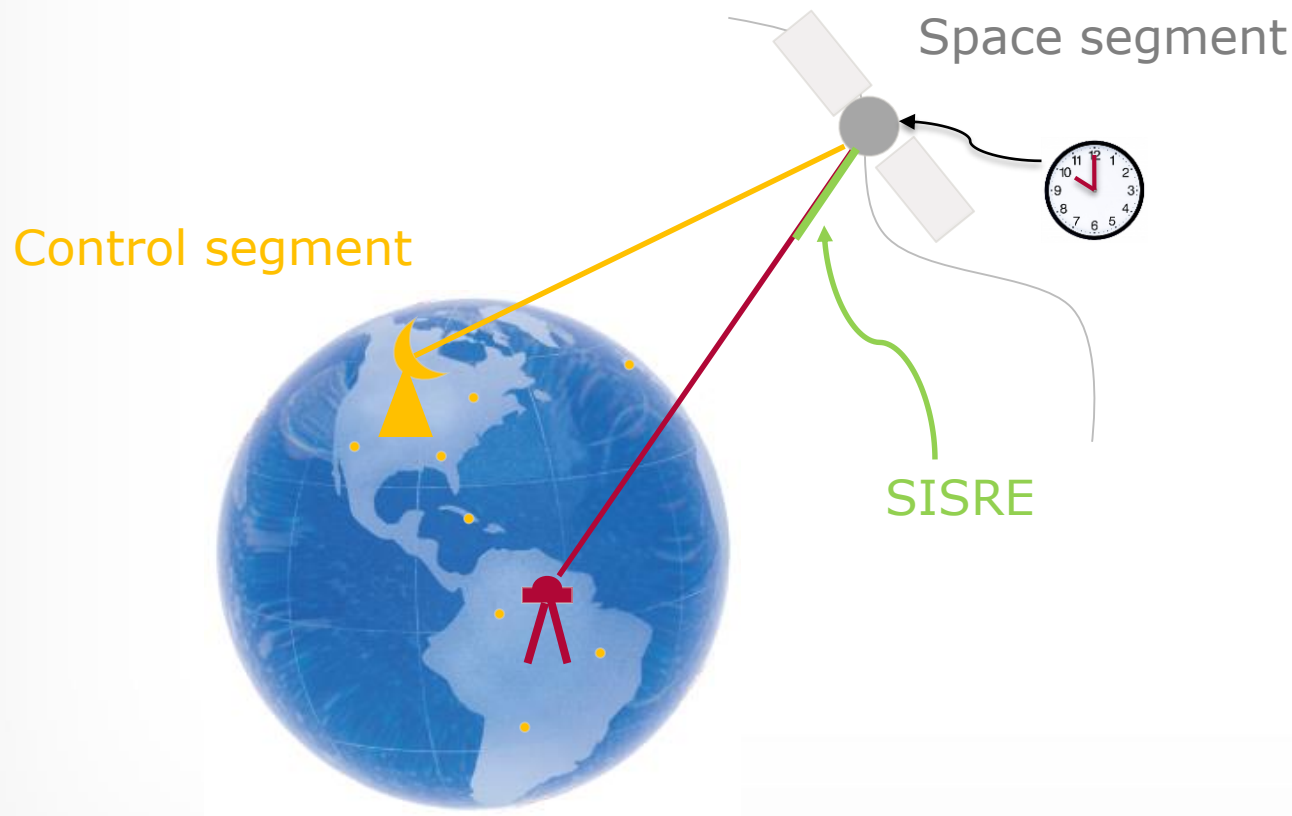
Control segment

User segment
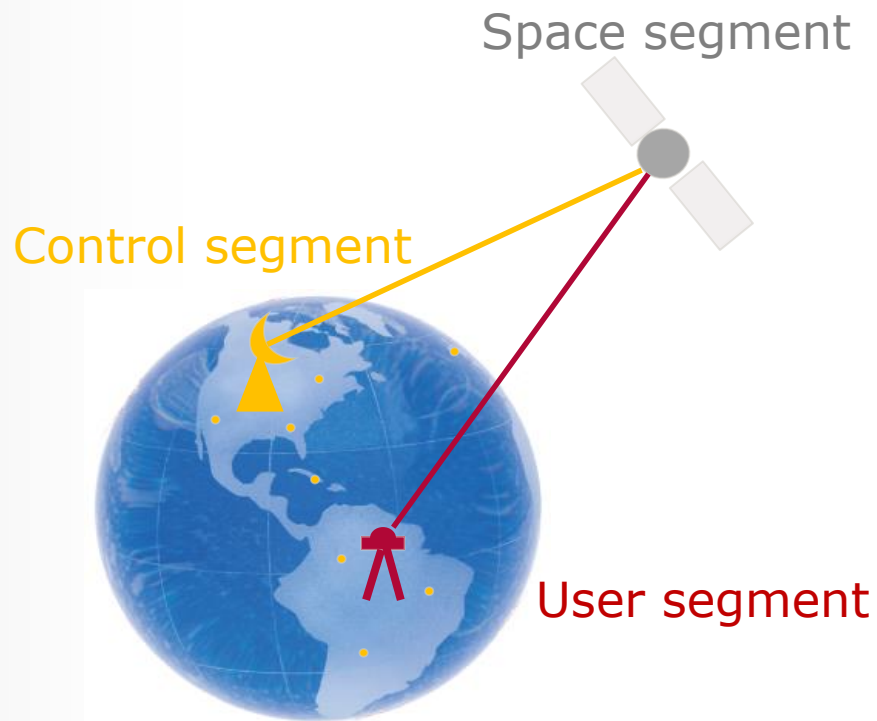
- testing and verifying the initial services

- 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
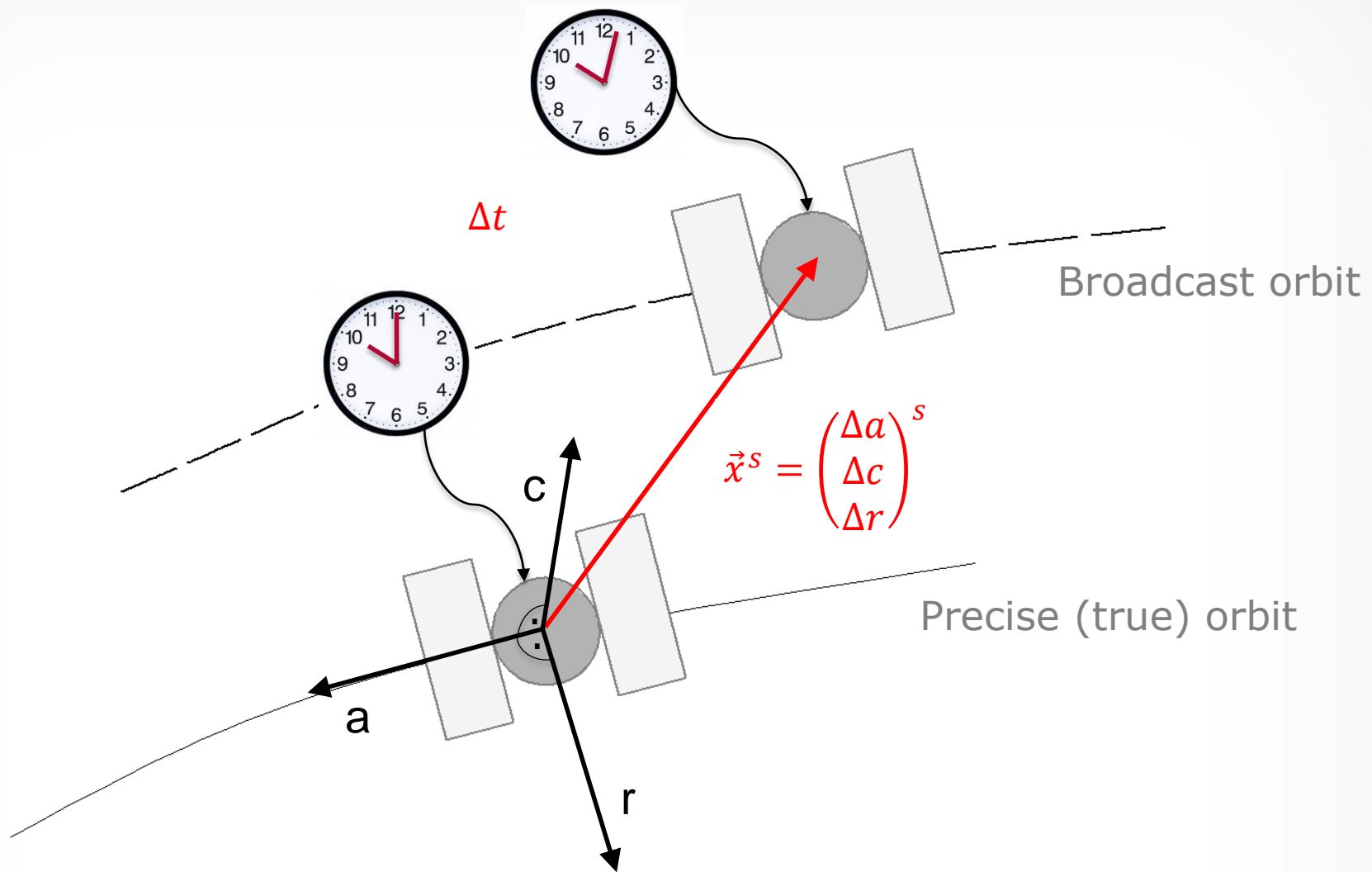
Kartverket

Part II

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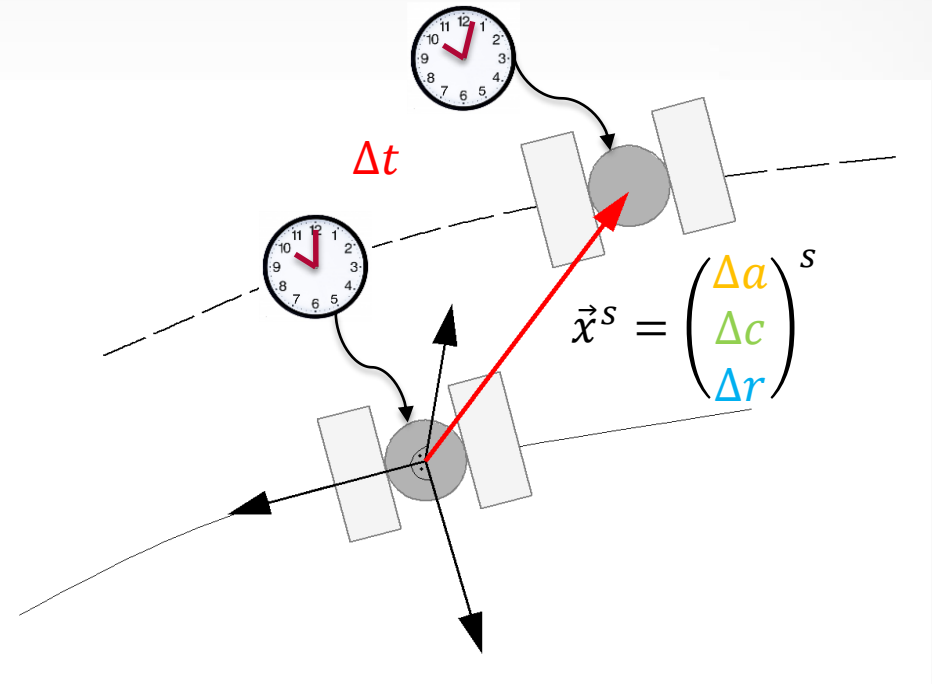
What is signal-in-space range error (SISRE)?

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

Space segment

Control segment

SISRE

Kartverket

$$\Delta t$$

$$\vec{x}^s = \begin{pmatrix} \Delta a \\ \Delta c \\ \Delta r \end{pmatrix}^s$$

Broadcast orbit

Precise (true) orbit

c

a

r

Kartverket

SISRE computation

$$\vec{x}^s = \begin{pmatrix} \Delta a \\ \Delta c \\ \Delta r \end{pmatrix}^s$$

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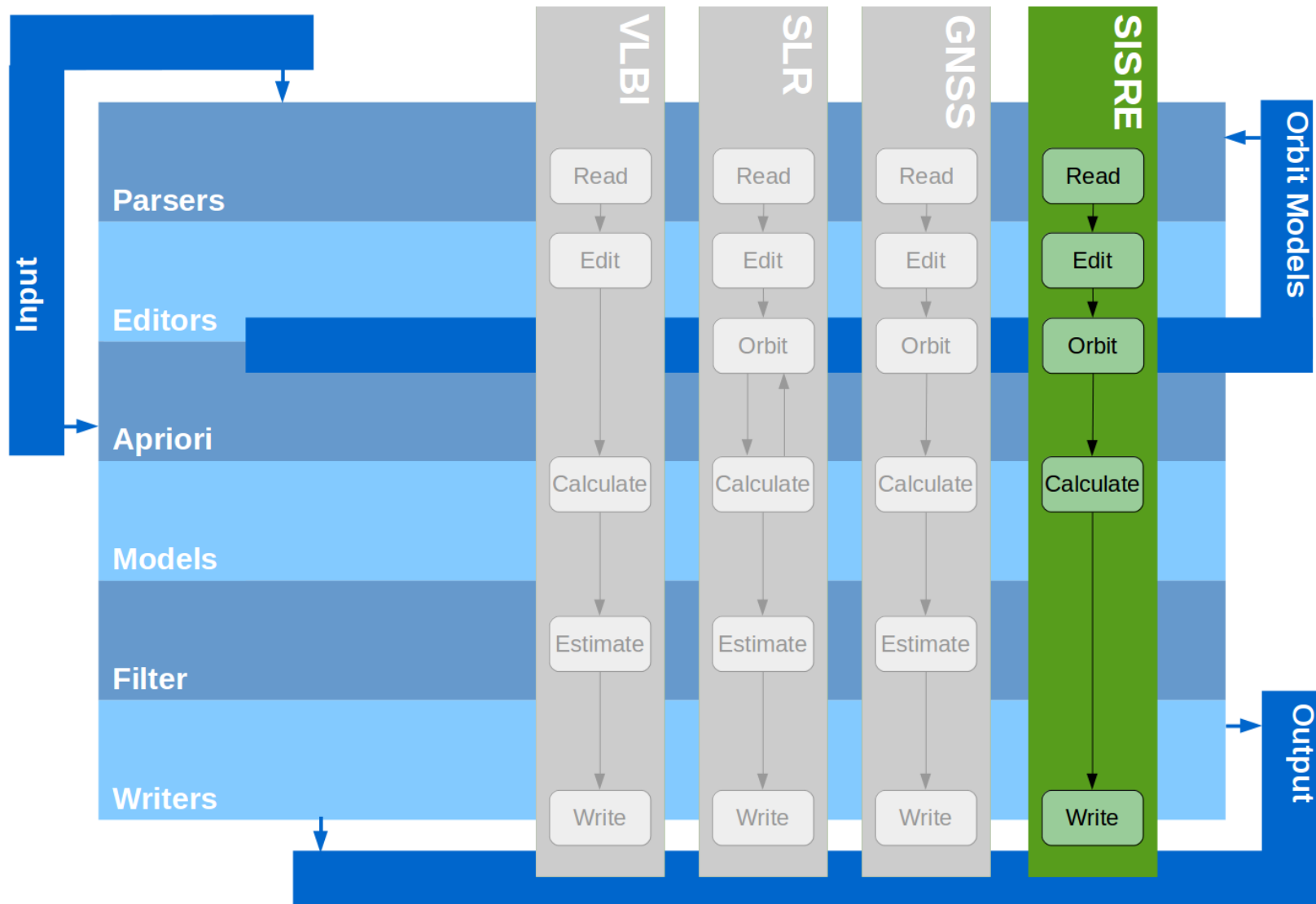
weight factors

Part III

SISRE implementation in Where
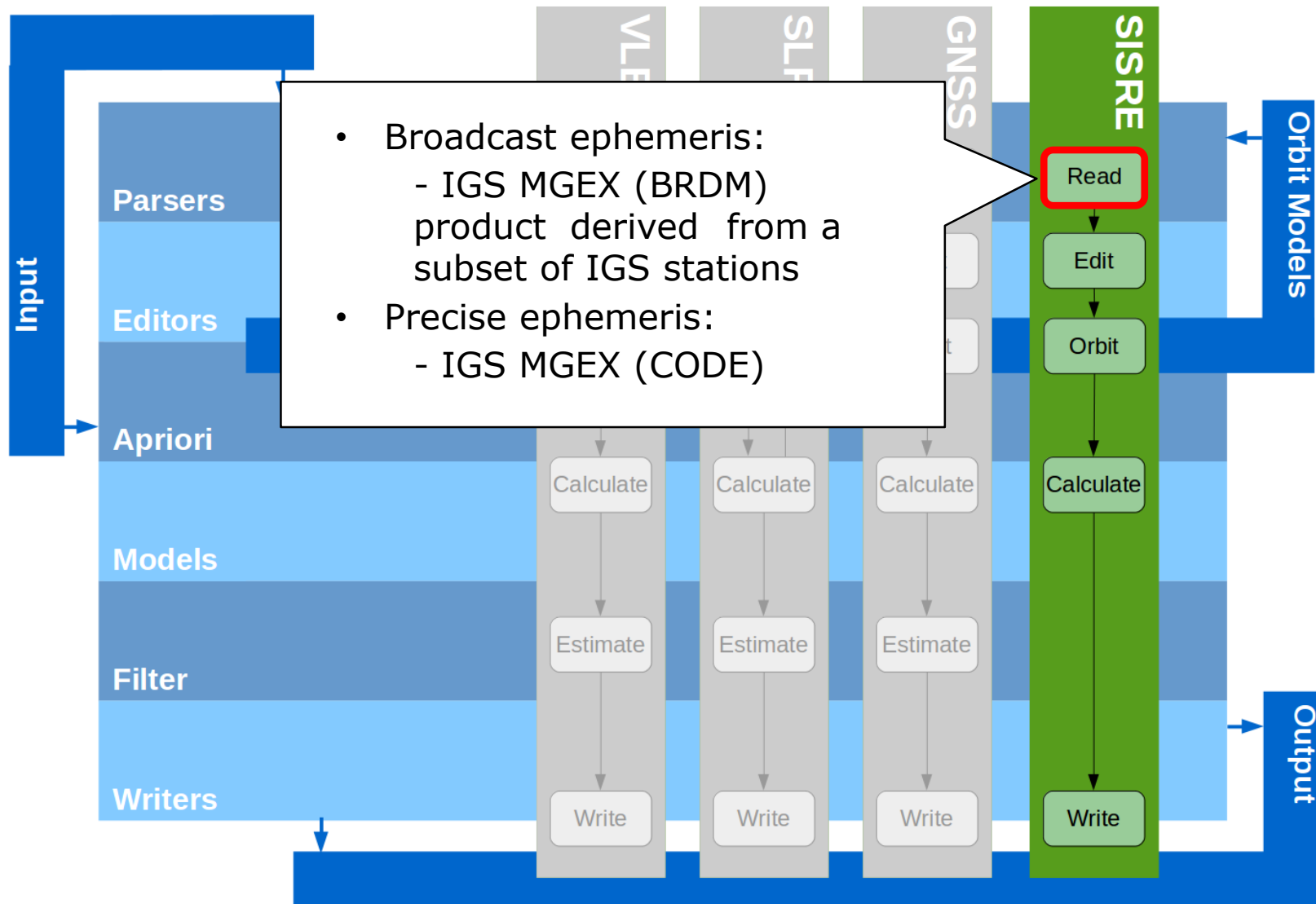
Kartverket

SISRE implementation in Where

Kartverket

SISRE implementation in Where

- Broadcast ephemeris:
  - IGS MGEX (BRDM) product derived from a subset of IGS stations
- Precise ephemeris:
  - IGS MGEX (CODE)

Kartverket

SISRE implementation in Where

- Ignore unhealthy satellites
- Remove duplicated navigation messages
- Select navigation message (INAV or FNAV) and valid navigation record
- Remove epochs exceeding validity length of broadcast ephemeris (> 4 hours)

Kartverket

SISRE implementation in Where

- Determine broadcast orbit and satellite clock corrections based on GALILEO-OS-SIS-ICD (2015)
- Interpolate precise orbit and clocks by using Lagrange and respectively linear interpolation

Kartverket

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

Kartverket

Part IV

Results
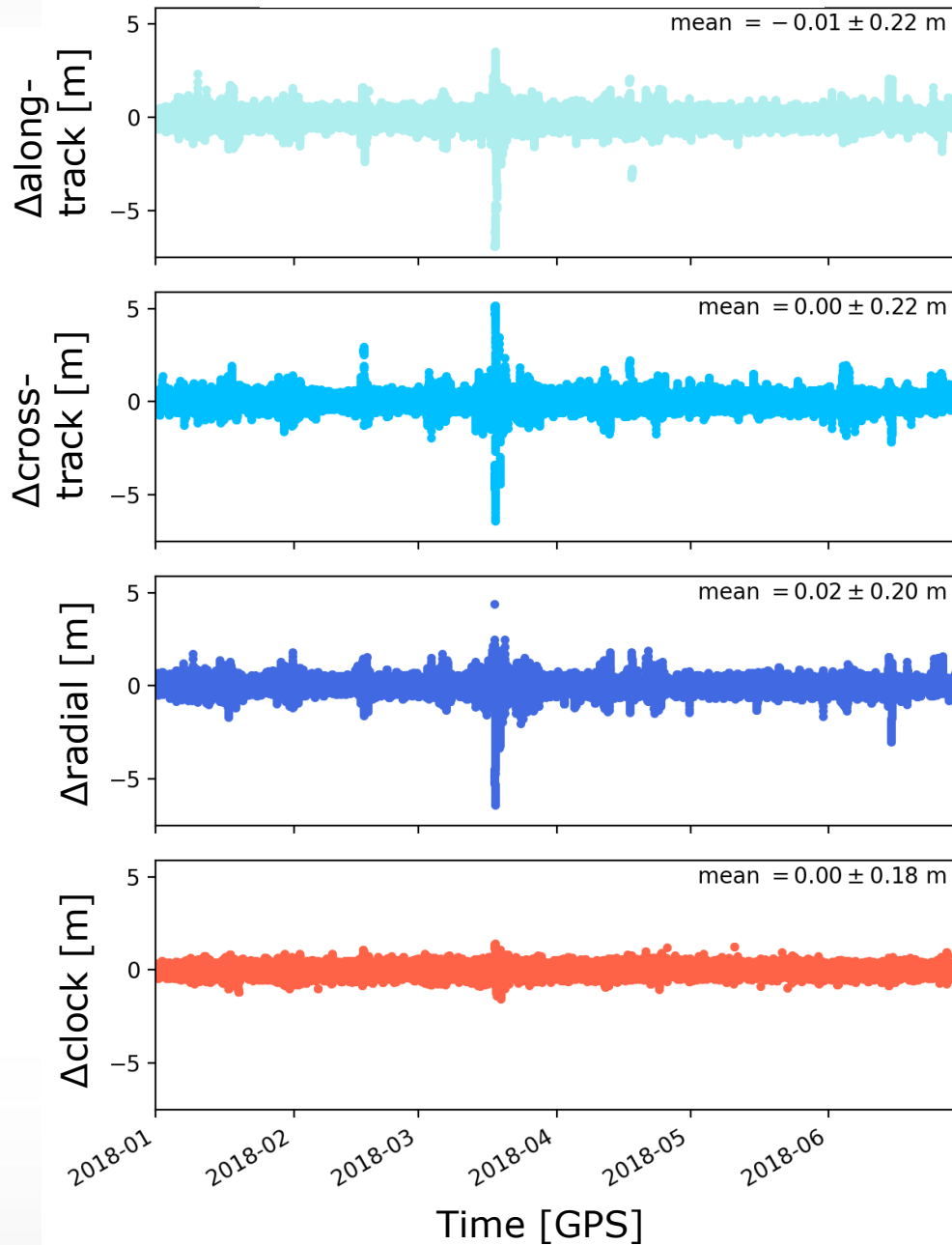
Galileo E1/E5a (FNAV)

Galileo E1/E5a (FNAV)

RMS = 0.16 m

Galileo-OS-SDD (2016)
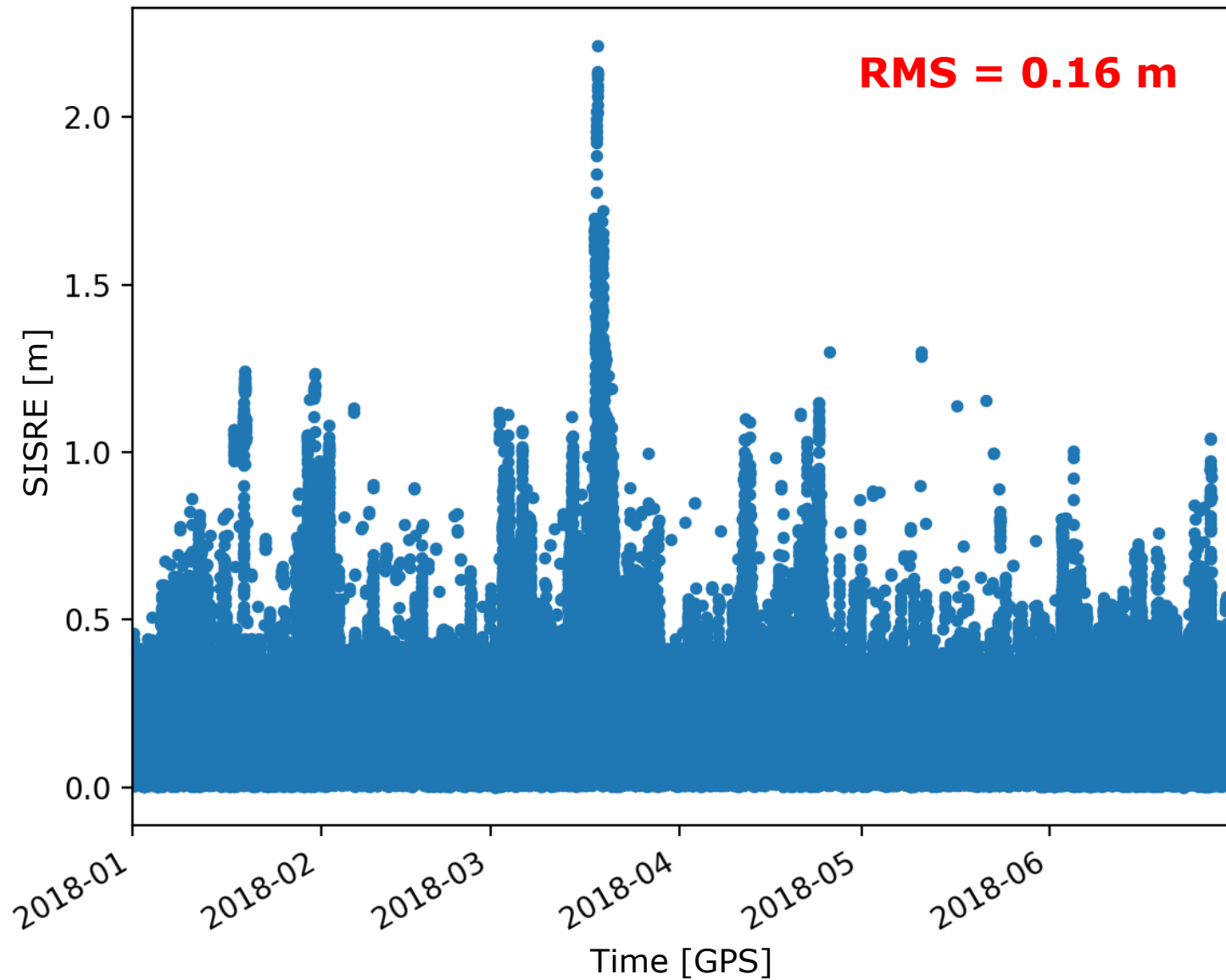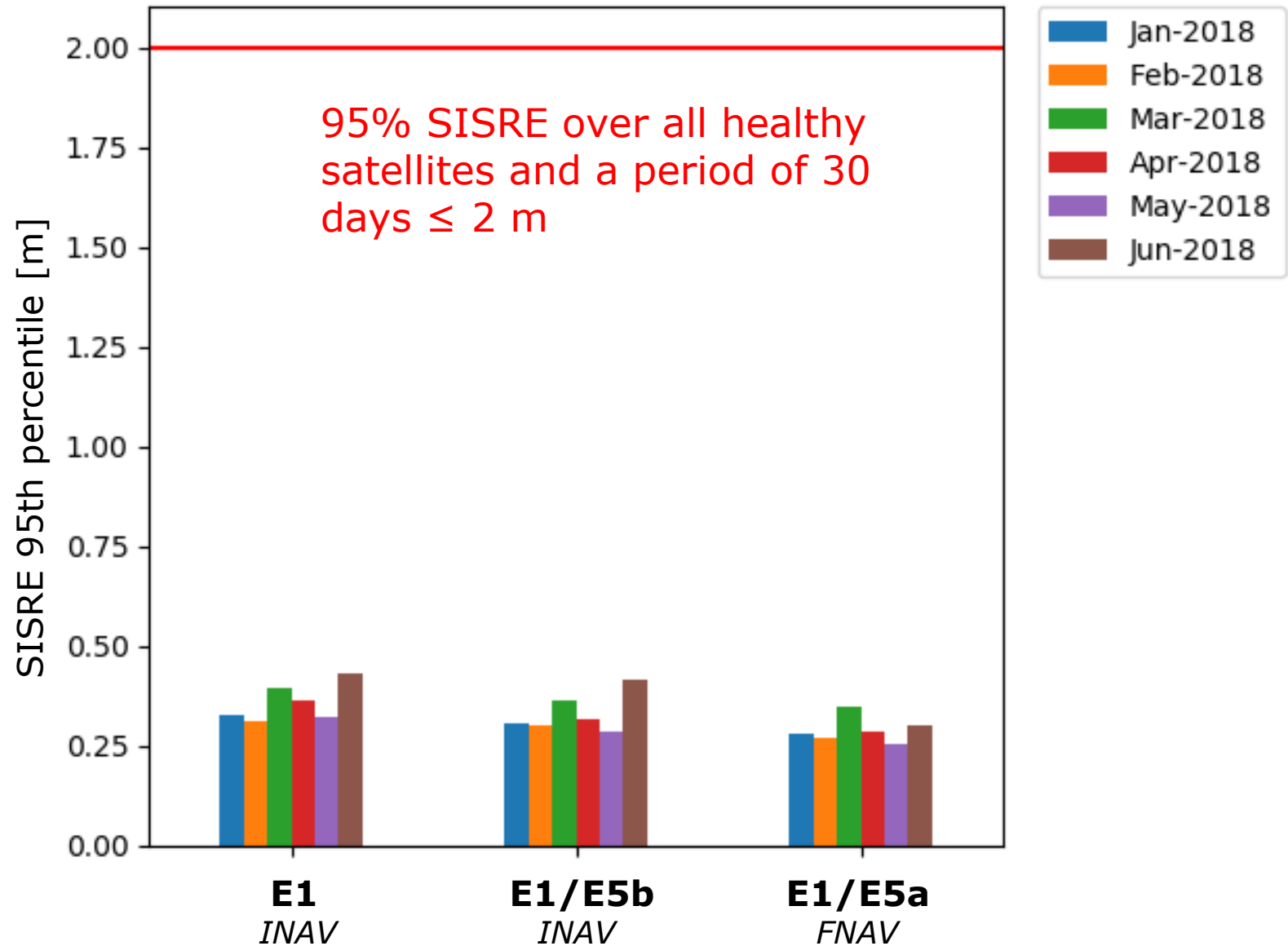
Galileo E1/E5a (FNAV)
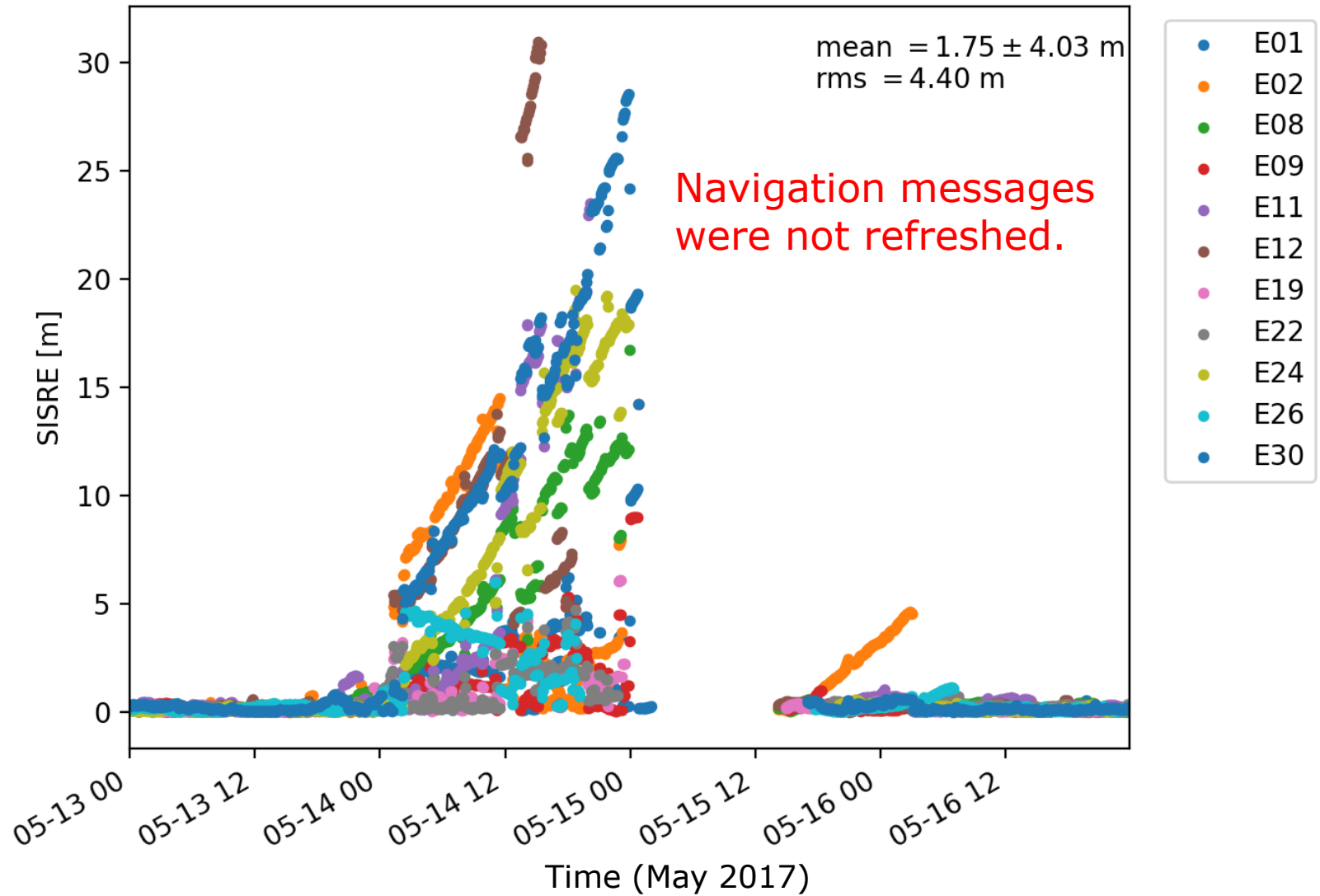
Part V

Conclusion and outlook

Kartverket

Conclusion and outlook

- Where SISRE solution shows comparable results to other studies (e.g. Montenbruck et. al (2018) or Galileo-IS-OS (2018)) with SISRE RMS of 16 cm and monthly 95th percentile of 30-50 cm

- Further validation of Where SISRE analysis needed

- Improvement of SISRE analysis by quality checking of input data and outlier rejection

Kartverket

Thank you for your attention!

Kartverket

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.

Kartverket

Galileo satellite constellation
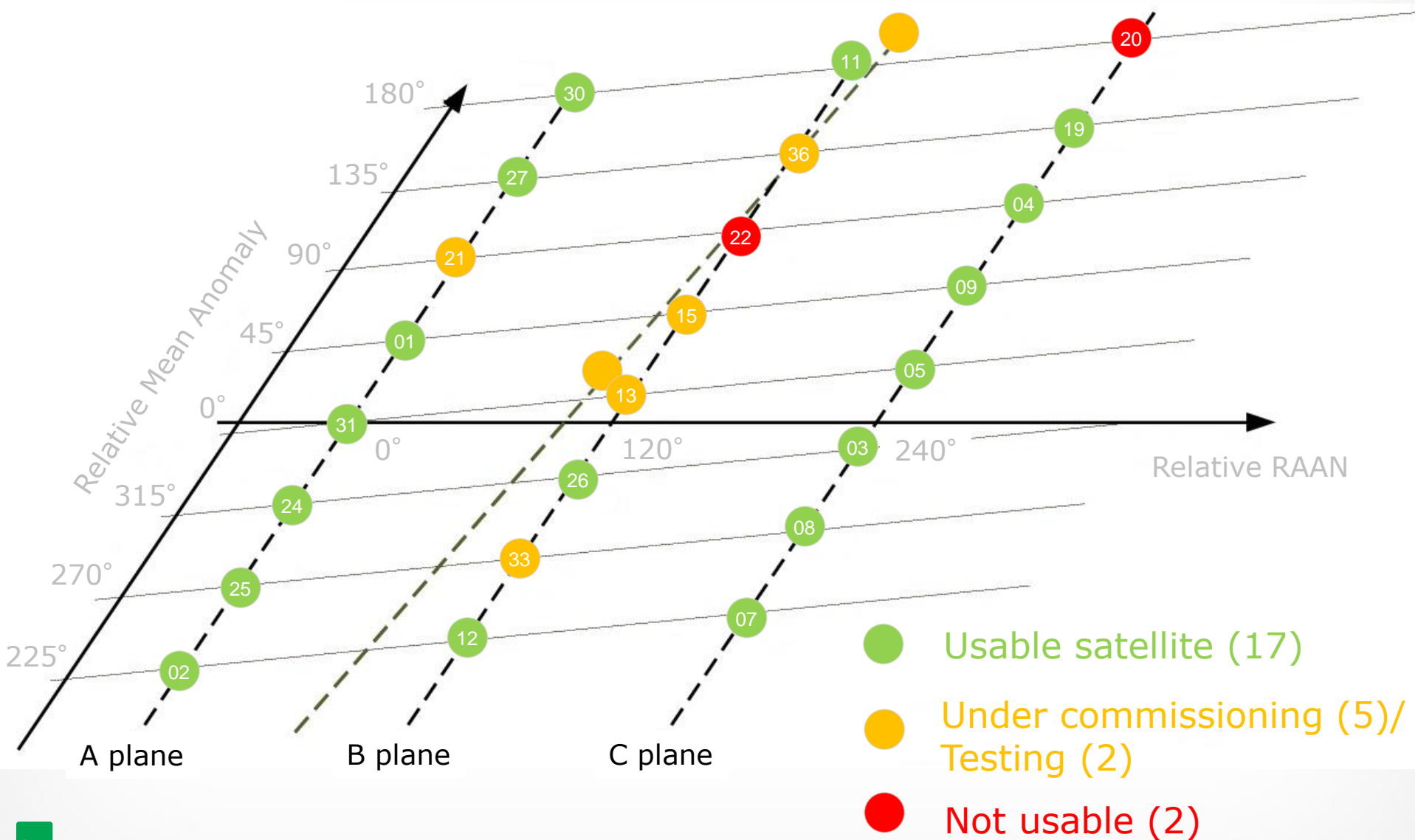
Satellite antenna relation

Broadcast orbit   Precise orbit

CoM

PCO

APC
[orbit + clock]

CoM
[orbit]

PCO

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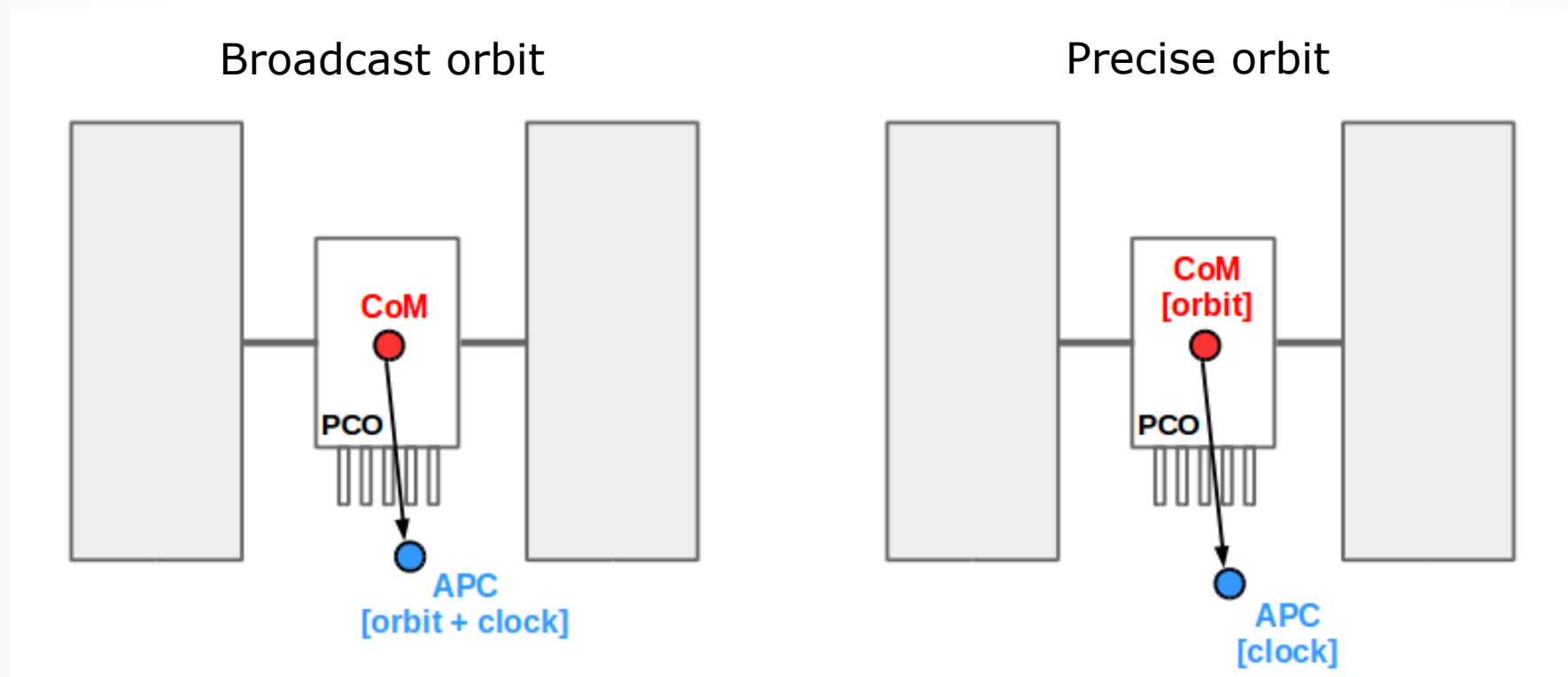
- Relate orbit and clock differences to center of mass by applying PCOs given by GSC and IGS (igs14.atx)

Kartverket

Montenbruck et. al (2018)

Flowchart:

IGS
DLR

Broad-cast orbits

IGS
CODE

Precise orbits

→ 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