State Space Technology - Principle, RTCM Standardization and Examples

Martin Schmitz

Geo++® GmbH
30827 Garbsen Germany
www.geopp.com

Abstract

State Space Technology - Principle, RTCM Standardization and Examples.

The basic principle of State Space Technology is the determination of the individual error components affecting different GNSS observable and to provide this information to users. Soon after the advent of GPS, state space information has been provided starting with precise ephemeris for post-processing applications.

In between various products are available e.g. by the International GNSS Service. Geo++ software is based on the state space principle and it is the fundamental approach within the real-time processing software GNSMART used for RTK Networking. State Space Technology has several benefits compared to conventional observation space methods. Consequently, RTCM currently develops state space representation (SSR) messages to provide a standardized format.

The talk discusses the principle of State Space Technology, summarizes the activities of the RTCM Committee's standardization and will show some examples.

Outline

- Introduction
- State Space Technology
  - Observation Space/State Space Representation
  - Application to Rover System
- RTCM SSR Working Group
  - 1st stage of RTCM SSR Messages
  - RTCM SSR Features
- RTCM SSR Interoperability Test
  - Test Setup
  - Test in Range Domain
  - Test in Position Domain
- Summary and Outlook

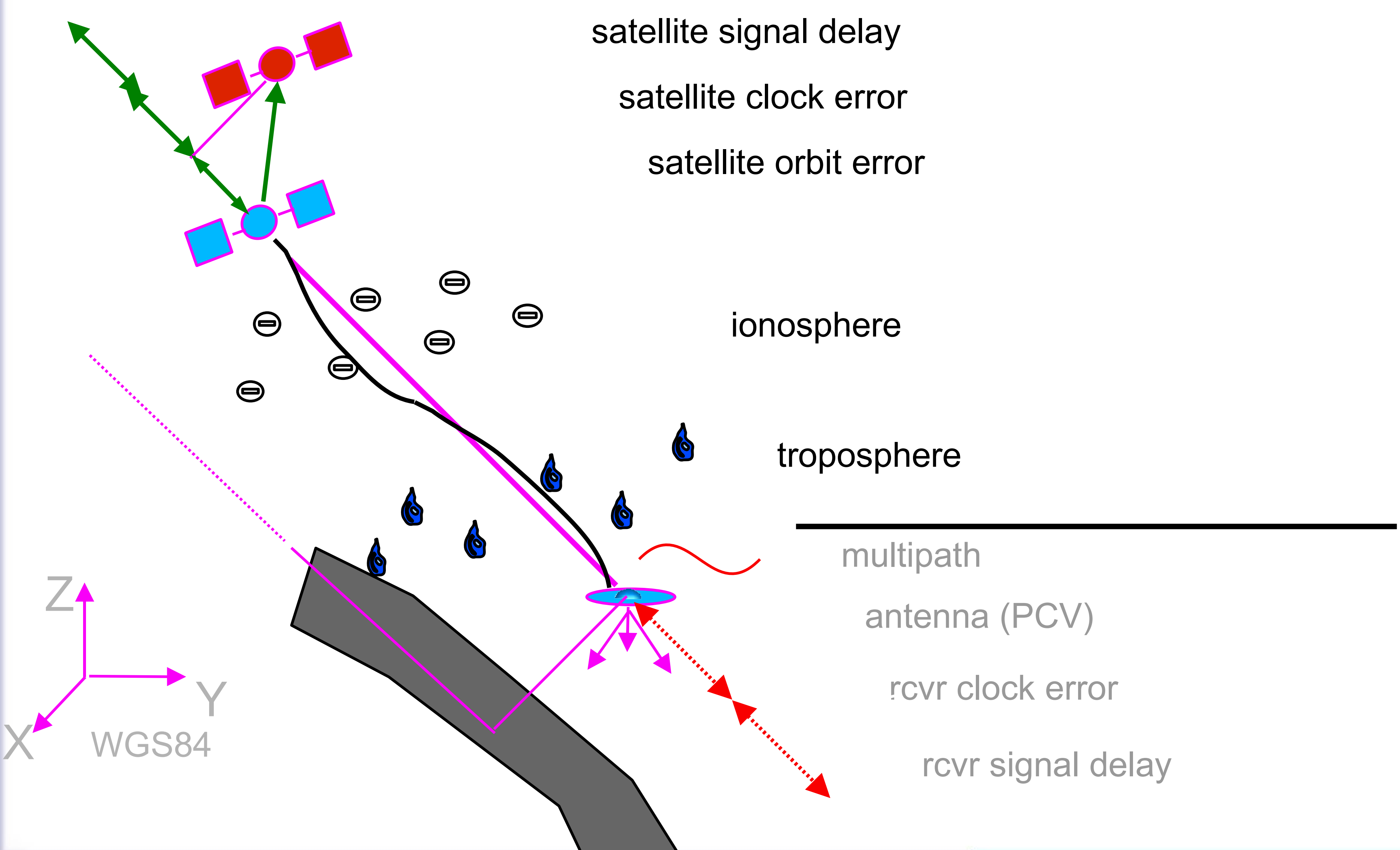
Introduction

- precise GNSS positioning requires the knowledge of all error components with corresponding accuracy

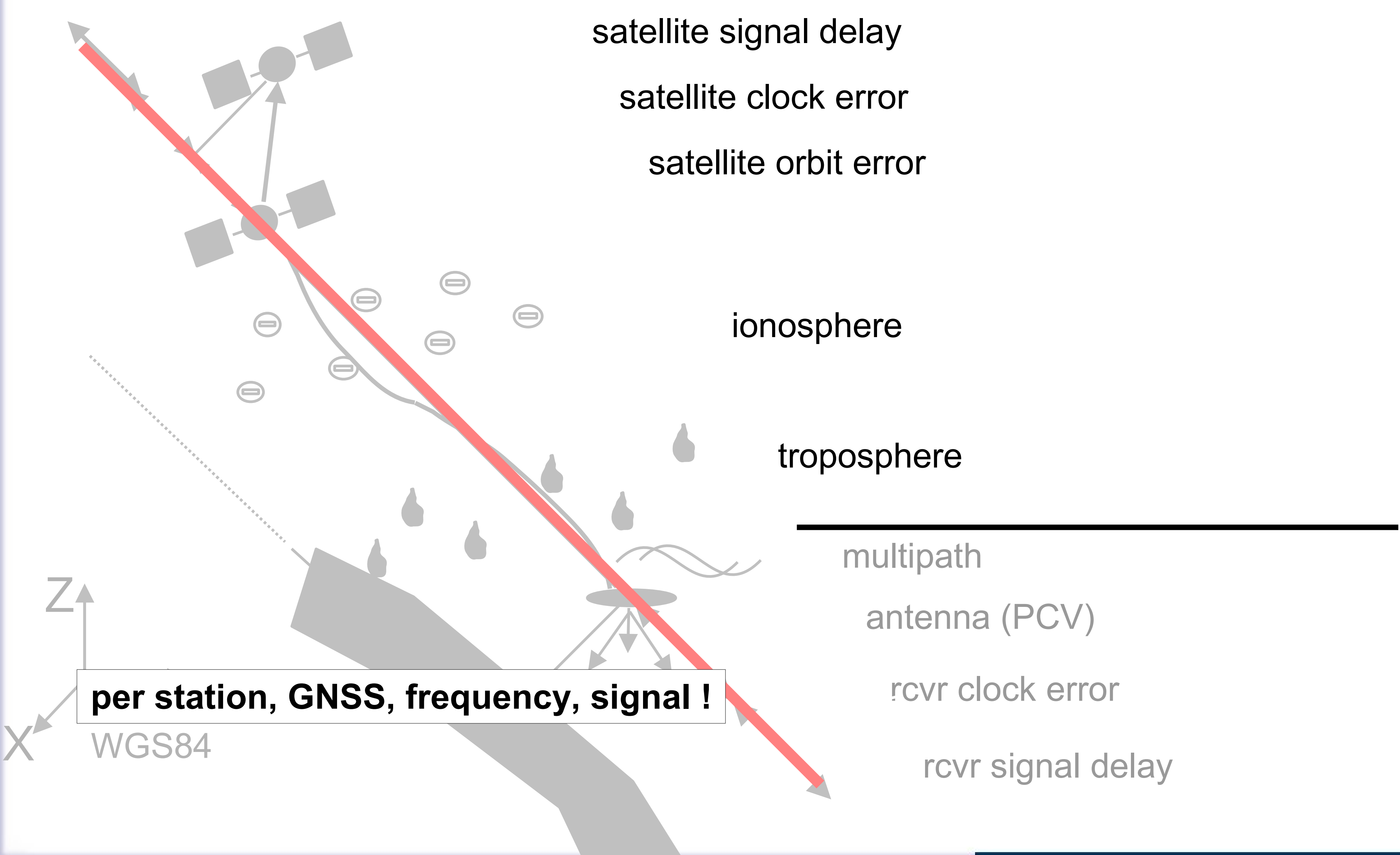
  - how do we provide this **information in real-time**?
  - what kind of **standardized formats** can be used?

- RTCM Standard
  - **SC104** Differential Global Navigation Satellite Systems (DGNSS)
  - supports developments of standards and regulations
  - latest development is support of **state space technology**

Introduction - Basic Error Components

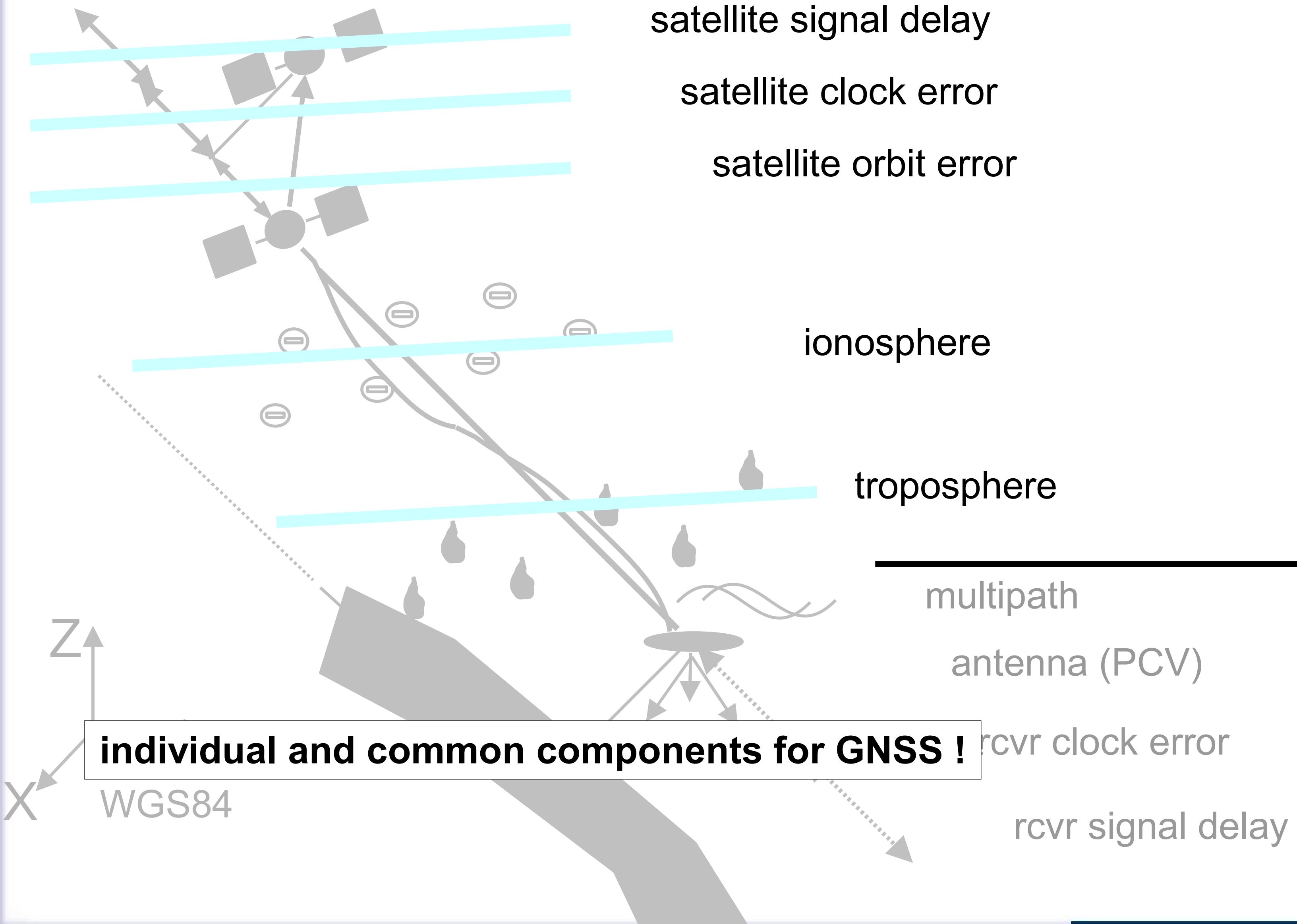


Observation Space Representation



per station, GNSS, frequency, signal !

State Space Representation



individual and common components for GNSS !

Observation Space Representation

- common procedure today
- **Observation Space Representation** (OSR)
  - distance dependent state parameters are derived and combined with reference station observations

- **OSR** describes lump sum of distance dependent GNSS errors

  Example:
- **RTK networking**
  - RTK services use network of reference stations
  - RTK rover use observations of reference station(s) and RTK network corrections* (e.g. VRS, PRS, MAC)

  * FKP considered SSR

VRS	Virtual Reference Station
PRS	Pseudo Reference Station
MAC	Master Auxiliary Concept
FKP	Flächenkorrekturparameter

State Space Representation

- provides all GNSS errors for direct use
  - **State Space Representation** (SSR)
  - functional and optional stochastic state description

- **SSR** describes each individual GNSS error

Example:

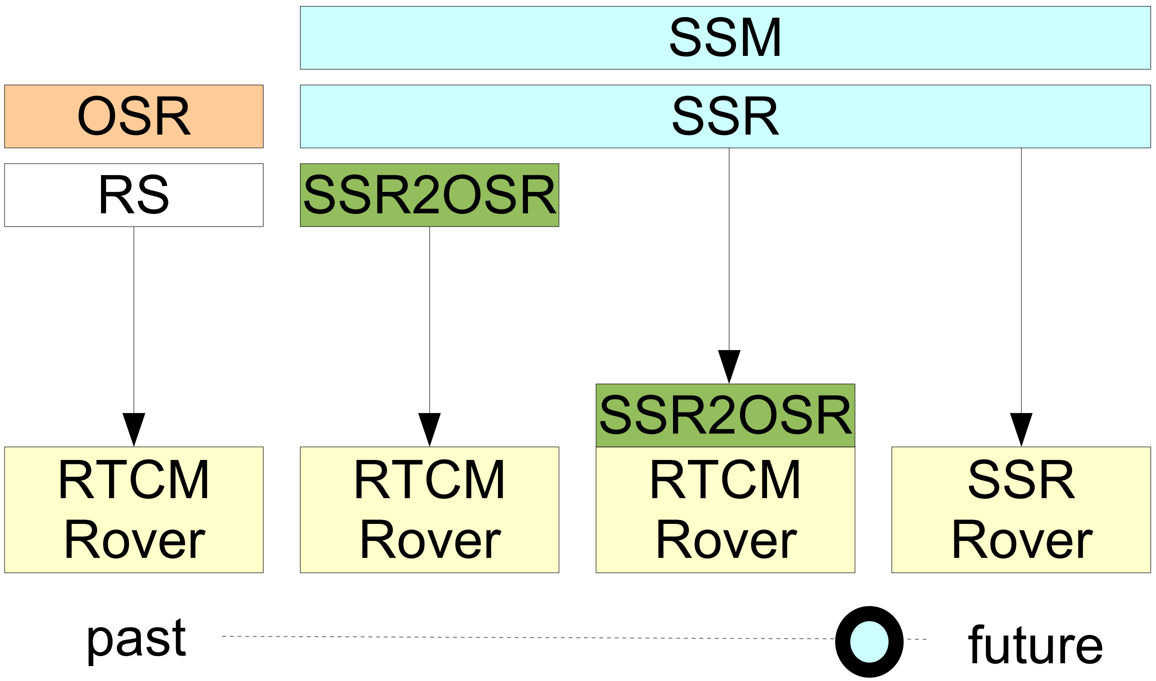
- **Precise Point Positioning (PPP)**
    - observations of single GNSS receiver
    - global or regional real-time network
    - rover uses state space information
      (e.g. IGS products)

Benefits of State Space Representation

- SSR of GNSS errors offers **better performance**
  - improves modeling and prediction (e.g. troposphere)
  - minimizes station dependent errors (e.g. multipath)
  - independent of GNSS (e.g. troposphere)
- SSR requires **low bandwidth for large areas**
  - practicable for certain communication links (e.g. radio, TV)
- **broadcast** capability
  - unlimited number of users and costs (Internet, mobile phone)
- **different services** with different accuracies (cm + dm) possible
- **single and dual frequency** application
- important for upcoming **variety of GNSS signals**

Application to Rover System

- today conventional **OSR** with RTCM rover
- **SSR** with conventional **OSR rover**
  - conversion of SSR into standardized OSR format (RINEX, RTCM)
    - in service center
    - or at rover
- direct usage of SSR in **SSR rover** for the future/under development



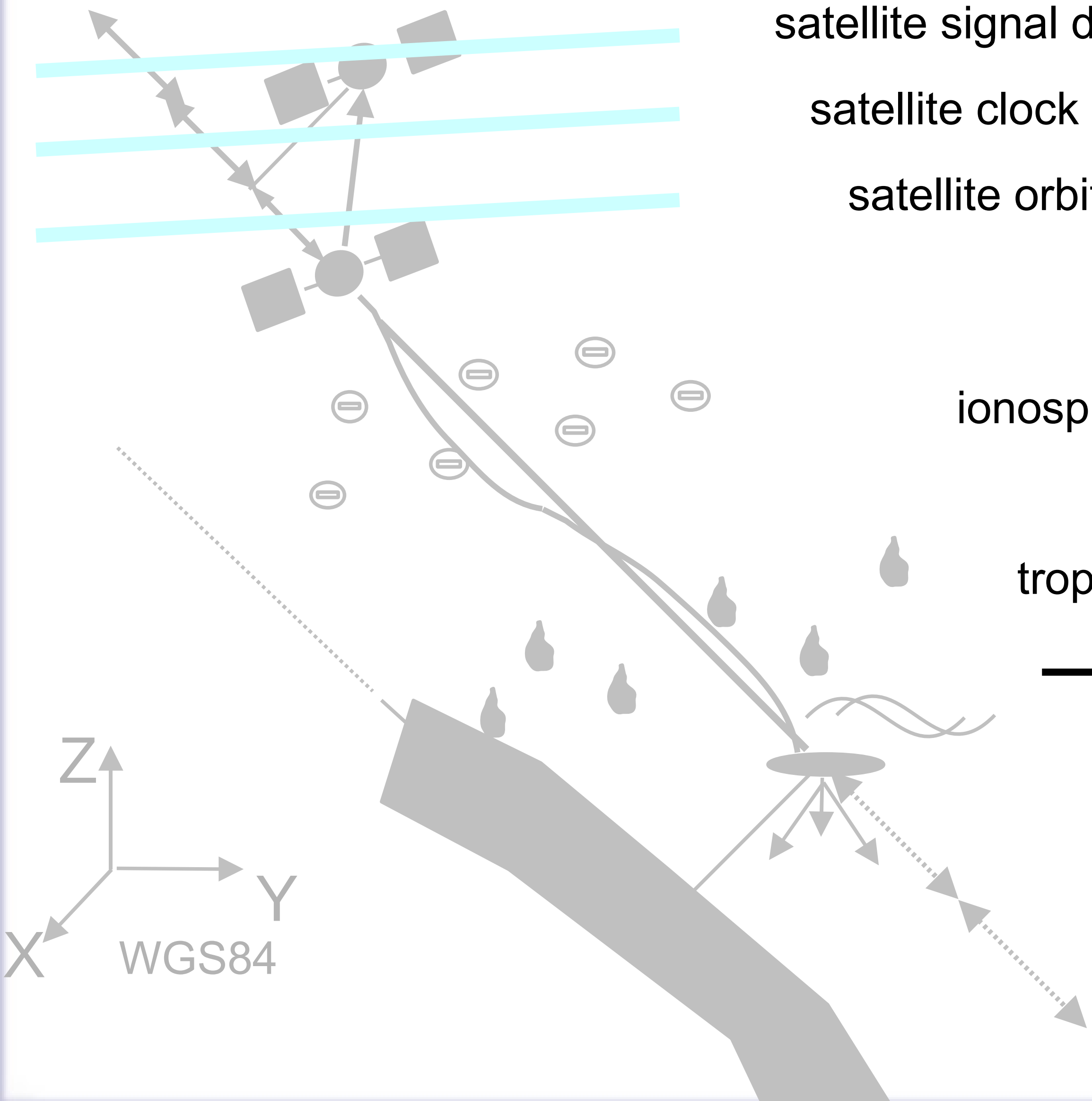
- SSM State Space Monitoring
- SSM/SSR concept operationally applied with Geo++ GNSMART

RTCM SSR Working Group

- International Standard required
- Working Group of RTCM SC-104 DGNSS Standards
- proposed work plan consists of three major steps/stages:
  - The development of messages for precise orbits and satellite clocks. This is compatible to the **basic PPP** mode using IGS products. Such messages will enable real time PPP for dual frequency receivers: **DF-RT-PPP**.
  - The development of vertical TEC (VTEC) messages. This will enable RT-PPP for **single frequency** receivers: **SF-RT-PPP**.
  - The development of slant TEC (STEC) messages, tropospheric messages and satellite signal delay messages. This will enable **RTK-PPP**.

Current message set (in 2010) deals only with the first stage DF-RT-PPP, based on orbit corrections, clock corrections and code biases.

RTCM SSR DF-RT-PPP (1st stage)



satellite signal delay (i.e code bias)

satellite clock error

satellite orbit error

ionosphere

troposphere

multipath

antenna (PCV)

rcvr clock error

rcvr signal delay

RTCM State Parameters

RTCM SSR Messages

- RTCM SSR messages of 1st stage
- enables basic PPP (DF-RT-PPP)

Message Type	**Message Name**
1057	SSR **GPS Orbit** Correction
1058	SSR **GPS Clock** Correction
1059	SSR **GPS Code Bias**
1060	SSR GPS Combined Orbit and Clock Corrections
1061	SSR GPS URA
1062	SSR GPS High Rate Clock Correction
1063	SSR **GLONASS Orbit** Correction
1064	SSR **GLONASS Clock** Correction
1065	SSR **GLONASS Code Bias**
1066	SSR GLONASS Combined Orbit and Clock Correction
1067	SSR GLONASS URA
1068	SSR GLONASS High Rate Clock Correction

RTCM SSR Messages Features

- **orbit** corrections **refer to broadcast** orbits
  - reduces bandwidth
- **clock** corrections **refer to broadcast** clocks
  - reduces bandwidth
- satellite reference **datum** may refer to ITRF or regional realization
  - support of regional datums like ETRF89, NAD, JGD2000, ...
- **consistency** of data
  - known issue with SSR
    (“use only consistent data from one provider”)
  - important issue to extend existing messages

RTCM SSR Interoperability Test Setup

- several **different** RTCM **SSR streams**
  - based on a **global network** of reference stations
  - streams all generated within the IGS Real Time Pilot Project (**IGS RTPP**)
  - streams generally available from the BKG Ntrip broadcaster

- **independent** GNSS processing software packages
  to generate **SSR data** (orbit/clock corrections and code biases)

- **independent** software for RTCM SSR **decoding and encoding**

- independent DF-RT-PPP **RTCM SSR client** software

RTCM SSR Interoperability Test Setup

- four independent **GNSS processing software** packages
  - GNSMART by Geo++
  - RETICLE by DLR/GSOC
  - RETINA by ESA/ESOC
  - RTNet by GPS Solutions (used by BKG)

- three independent **RTCM SSR decoding and encoding** softwares
  - BKG Ntrip State Space Server (BNS)
  - GNSMART by Geo++
  - RETICLE by DLR/GSOC

- two different **DF-RT-PPP RTCM SSR client** softwares
  - BKG Ntrip Client (BNC)
  - GNSMART by Geo++

BKG	Bundesamt für Kartopgraphie und Geodäsie
DLR/GSOC	Deutsches Zentrum für Luft- und Raumfahrt/ German Space Operation Center
ESA/ESOC	European Space Agency/ European Space Opservati

RTCM SSR Interoperability Test in Range Domain

take into account

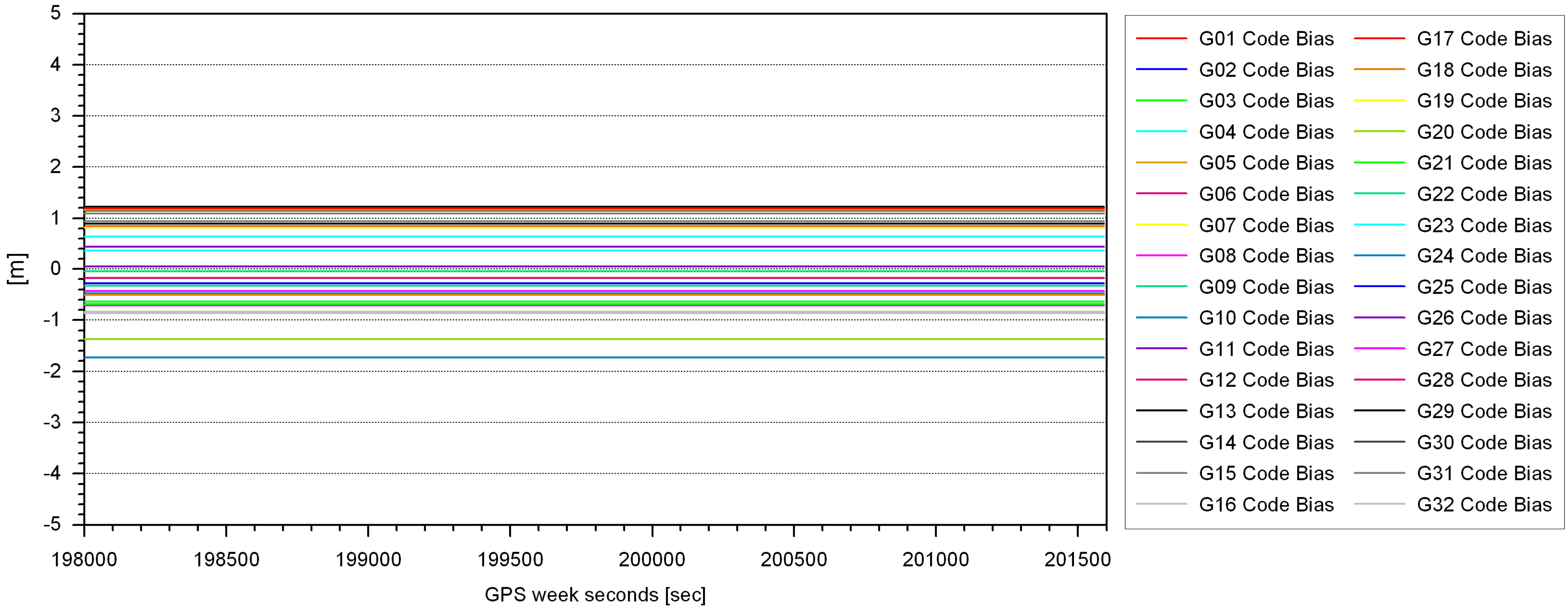
- **individual components** must be **consistently generated**
  - consistency essential objective of the RTCM SSR concept
  - different approaches implemented in SSR generation software
  - estimation of all SSR parameters simultaneously or
    use of external information
    (e.g. IGS Ultra-Rapid Orbits, IGS code biases)

- individual components might differ

- **combined SSR correction is consistent**
  - different streams serve an application equally

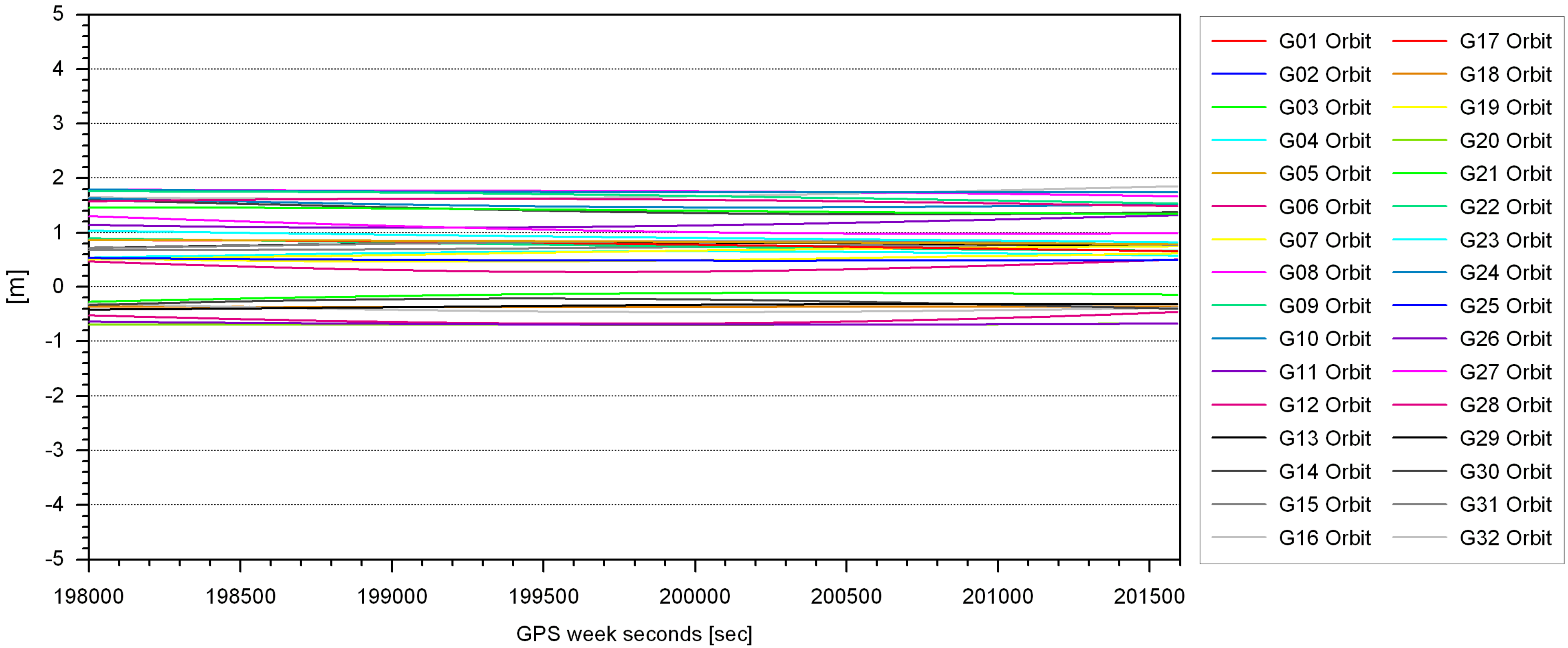
Individual RTCM SSR components

- example of code biases from DLR stream, (1584 138h)
  - magnitude/range between -2 to +1.5 m



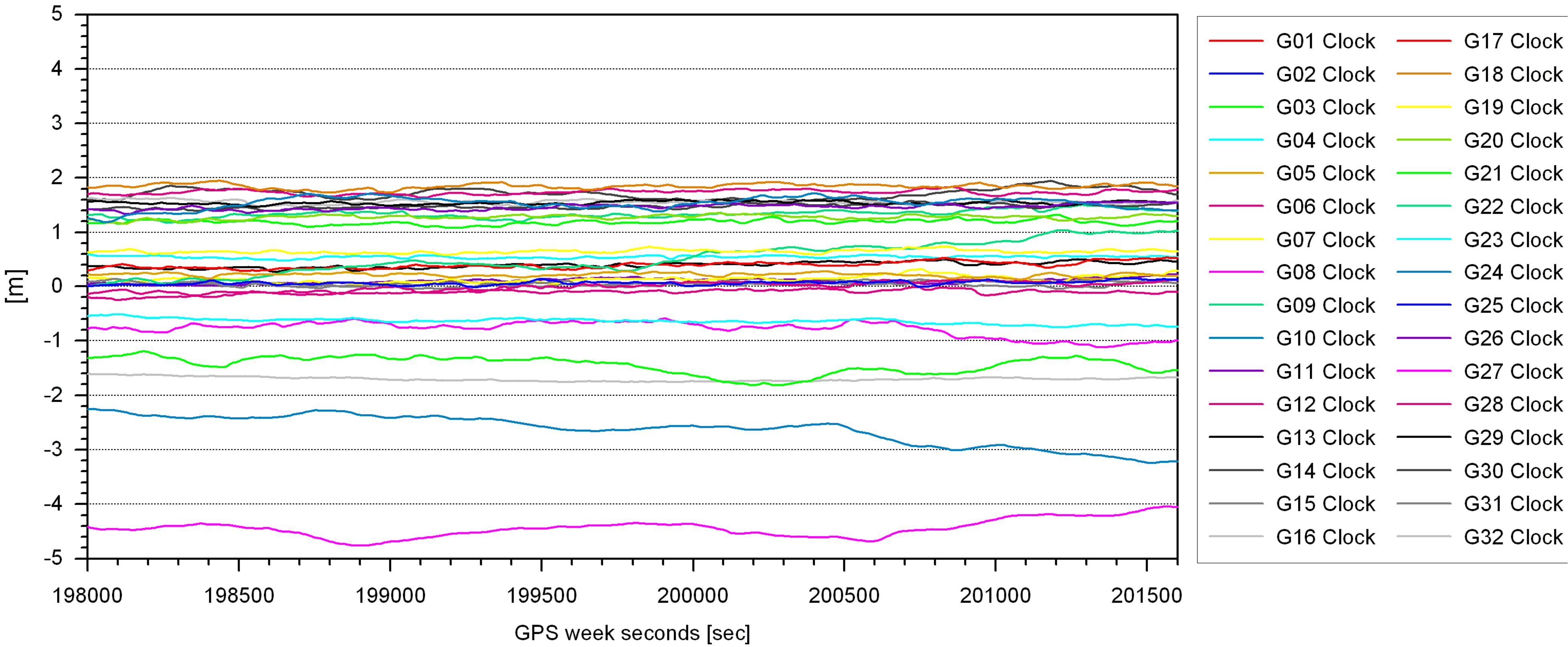
Individual RTCM SSR components

- example of orbit corrections from DLR stream, (1584 138h)
  - magnitude/range between -0.5 to +2 m



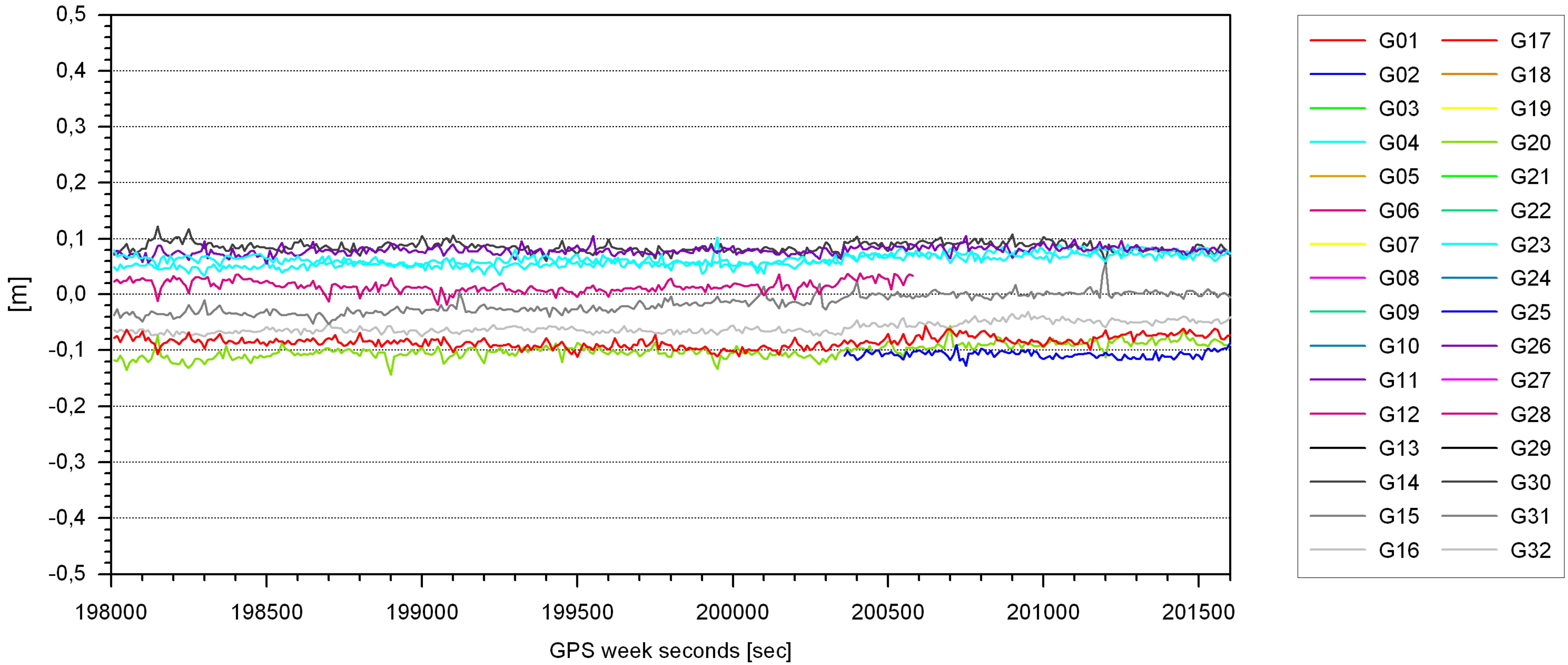
Individual RTCM SSR components

- example of clock corrections from DLR stream, (1584 138h)
  - magnitude/range between -5 to +2 m



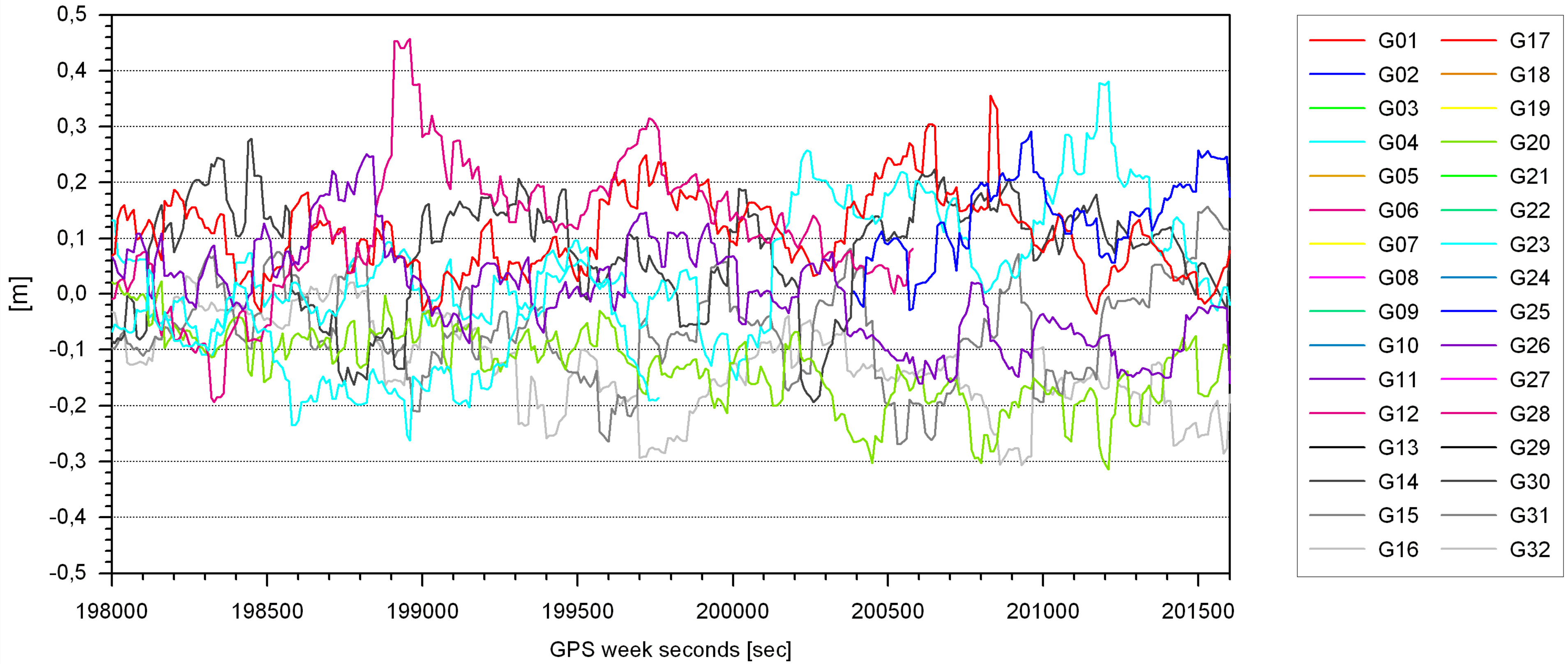
Interoperability Test in Range Domain

- comparison of ionospheric free C0 range correction computed from RTCM SSR, stream BKG vs DLR (1584 138h)



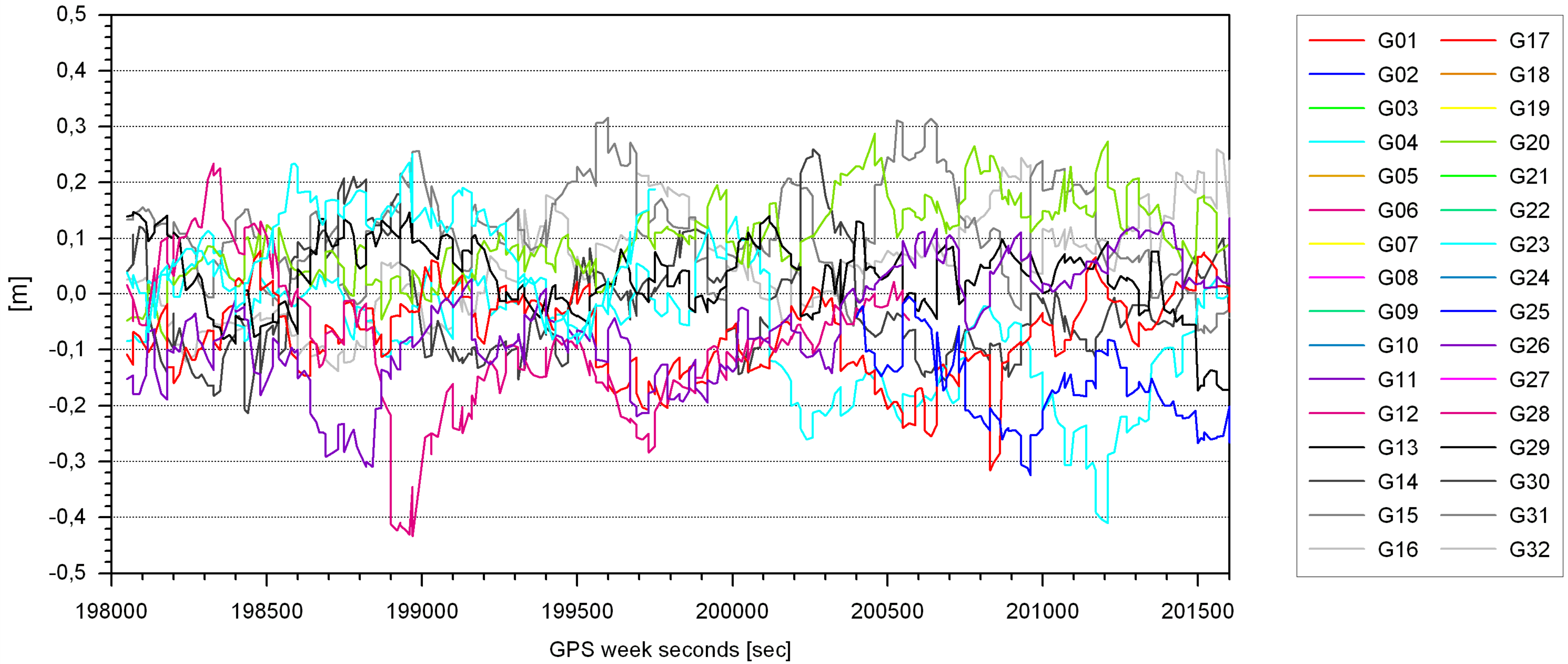
Interoperability Test in Range Domain

- comparison of ionospheric free C0 range corrections computed from RTCM SSR, stream Geo++ vs BKG (1584 138h)



Interoperability Test in Range Domain

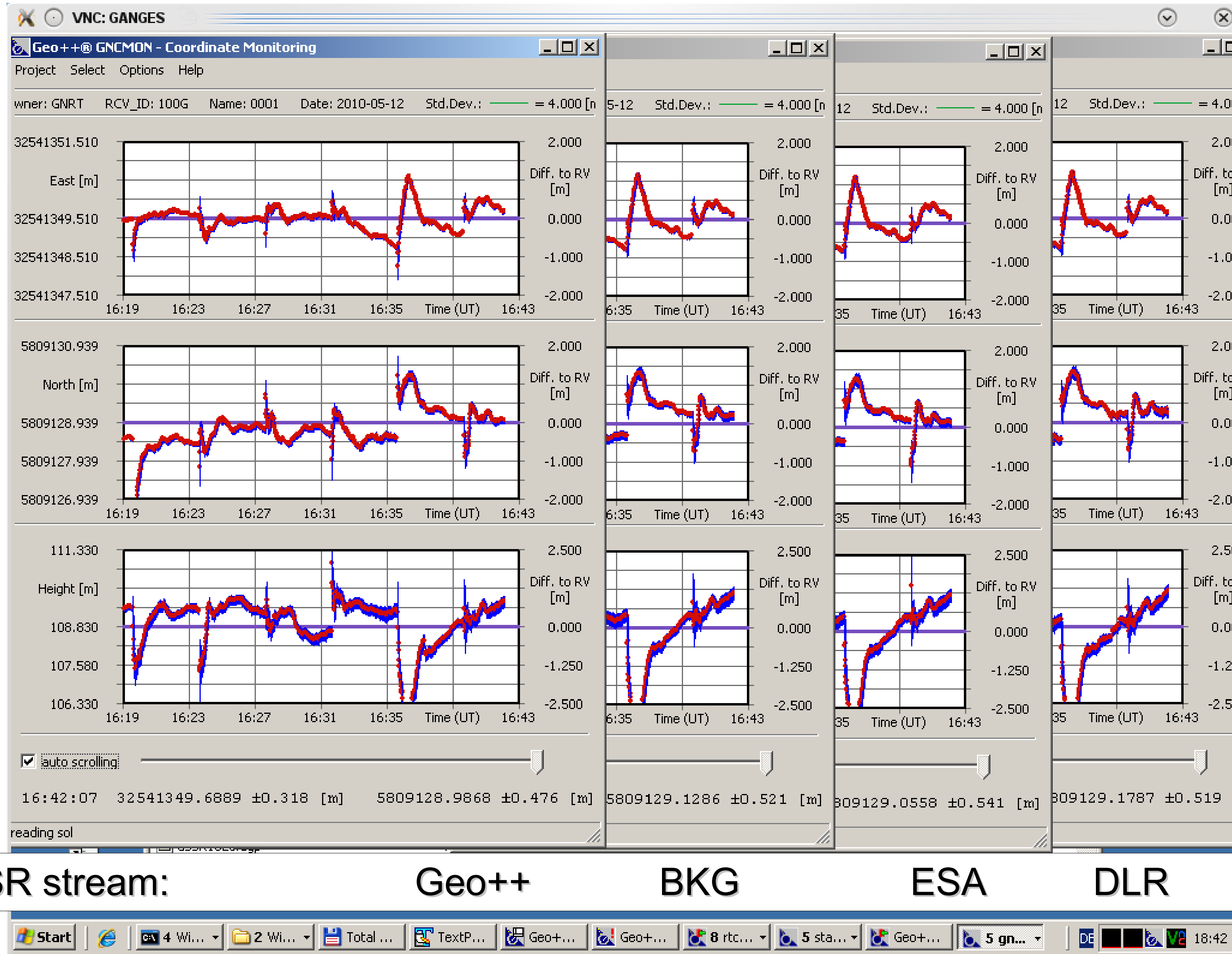
- comparison of ionospheric free C0 range corrections computed from RTCM SSR, stream ESA vs Geo++ (1584 138h)



Interoperability Test in Position Domain

- actual **application of the RTCM SSR** corrections to GNSS rover data
  - **rigorous** approach of interoperability testing
  - comparing position performance
- example of **Geo++ RTCM SSR client**
  - **different RTCM SSR streams** (Geo++, BKG, ESA, DLR)
  - Geo++ RTCM SSR client still uses SSR to OSR
  - dual-frequency data from a rover (located at Geo++, Garbsen, Germany)
  - 1 Hz GPS + GLONASS data
  - **reset of position filter** every 4 min to analyze convergence

Interoperability Test Results in Position Domain



SSR stream: Geo++ BKG ESA DLR

Interoperability Test in Position Domain

interoperability tests demonstrate

- different RTCM SSR streams work with the RTCM SSR client
- clients show **high correlation** in position domain
  and **comparable standard deviations**
- position estimation is superimposed by multipath
  and high noise of ionospheric free code linear combination of rover data
- agreement at **expected performance level**
  of about 1 to 2 decimeters for such an application
- **content and the application** of the RTCM SSR streams is **consistent**
  for all four depicted streams

Status of RTCM SSR Messages

- **final set of RTCM SSR messages** for 1st stage defined and message numbers assigned
- **interoperability test** successfully conducted
- RTCM SSR messages proposed for **voting** in RTCM SC-104 (Mai 2010 meeting)
- to be included in **RTCM 3 Standard**

Summary and Outlook

- increasing use **state space technology** (SSR)
- **new RTCM SSR messages** (orbit, clock, code biases)
- conducted tests demonstrate
  - **interoperability** between different RTCM SSR implementation, different SSR generating software packages, different RTCM SSR clients (only one shown)
  - application of RTCM SSR format serves 1st stage of **dual-frequency real-time PPP** (DF-RT-PPP) with respect to content and implementation

- **strong demand for a real-time PPP streaming standard** underlined by
  - already existing number of implementations
  - number of participants in interoperability testing
  - feedback/acceptance from several individuals, groups and institutions

- **broad application of RTCM SSR expected**, which will push further developments