RTCM State Space Representation Messages, Status and Plans

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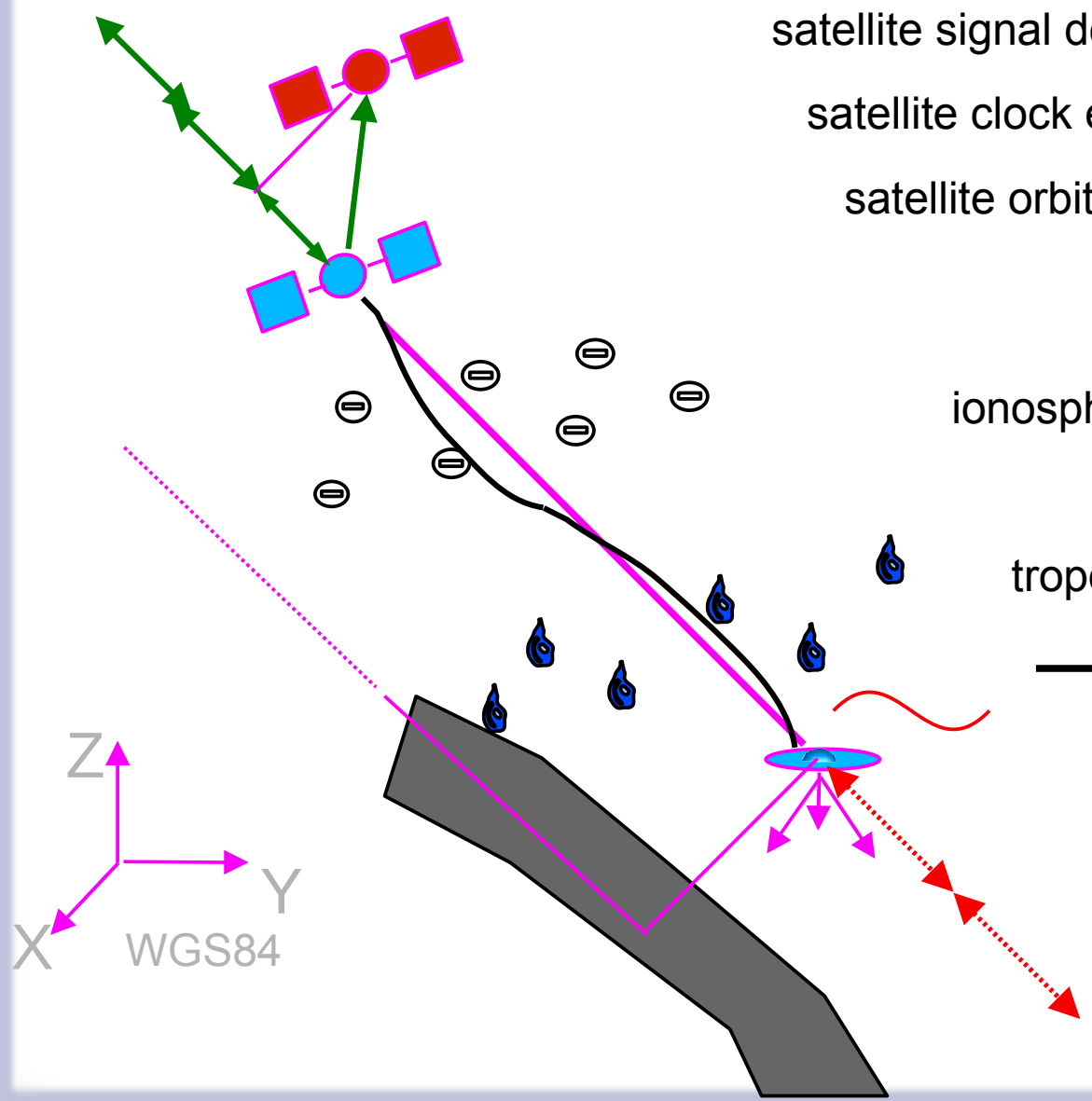
Outline

- Introduction
  - Observation Space/
    State Space Representation
- Status of RTCM SSR Messages
  - proposed work plan
  - 1st stage of RTCM SSR Messages
  - Messages and Features
- Plans for RTCM SSR Messages
  - 2nd stage of RTCM SSR Messages
- Future Plans for RTCM SSR Messages
  - 3rd stage of RTCM SSR Messages
- Summary

Introduction

- precise **GNSS positioning** requires the knowledge of **all error** components with corresponding **accuracy** for a variety of **different applications**
  - how do we provide this **information in real-time**?
  - what kind of open **standardized formats** can be used?

Introduction - Simplified Error Components



satellite signal delay

satellite clock error

satellite orbit error

ionosphere

troposphere

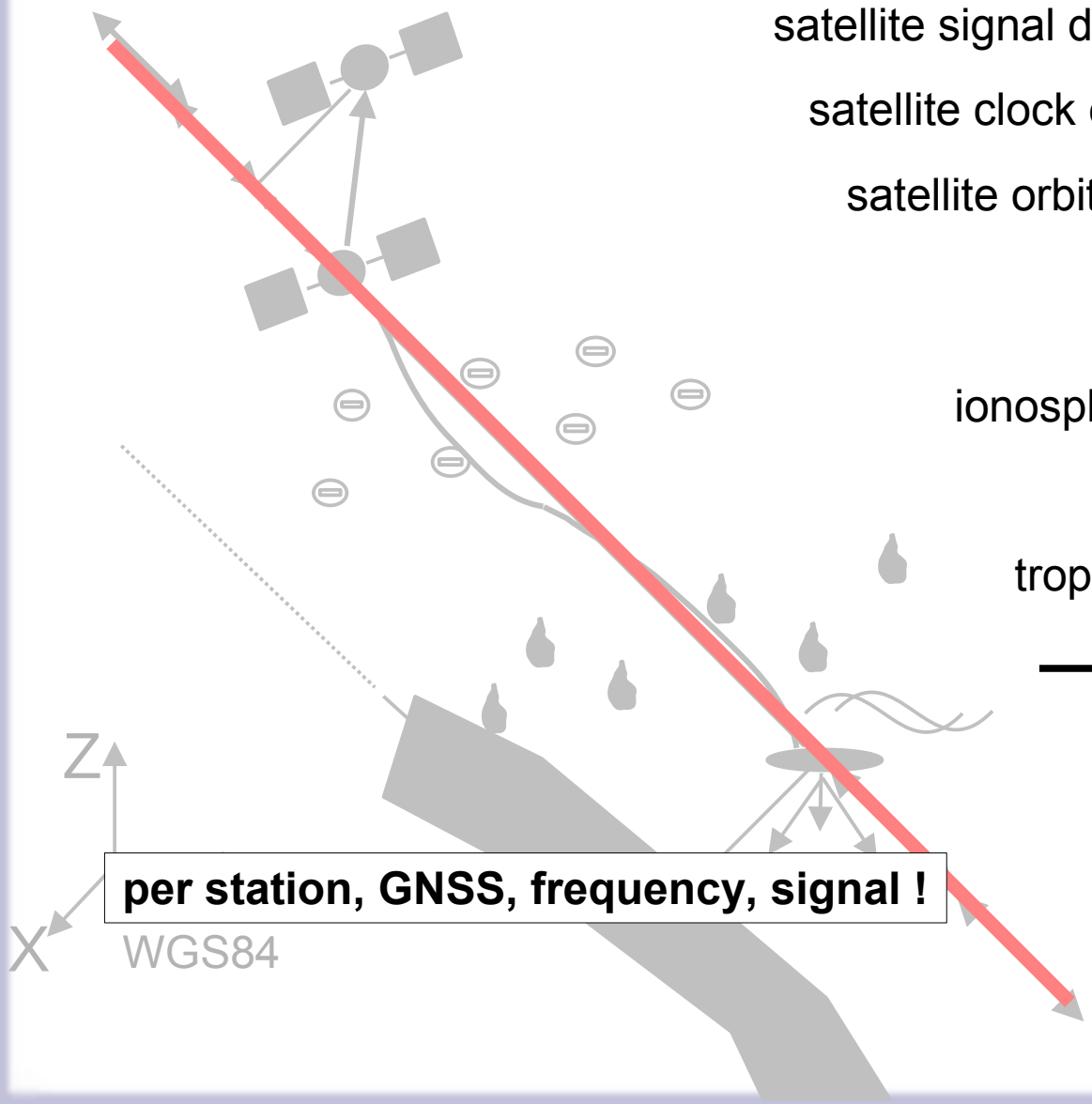
multipath

antenna (PCV)

rcvr clock error

rcvr signal delay

Introduction - Observation Space Representation



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antenna (PCV)

rcvr clock error

rcvr signal delay

per station, GNSS, frequency, signal !

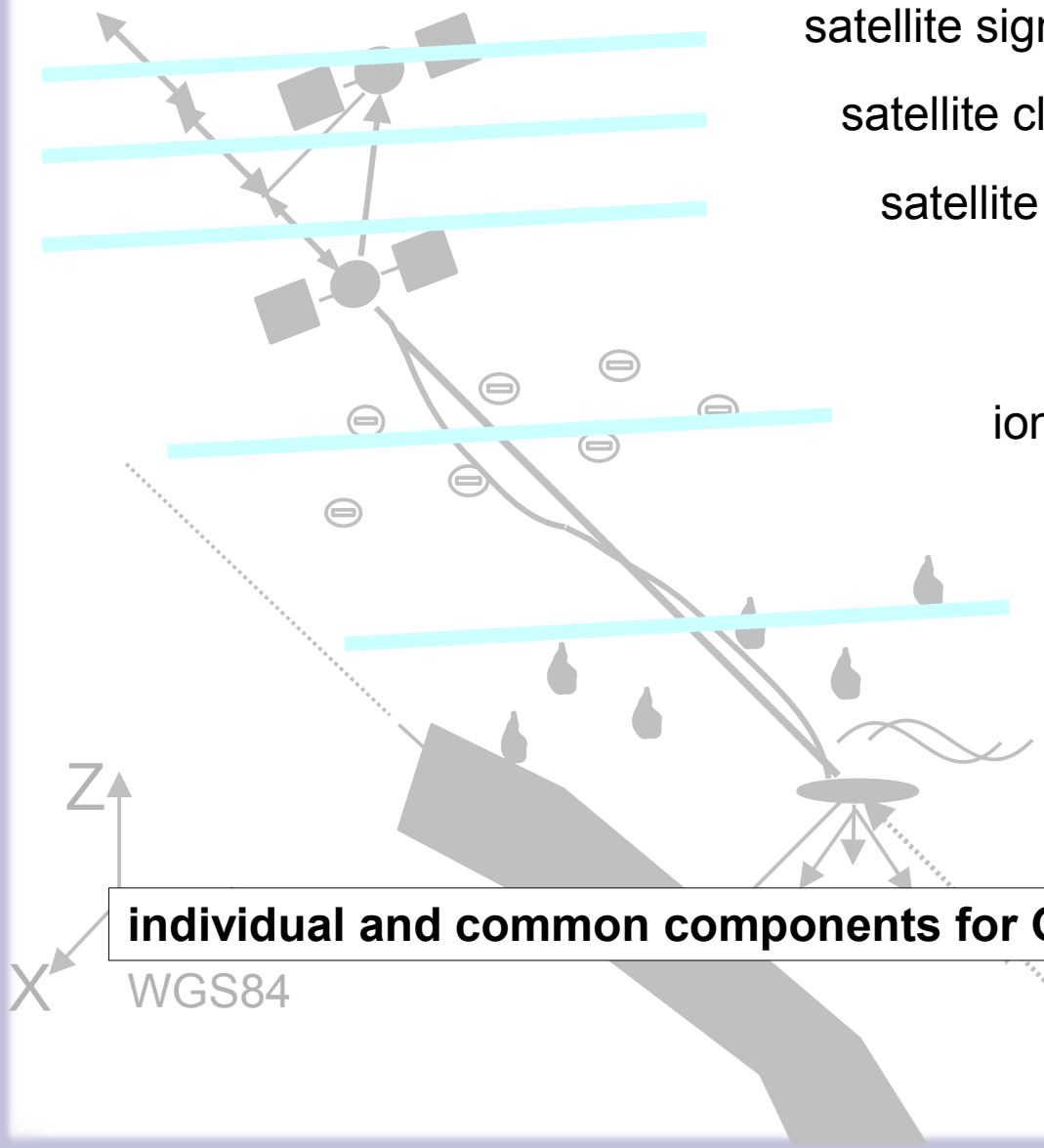
Introduction - Observation Space Representation

- **common procedure today**
  - **Observation Space Representation** (OSR)
    - distance dependent state parameters are derived and combined with reference station observations
  - OSR describes **lump sum** of GNSS **error**s
- 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

Introduction - State Space Representation



satellite signal delay

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individual and common components for GNSS !

Introduction - State Space Representation

- **state-of-the-art procedure today**
- 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**)

Status of RTCM SSR Messages

- **RTCM** (Radio Technical Commission for Maritime Services)
- development of
  - International Standards
  - Open Standards

- **RTCM SC-104** DGNSS Standards
  (Differential Global Navigation Satellite Systems)

- **Working Group State Space Representation**
  - since 2007
  - RTCM SSR Messages

Status of RTCM SSR Messages

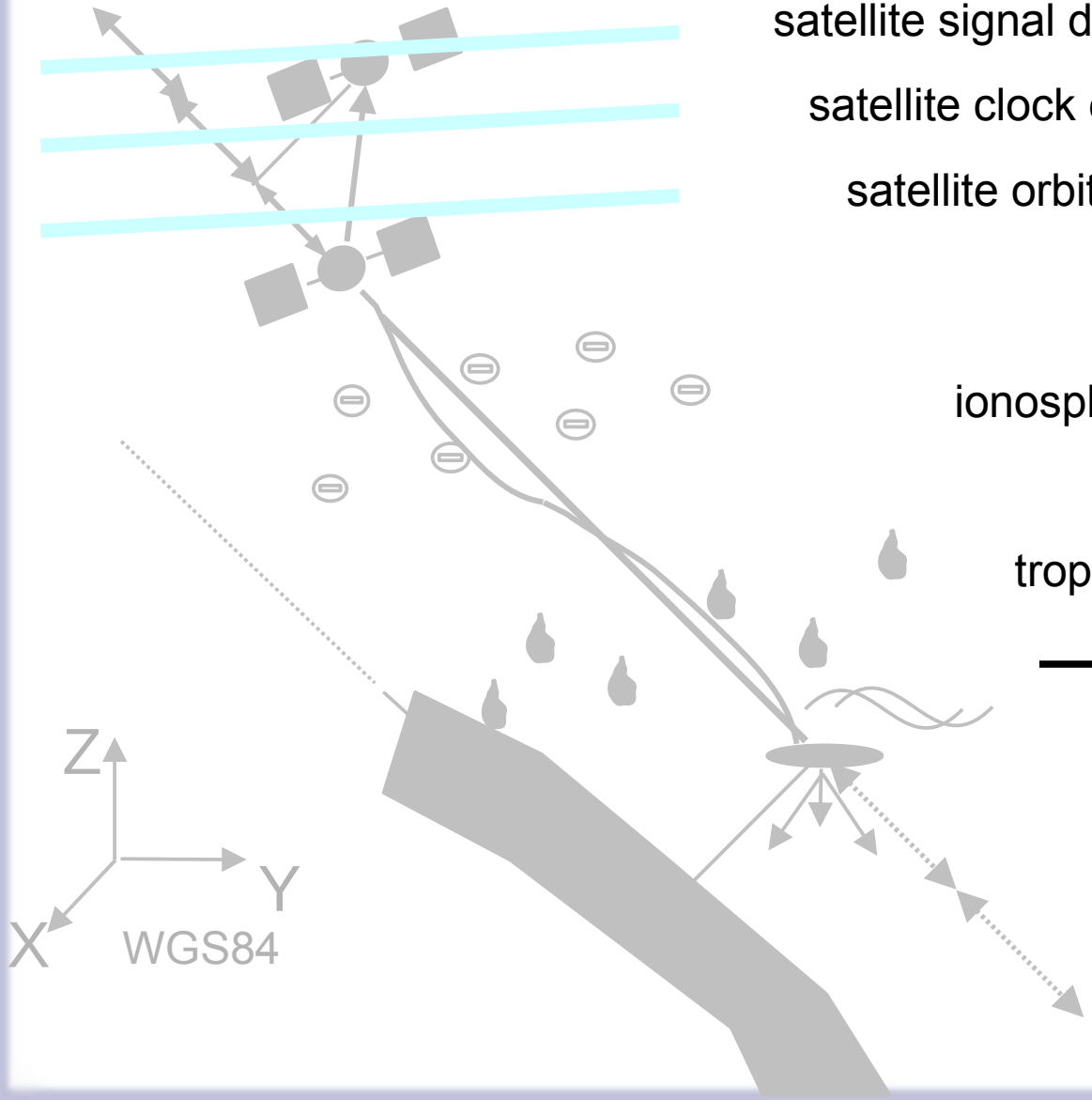
- proposed work plan consists of
  three major steps/stages and the development of messages:

  - 1st stage:
    for precise **orbits**, satellite **clocks**, satellite **code biases**
    as well as **quality indicator** (URA)
    - compatible to the basic PPP mode using IGS products
    - enables real time PPP for dual frequency receivers: DF-RT-PPP

  - 2nd stage:
    for **vertical** TEC (VTEC) **ionosphere** and satellite phase biases
    - enables RT-PPP for single frequency receivers: SF-RT-PPP

  - 3rd stage:
    for slant TEC (STEC) **ionosphere** and **troposphere**
    - enables PPP-RTK

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



RTCM State Parameters

satellite signal delay (i.e. code bias)

satellite clock error

satellite orbit error

ionosphere

troposphere

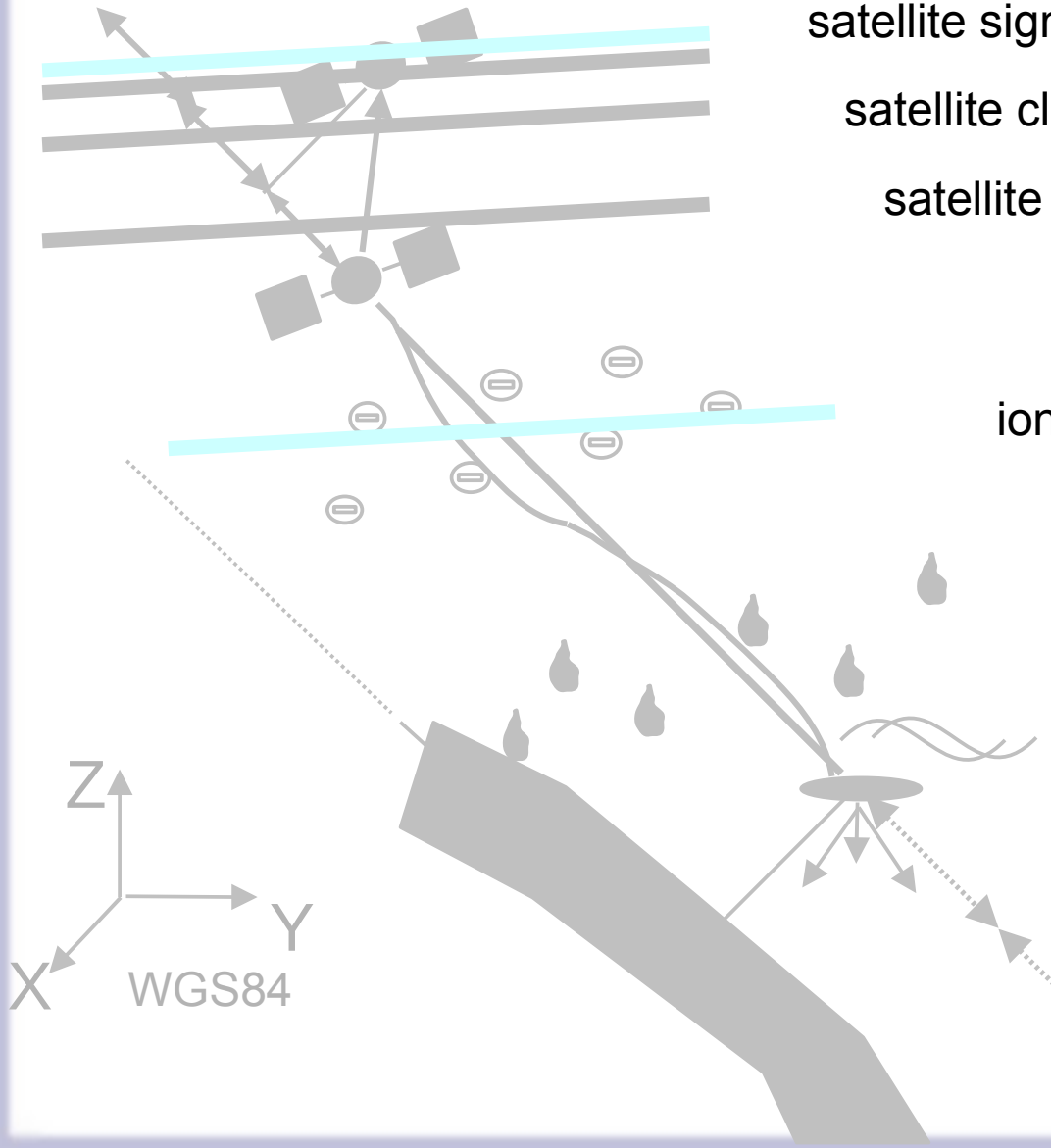
multipath

antenna (PCV)

rcvr clock error

rcvr signal delay

RTCM SSR DF-RT-PPP (2st stage)



RTCM State Parameters

satellite signal delay (i.e. phase bias)
(code bias)

satellite clock error

satellite orbit error

ionosphere (i.e. VTEC)

troposphere

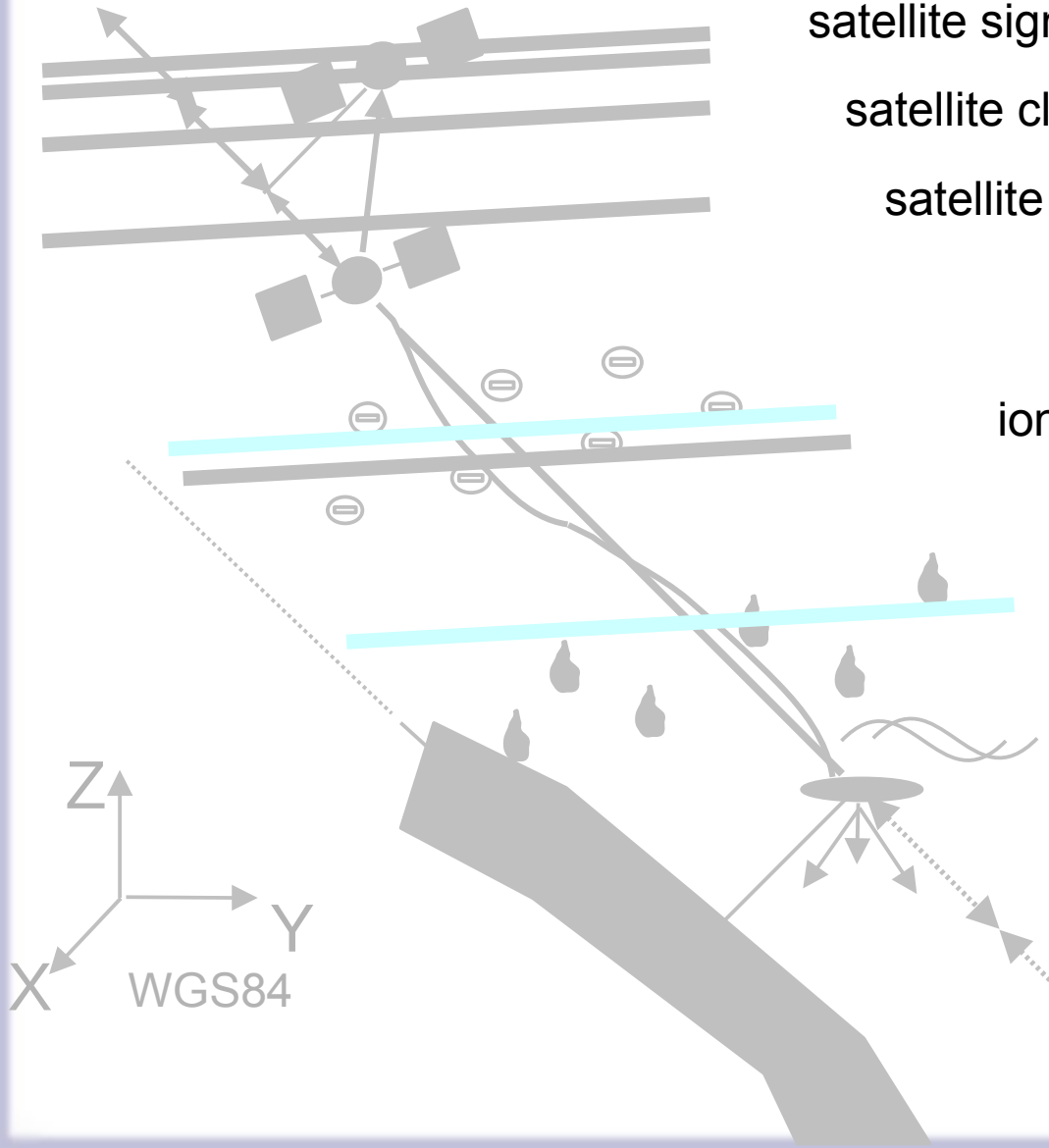
multipath

antenna (PCV)

rcvr clock error

rcvr signal delay

RTCM SSR RTK-PPP (3rd stage)



RTCM State Parameters

satellite signal delay (i.e. phase bias)
(code bias)

satellite clock error

satellite orbit error

ionosphere (i.e. STEC)
(VTEC)

troposphere

multipath

antenna (PCV)

rcvr clock error

rcvr signal delay

Status of RTCM SSR Messages

- **1st stage** of **RTCM SSR Messages** passed Mai 2011

- included in RTCM 3 Standard

  - **RTCM STANDARD 10403.1**
    DIFFERENTIAL GNSS
    (GLOBAL NAVIGATION SATELLITE SYSTEMS)
    SERVICES – VERSION 3
    DEVELOPED BY RTCM SPECIAL COMMITTEE NO. 104
    JULY 1, 2011

  - Amendment 5 RTCM Paper 142-2011-SC104-STD

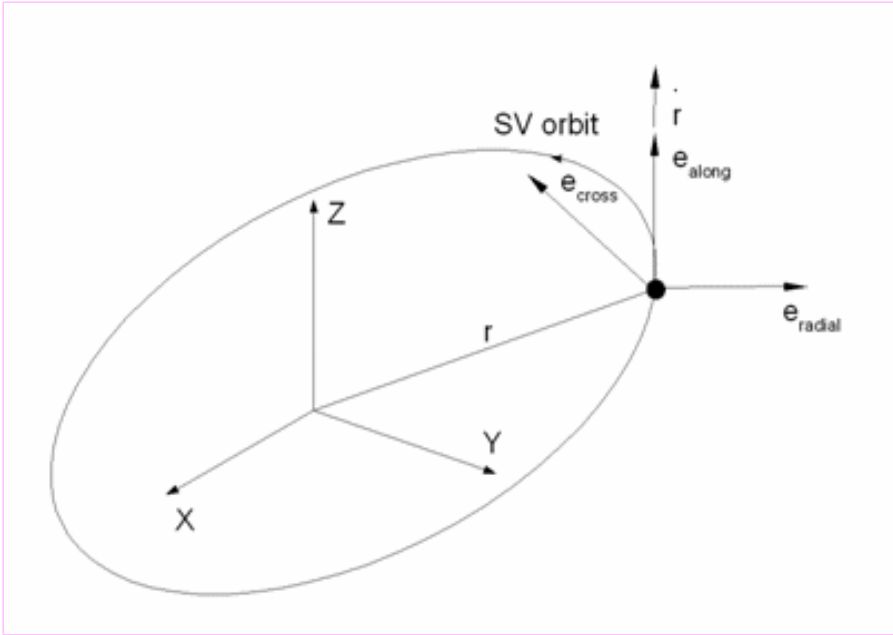
RTCM SSR Messages

- 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 - Orbit

- **orbit** corrections
  refer to broadcast orbits
  - reduces bandwidth

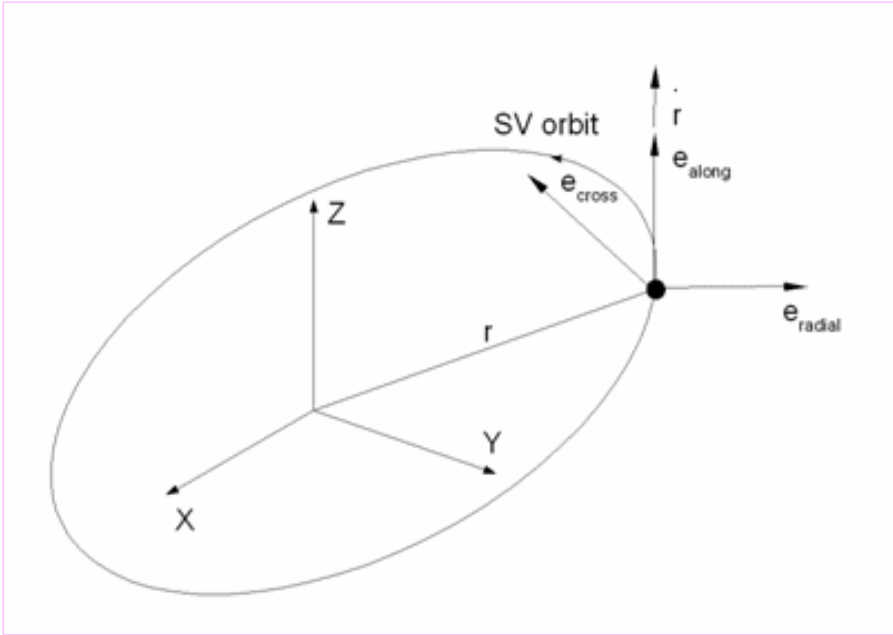


$$\boldsymbol{X}_{orbit} = \boldsymbol{X}_{broadcast} - \delta\boldsymbol{X}$$

$\boldsymbol{X}_{orbit}$	satellite position corrected by SSR Orbit Correction message
$\boldsymbol{X}_{broadcast}$	satellite position computed according to corresponding GNSS ICD from broadcast ephemeris parameter set identified by IOD/IODE in SSR Orbit Correction message
$\delta\boldsymbol{X}$	satellite position correction

RTCM SSR Messages - Orbit

- orbit corrections defined **radial**, **along**-track, **cross**-track
  - reduces bandwidth



$$\boldsymbol{e}_{along} = \frac{\dot{\boldsymbol{r}}}{|\dot{\boldsymbol{r}}|}$$

$$\boldsymbol{e}_{cross} = \frac{\boldsymbol{r} \times \dot{\boldsymbol{r}}}{|\boldsymbol{r} \times \dot{\boldsymbol{r}}|}$$

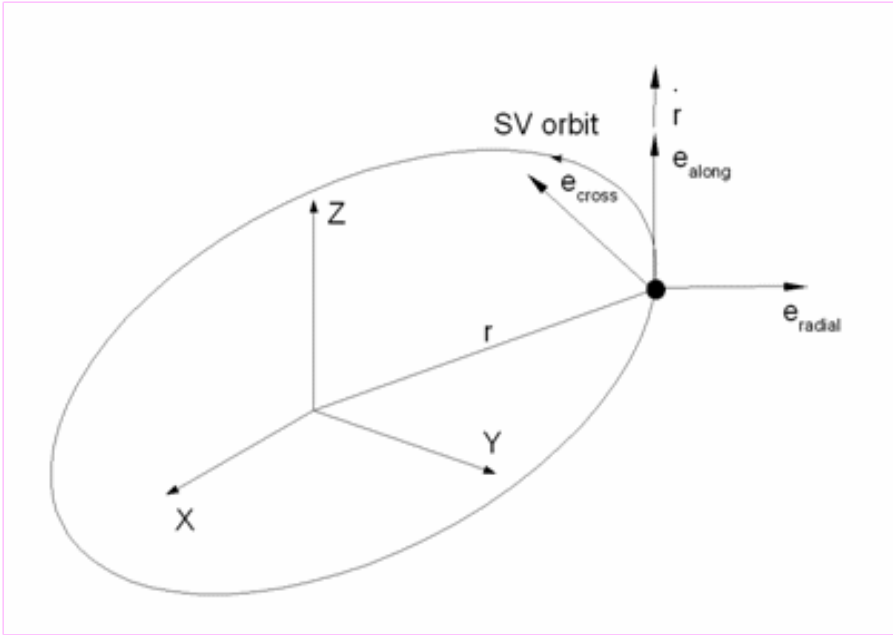
$$\boldsymbol{e}_{radial} = \boldsymbol{e}_{along} \times \boldsymbol{e}_{cross}$$

$$\delta \boldsymbol{X} = [\boldsymbol{e}_{radial} \quad \boldsymbol{e}_{along} \quad \boldsymbol{e}_{cross}]\ \delta \boldsymbol{O}$$

$\boldsymbol{r} = \boldsymbol{X}_{\boldsymbol{broadcast}}$	satellite broadcast position vector
$\dot{\boldsymbol{r}} = \dot{\boldsymbol{X}}_{\boldsymbol{broadcast}}$	satellite broadcast velocity vector
$\boldsymbol{e}_i$	direction unit vector, i = {radial, along, cross}
$\delta \boldsymbol{O}$	orbit correction vector

RTCM SSR Messages - Orbit

- orbit correction consists of
  - **correction** term
  - **velocity** correction term



$$\delta \boldsymbol{O} = \begin{bmatrix} \delta O_{radial} \\ \delta O_{along} \\ \delta O_{cross} \end{bmatrix} + \begin{bmatrix} \delta \dot{O}_{radial} \\ \delta \dot{O}_{along} \\ \delta \dot{O}_{cross} \end{bmatrix} (t - t_0)$$

t	time
t_0	reference time obtained from SSR Orbit Correction message
$\delta O_i, \delta \dot{O}_i$	orbit correction terms from SSR Orbit message, i = {radial, along, cross}

RTCM SSR Messages – Orbit
Satellite Reference Datum Feature

- definition of coordinate reference system required
- satellite reference **datum** may refer to
  - ITRF for **global** services
  - **regional** realization related to the tectonic plate (e.g. ETRF, NAD, JGD, ...)
- **Satellite Reference Datum flag** indicates
  - “0” = ITRF or “1” = regional
- actual coordinate reference system identified by stream of service provider/ upcoming RTCM Transformation Message
- no transformation for rover required

RTCM SSR Messages – Satellite Clock

- **clock** corrections **refer to broadcast** clocks
  - reduces bandwidth
- clock corrections terms
  - C0, C1, C2 **polynomial coefficients**
- **relativistic effects** handled as defined in corresponding GNSS Interface Documents

$$t_{satellite} = t_{broadcast} - \frac{\delta C}{Speed\ of\ light}$$

$t_{broadcast}$	satellite time computed according to corresponding GNSS ICD from broadcast clock parameters, identified by IOD/IODE of corresponding SSR Orbit Correction message
$t_{satellite}$	satellite time corrected by SSR Clock Correction message
δC	clock correction obtained from SSR Clock Correction message

$$\delta C = C_0 + C_1(t - t_0) + C_2(t - t_0)^2$$

t	time
t_0	reference time obtained from SSR Clock Correction message
C_i	polynomial coefficients from SSR Clock Correction message, i = {0, 1, 2}

RTCM SSR Messages – Satellite High Rate Clock

- **high rate clock**
- additional message type
- **correction** term added to satellite clock correction
  - enables higher resolution
  - enables higher update rates

- RTCM SSR clock messages are **multi-stage message types**
  - two constituents (polynomial, high rate clock)
  - high rate clock optional
  - both constituents describe complete state of clock

RTCM SSR Messages – Satellite Code Bias, URA

- satellite **code bias**
  - **absolute** correction term
    (relative code biases obtained defining one bias to zero)
  - for every **signal** and **tracking** mode

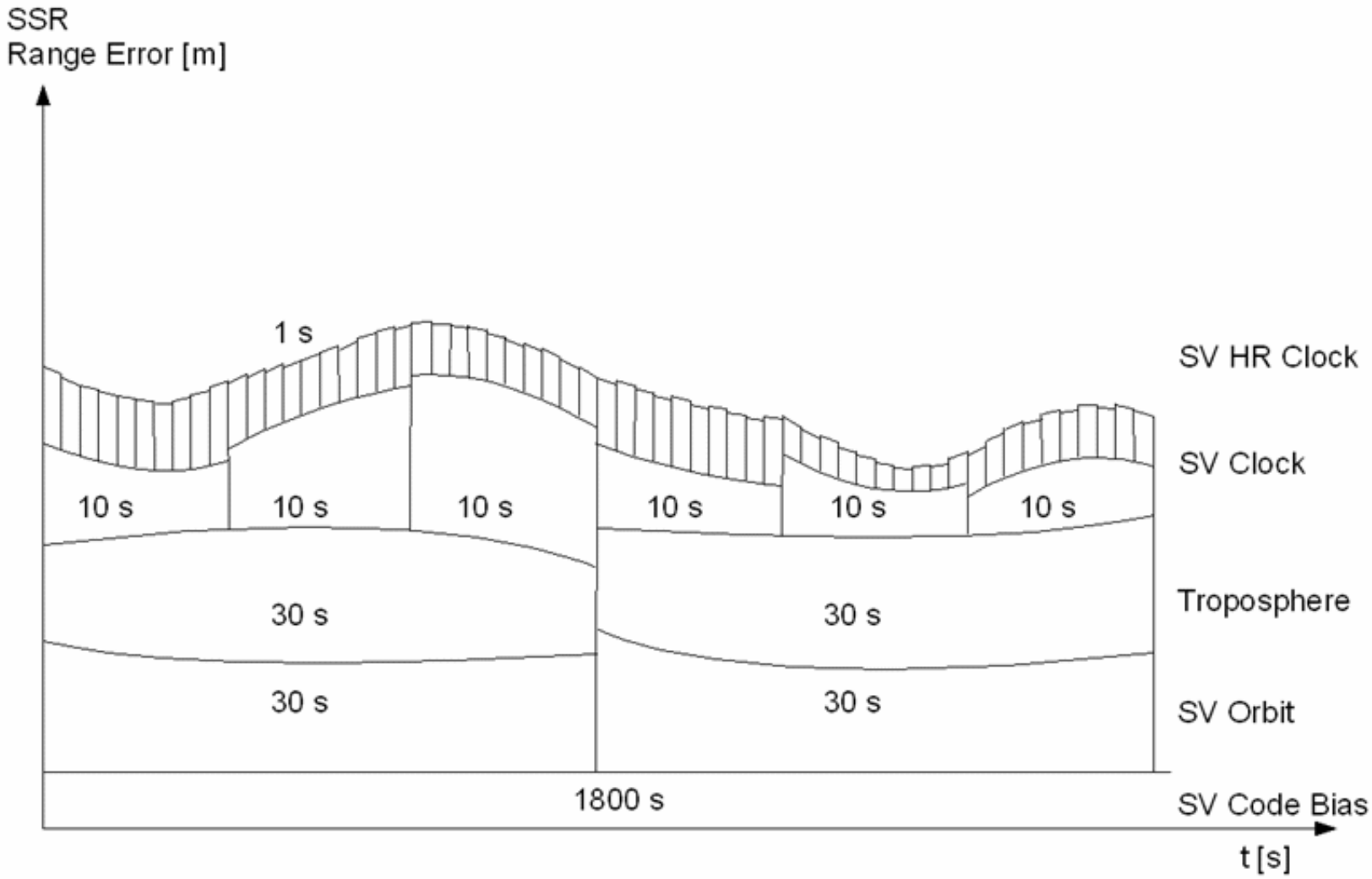
- SSR User Range Accuracy (**URA**)
  - **quality indicator** for range correction
  - for complete set of disseminated RTCM SSR messages
  - high/low resolution for small/large numbers
    (URA_CLASS and URA_VALUE)
- URA is computed by:

$$\mathrm{URA}\ [\mathrm{mm}] \leq 3^{\mathrm{URA\_CLASS}}\left(1+\frac{\mathrm{URA\_VALUE}}{4}\right)-1\ [\mathrm{mm}]$$

RTCM SSR Messages - SSR Consistency of Data

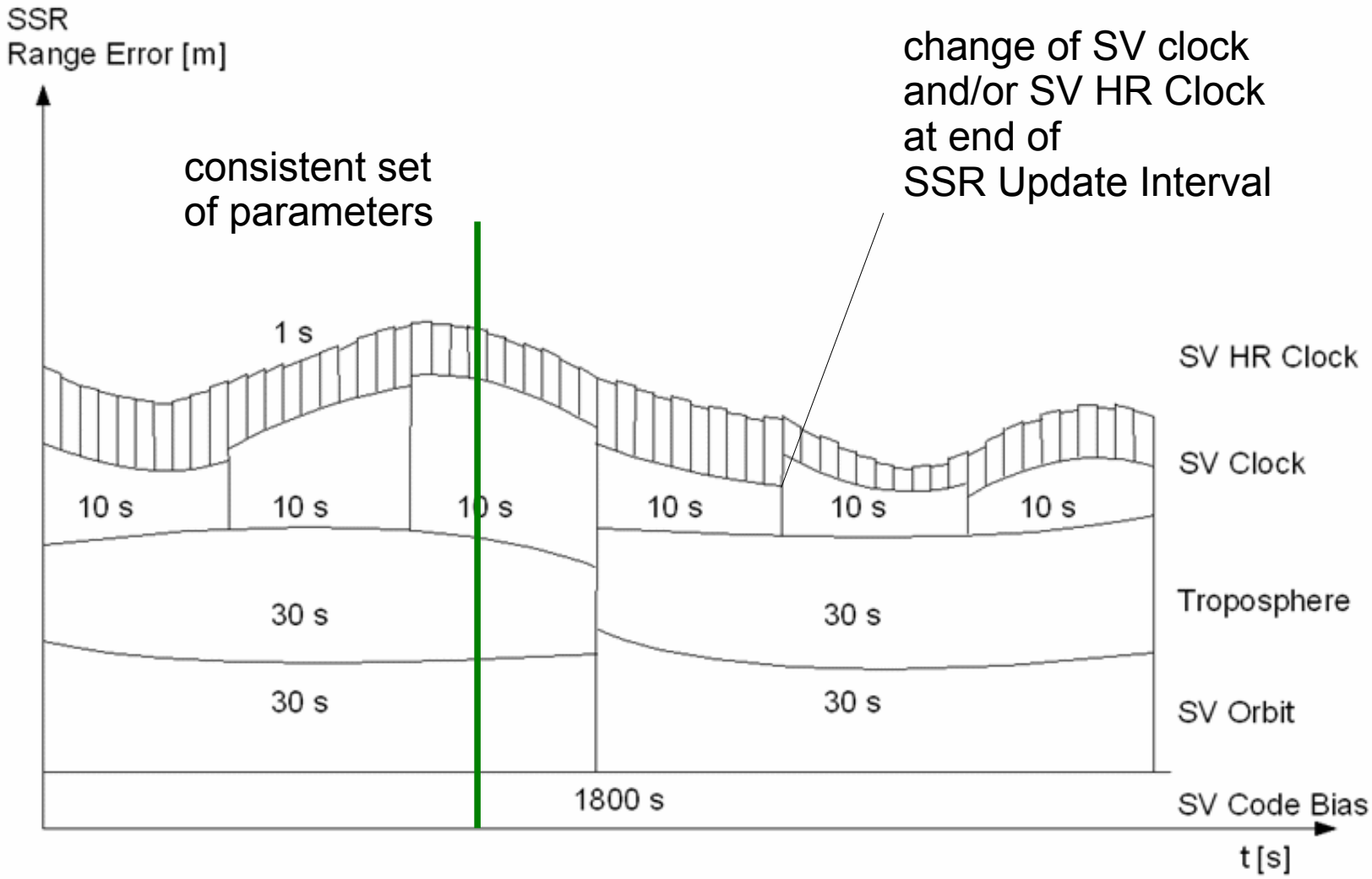
- SSR messages support
  different applications, update rates and accuracy requirements
- **basic concepts** are
  - additional SSR message type adds
    additional resolution and positioning accuracy
  - SSR parameter may consist of different constituents
  - disseminated in different SSR message types
  - all relevant information without dependencies (as far as possible)
- SSR **consistency essential issue**
  - due to correlation state parameters
  - consistent set of parameters defines complete and accurate correction
  - importance increases with resolution and additional messages
- **SSR Update Interval** and GNSS epoch time
  - defines change of parameters (i.e. at the end of a SSR Update Intervals)
  - ensures consistency of data and processing

RTCM SSR Messages - SSR Consistency of Data



sketch to demonstrate concept

RTCM SSR Messages - SSR Consistency of Data



sketch to demonstrate concept

Plans for RTCM SSR Messages

- RTCM SSR Working Group
  currently working on
  addition to 1st stage and 2nd stage

Plans for RTCM SSR Messages

- additions to RTCM SSR messages of 1st stage
  - SSR **Galileo** Messages compliant to 1st stage
  - enables basic PPP (DF-RT-PPP) for Galileo

Message Type	**Message Name**
MT+1	SSR Galileo **Orbit** Correction
MT+2	SSR Galileo **Clock** Correction
MT+3	SSR Galileo **Code Bias**
MT+4	SSR Galileo **Combined** Orbit and Clock Corrections
MT+5	SSR Galileo **URA**
MT+6	SSR Galileo **High Rate Clock** Correction

Plans for RTCM SSR Messages

- SSR **Phase Bias** Messages
  - demand from users of RTCM SSR Messages 1st stage
  - supports use of phase observations
  - requires e.g. standardization of satellite orientation (yaw)
  - originally indented in 3rd stage
  - supports basic PPP (DF-RT-PPP)

Message Type	**Message Name**
MT+7	SSR **GPS** Phase Bias
MT+8	SSR **GLONASS** Phase Bias
MT+9	SSR **Galileo** Phase Bias

Plans for RTCM SSR Messages

- RTCM SSR Messages 2nd stage
- independent from GNSS
- SSR **vertical** TEC (VTEC) **ionosphere** Messages
  - proposal of **multi-stage message types**
    - **spherical harmonics** to describe global ionosphere
    - grided **higher resolution model**
      to be added to first stage message MT+10
      (regional/continental densification)
  - enables single frequency PPP (SF-RT-PPP)

Message Type	**Message Name**
MT+10	SSR Ionosphere **Vertical TEC** Spherical Harmonics
MT+11	SSR Ionosphere **Vertical TEC**

Future Plans for RTCM SSR Messages

- RTCM SSR Working Group
  future work on
  3rd stage RTCM SSR Messages
  - independent from GNSS
  - SSR **slant** TEC (STEC) **ionosphere** Messages
    - multi-stage message based on SSR VTEC Messages
  - SSR **troposhere** Messages

Summary

- increasing use **state space technology** (SSR)
- **RTCM SSR messages 1st stage** widely in use (orbit, clock, code biases)
- **strong demand for a real-time streaming standard**
  underlined by
  - already existing number of implementations
  - feedback/acceptance
- demand for an **Open Standard** as supported by RTCM SC104
- **broad applications of RTCM SSR expected**,
  which will push further developments
- further **standardization efforts** required
  - next stages are more complex
  - next stages add accuracy and applications
- final goal is **Open Standard**
  for PPP up to PPP-RTK