SAPA Format 1.7

Christopher Perschke

Geo++® GmbH
30827 Garbsen, Germany
www.geopp.de

SSR Formats - Overview

SSR Basic Parameters	Multi-stage/ Scalabilty		SSR/SSA binary/ASCII	SSRG Geo++ 4090.2	RTCM-SSR	RTCM Geo++ 4090.4	RTCM Geo++ 4090.5	SSRZ RTCM Geo++ 4090.7	Compact SSR	SAPA
			RTCM framing							
			stand-alone	stand-alone	allowed in one stream			stand-alone	stand-alone	stand-alone
SV clock			available	available	available			available	available	available
SV orbit			available	available	available			available	available	available
SV code bias			available	available	available			available	available	available
SV phase bias			available	available	proposed			available	available	available
ionosphere	global	VTEC	available		proposed			available		
	global	STEC	available		under discussion	canceled		available		
	regional	STEC	available		under discussion	available		available	available	available
	residual	gridded/ site	available	available	under discussion		canceled	available	available	available
troposphere	global		under discussion		under discussion			available		
	regional		available		under discussion			available		available
	residual	gridded/ site	available	available	under discussion		available	available	available	available
complete SSR model			yes	yes	no	no	no	yes	yes	yes

SSR Formats - Supported Systems and Signals

GNSS	SSRZ	SAPA	Compact SSR
GPS	L1, L2, L5	1C,2W,2L	L1, L2,L5
GLONASS	L1, L2, L3	1C, 2C	L1, L2, L3
Galileo	E1, E5, E6		E1, E5
BDS	B1, B2, B3		B1, B2, B3
SBAS	L1, L5		L1C, L5
QZSS	L1, L5		L1, L5
IRNSS	S, L5		

- L1, L2, L5 :carrier frequencies indicate more than one signal per frequency
- GNSS IDs and signal bitmasks are defined, satellite bitmasks are not defined

SSR Formats – Parameter Resolutions and Timing

SSR Parameter	SSRZ		SAPA		Compact SSR	
	resolution	update rate [s]	resolution	update rate [s]	resolution	update rate [s]
clock	1 mm (0.1)	5	2mm	5	1.6mm	5
orbit	32 mm (0.1) 4 mm (0.1) 4 mm (0.1)	30	2mm 2mm 2mm	30	1.6mm 6.4mm 6.4mm	30
code Bias	10mm (0.1)	30	20mm	30	20mm	30
phase Bias	~1mm (cyc)	30	2mm	30	1mm	30
ionosphere (residual)	~1mm	30	0.04TECU	30	0.04 TECU	30
troposphere (residual)	~1mm	30	0.04mm	30	0.04 mm	30

SAPA Format

SAPA Message Types

Type	Subtype	Message name	Description
0	0	GPS OCB	GNSS Orbit, Clock, Bias (OCB) message
	1	GLONASS OCB	
	2 to 15	TBD	
1	0	GPS HPAC	High-Precision Atmosphere Correction (HPAC) message
	1	GLONASS HPAC	
	2 to 15	TBD	
2	0	GAD	Geographic Area Definition (GAD) message
	1 to 15	TBD	
3 to 127	TDB	TBD	TBD

SAPA OCB Messages SM 0-0, SM 0-1

- **OCB present flag** (SF014) allows low rate and high rate messages (30s and 5s update intervals)

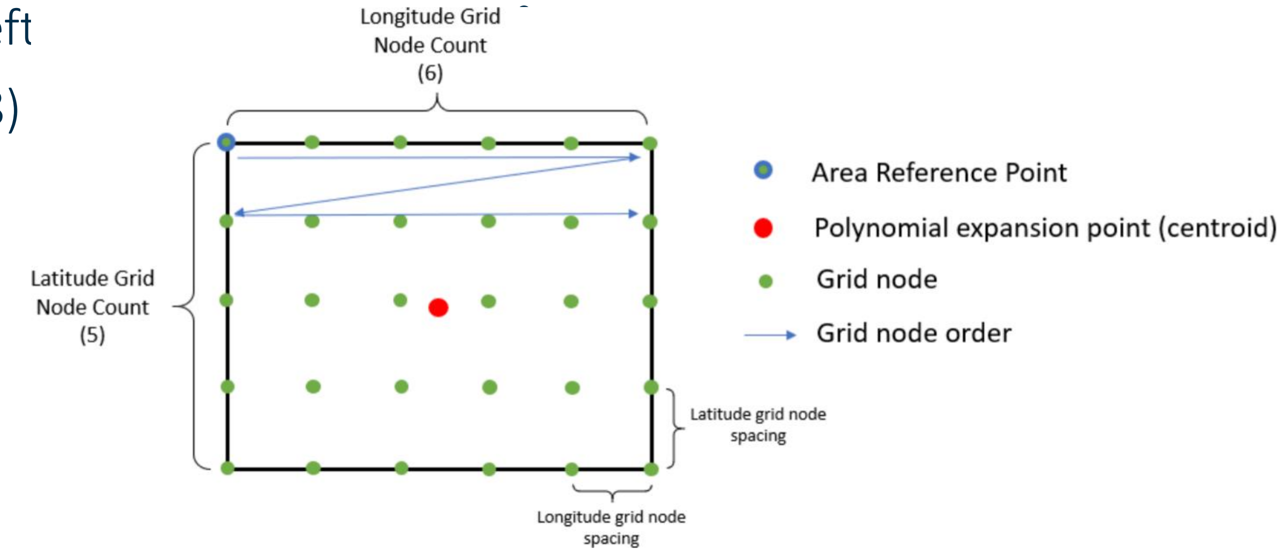
Type	Subtype	Message Name	Parameter	"Low Rate"	"High Rate"	
0	0	GPS OCB	GPS Orbit	1	0	OCB present flag SF014
			GPS Clock	0/1	1	
			GPS Biases	1	0	
0	1	GLO OCB	GLO Orbit	1	0	OCB present flag SF014
			GLO Clock	0/1	1	
			GLO Biases	1	0	

SAPA HPAC Messages SM 1-0, SM 1-1

Type	Subtype	Message name	Area ID	Blocks Indicator (SF040)	
			Atmosphere Block		
1	0/1	GPS/ GLO HPAC	ID	Area data Block	
				1	tropo poly coeff block ($\overline{T_h^z}, T_{00}, T_{10}, T_{01}, T_{11}$)
				2	tropo poly coeff block ($\overline{T_h^z}, T_{00}, T_{10}, T_{01}, T_{11}$)
					gridded tropo block
				1	iono poly coeff block per SV ($C_{00}, C_{10}, C_{01}, C_{11}$)
				2	iono poly coeff block per SV ($C_{00}, C_{10}, C_{01}, C_{11}$)
					gridded iono block per SV

SAPA GAD message SM2-0

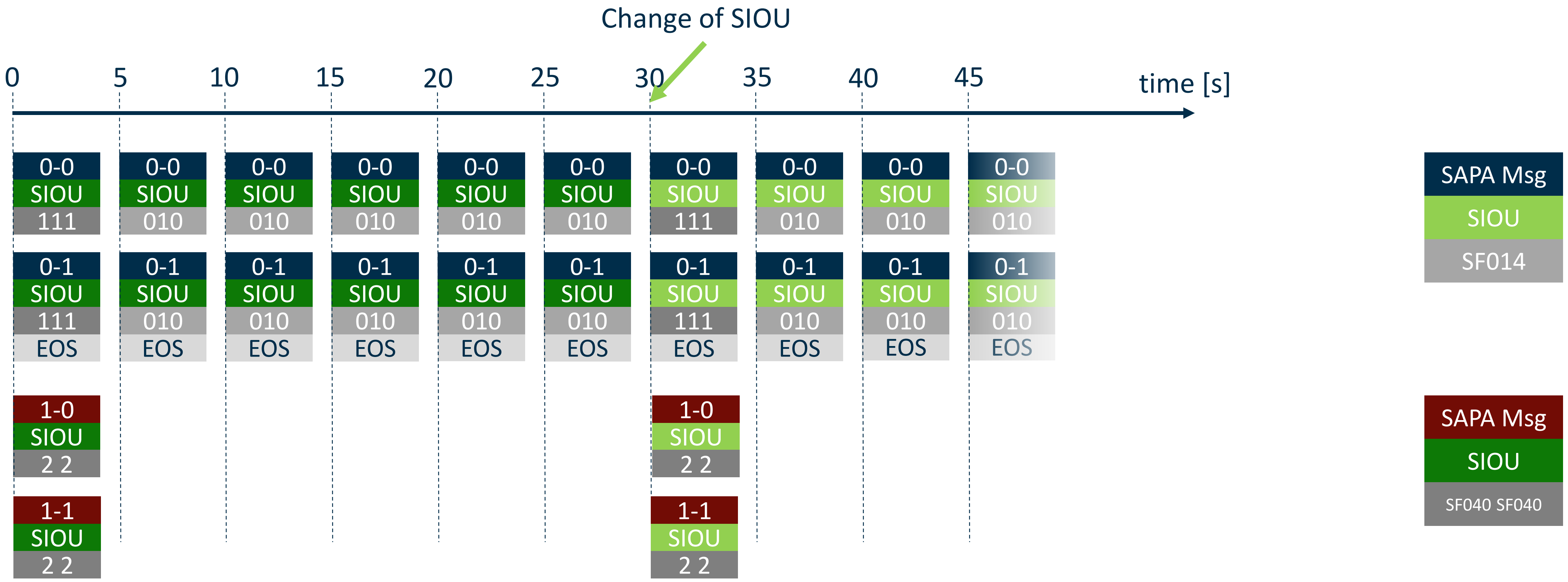
- maximum number of grids: 32
- reference point (Φ_0, λ_0); upper left
- number of grid nodes N_Φ, N_λ (1-8)
- spacing $\Delta\Phi, \Delta\lambda$ (0.1° - 3.2°)
- maximum latitude: $\pm$85°



- minimum grid $N_\Phi, N_\lambda = 1, \Delta\Phi, \Delta\lambda = 0.1$ ➔ 11km x 1km / 11km x 11km
- Maximum grid $N_\Phi, N_\lambda = 8, \Delta\Phi, \Delta\lambda = 3.2$ ➔ 2816km x 256km / 2816km x 2816km

SAPA Timing and Data Assignment (30s/5s)

- consistent SSR parameter (i.e. parameters of one solution) are connected with SIOU (SF005)
- an absolute time information is also part of the message



SAPA Bandwidth Optimization Concepts

- satellite bitmask length
- signal bitmask length
- data field length of tropo and iono coefficients
- data field length of tropo and iono residual values
- “tropo offsets”
    - Average vertical hyd. Delay $\overline{T_h^z}$ minus 2.3m
    - T_{00} minus 0.252m

	SF044/ SF056	T_{00} / C_{00}	T_{10} / C_{10} T_{01} / C_{10}	T_{11} / C_{11}
tropo	0	7	7	9
	1	9	9	11
iono	0	12	12	13
	1	14	14	15

	SF051/SF057 / data field length residuals			
	0	1	2	3
tropo	6	8	-	-
iono	4	7	10	14

GNSS	left most bit / satellite bitmask length			
	0	1	2	3
GPS	32	44	56	64
GLO	24	36	48	63

GNSS	left most bit / signal bitmask length	
	0	1
GPS	6	11
GLO	5	9

Implementation Details

- Numerical Constants (c, π) are identical
- Reference Datum: “Therefore, it is not necessary to define the exact realization of ITRF used in SAPA message format”.
- Broadcast Ephemeris

GNSS	Document
GPS	IS-GPS-200H
GLO	Version 5.1

GNSS Satellite Clock Correction

- clock correction δC
- broadcast satellite clock t_b
- corrected satellite clock t_s

$$t_s = t_b - \frac{\delta C}{c}$$

- Relativistic Effects must be applied for all constellations, except for GLONASS, where relativistic effect is already accounted for in the broadcast clock parameter.

$$t_r - \frac{2\,\boldsymbol{r}\cdot\dot{\boldsymbol{r}}}{c^2}$$

GNSS Satellite Orbit Calculation

- orbit correction $\delta\boldsymbol{O}$
- satellite position correction $\delta\boldsymbol{X}$
- broadcast satellite position correction $\delta\boldsymbol{X_b}$
- corrected satellite nominal antenna phase center position $\delta\boldsymbol{X}_{orb}$
- satellite broadcast position(velocity) vector $\boldsymbol{r} = \boldsymbol{X}_b$ $(\boldsymbol{r} = \dot{\boldsymbol{X}}_{\mathrm{b}})$
- $\boldsymbol{e}_i$ direction unit vector, $i = \{radial, along, cross\}$

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

$$\delta\boldsymbol{X}_{\boldsymbol{orb}} = \delta\boldsymbol{X}_b - \delta\boldsymbol{X}$$

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

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

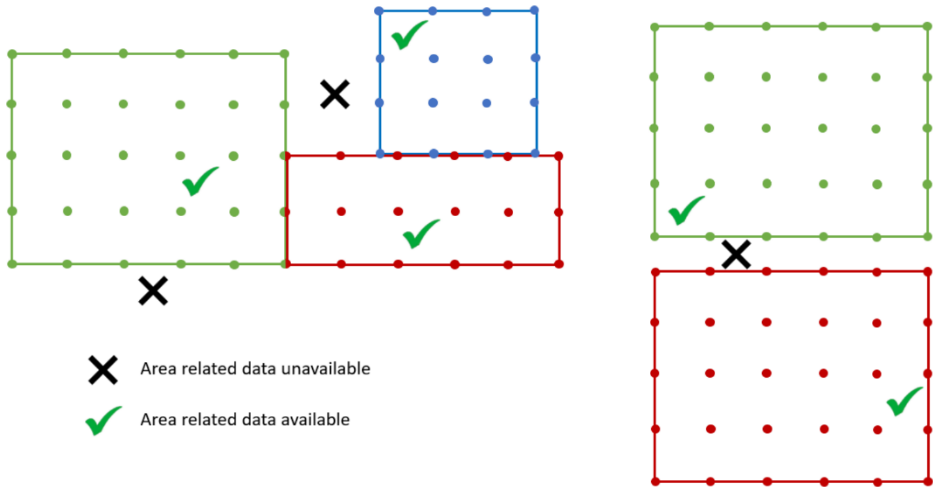
$$\boldsymbol{\delta X} = [\,\boldsymbol{e}_{radial}, \boldsymbol{e}_{along} \boldsymbol{e}_{cross}] \cdot \delta\boldsymbol{O}$$

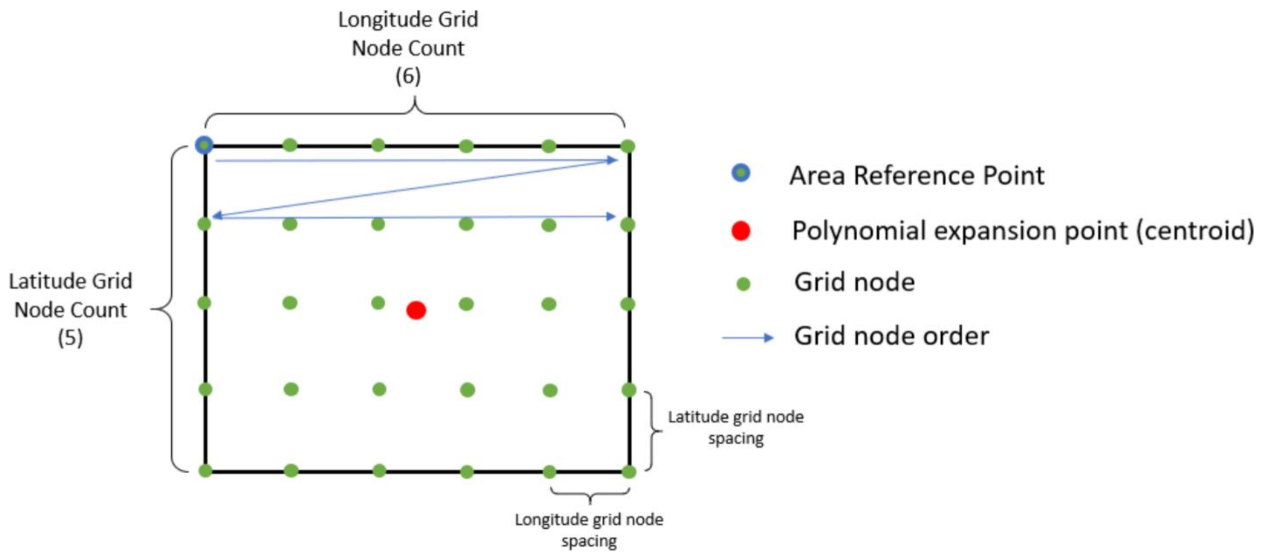
GNSS Satellite Bias Calculation

- SAPA OCB message contains parameters for bias correction for various track types. These biases shall be subtracted from the raw pseudorange and carrier phase measurements for the corresponding track types.
- GLONASS biases are aligned to a theoretical zero bias receiver

SAPA Atmospheric Corrections

- regular grids
- User position must be located inside of the area definition for the data to be used.





Ionosphere Slant Delay Calculation

- slant iono delay of satellite i for carrier phase measurements δI_{CP}^{i} [m]
- slant iono delay of satellite i for pseudorange measurements δI_{PR}^{i} [m]
- slant iono delay evaluated from polynomial I_{P}^{i} [TECU]
- slant iono delay evaluated from gridded residuals I_{G}^{i}[TECU]

$$\delta I_{CP}^{i} = -40.3 \times \frac{10^{-16}}{f_j^2} \cdot (I_P^i + I_G^i)$$

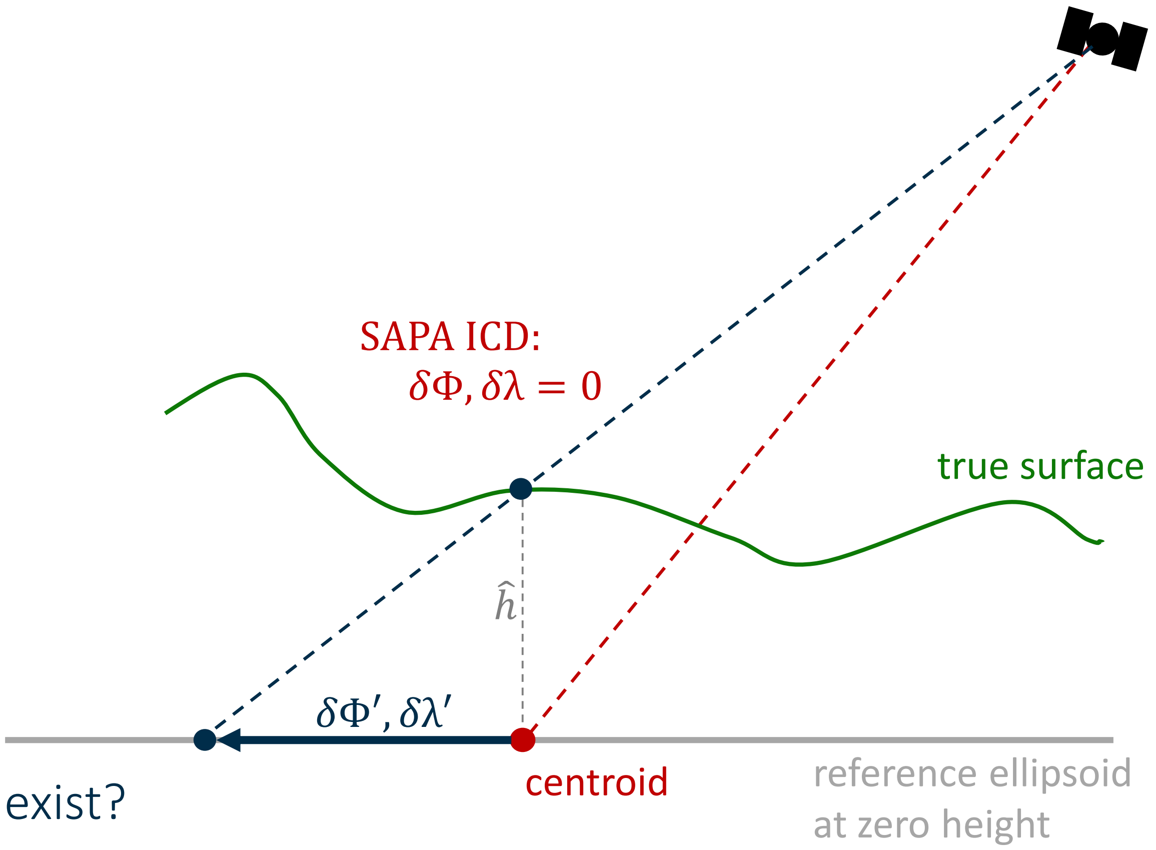
$$\delta I_{PR}^{i} = 40.3 \times \frac{10^{-16}}{f_j^2} \cdot (I_P^i + I_G^i)$$

Slant TEC Polynomial Evaluation

- latitude of the user Φ_u [deg]
- area centroid latitude Φ_c [deg]
- latitude of the user λ_u[deg]
- area centroid latitude λ_c[deg]

$$I_P^i = C_{00} + C_{01}(\delta\Phi) + C_{10}(\delta\lambda) + C_{11}(\delta\Phi)(\delta\lambda)$$

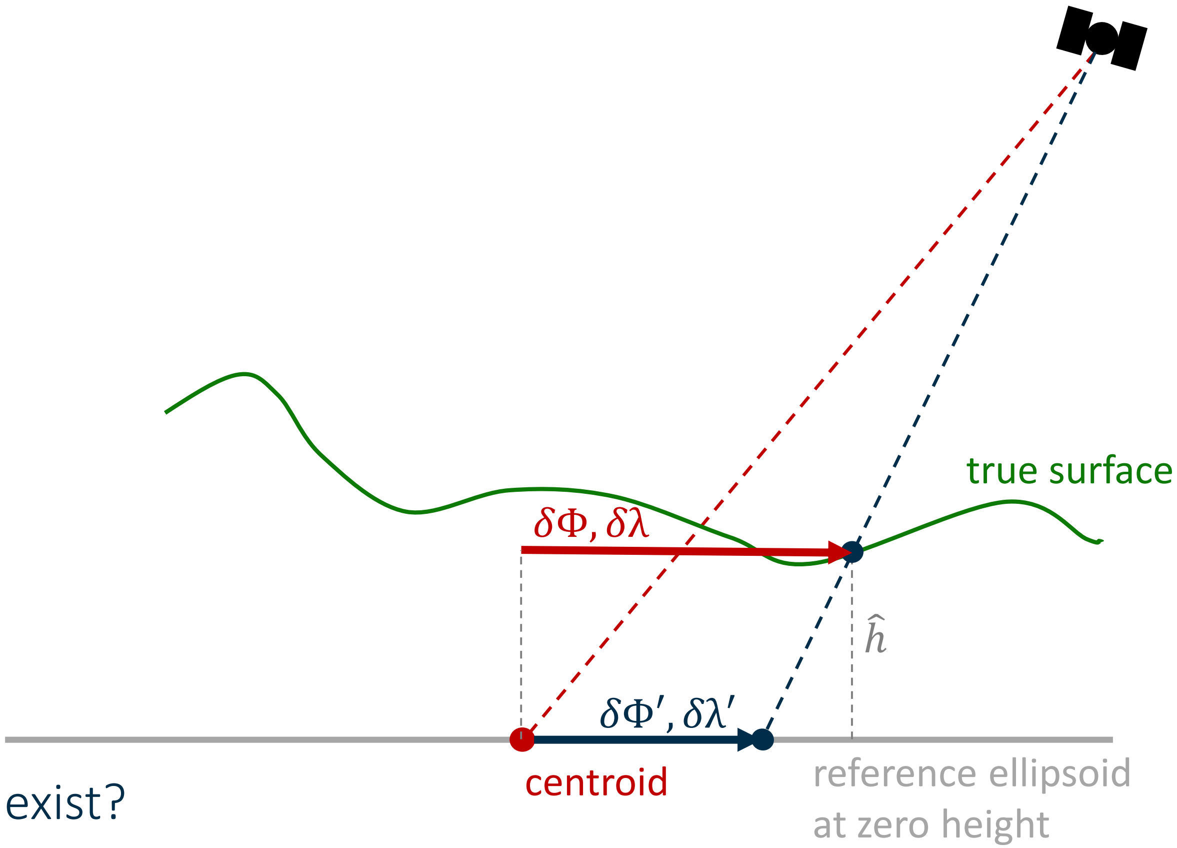
- Calculation neglects height of the user $\delta\Phi', \delta\lambda' \neq \delta\Phi, \delta\lambda$.
- Does an estimation of this geometric error exist?
- In general: the larger the height difference between reference height and user‘s height.



Slant TEC Polynomial Evaluation

- latitude of the user Φ_u [deg]
- area centroid latitude Φ_c [deg]
- latitude of the user λ_u[deg]
- area centroid latitude λ_c[deg]

$$I_P^i = C_{00} + C_{01}(\delta\Phi) + C_{10}(\delta\lambda) + C_{11}(\delta\Phi)(\delta\lambda)$$



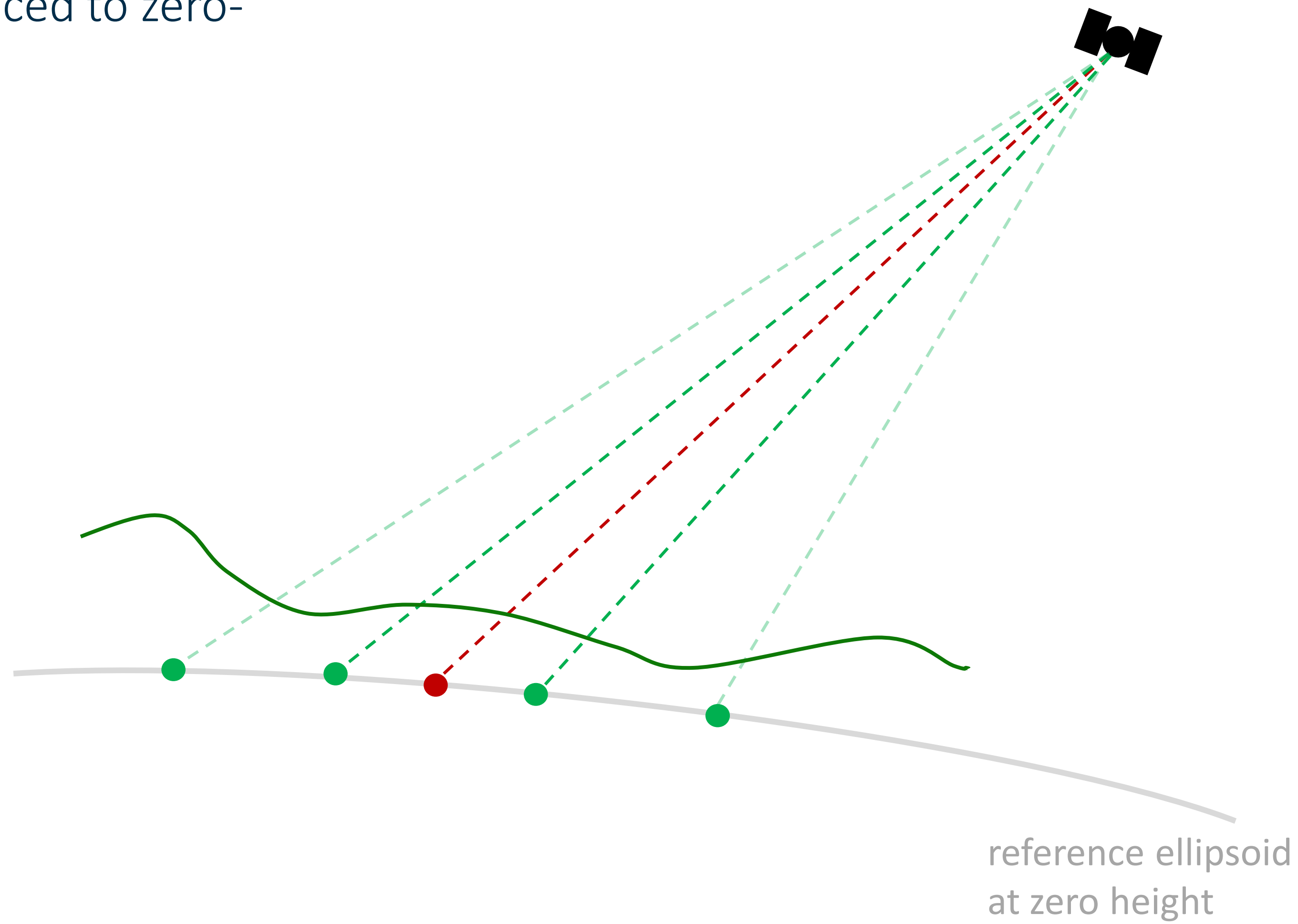
- Calculation neglects height of the user $\delta\Phi', \delta\lambda' \neq \delta\Phi, \delta\lambda$.
- Does an estimation of this geometric error exist?
- In general: the larger the height difference between reference height and user‘s height.

Polynomial and gridded Slant TEC

- gridded STEC data also referenced to zero-height
- bi-linear grid interpolation

$$\mathrm{I}_G^i = \sum_{k=1}^{4} W_k I_{G_K}^i$$

- weighting factor depending on the grid point distance



Troposphere Delay Calculation

- troposphere slant delay for satellite i at the user's location δT^i
- average zenith hydrostatic delay for a given area (**zero** ellipsoidal height) $\overline{T_h^z}$
- hydrostatic mapping function (Neill, 1996) for satellite elevation $m_h(\epsilon_i)$
- non-hydrostatic mapping function (Neill, 1996) for satellite elevation $m_{nh}(\epsilon_i)$
- residual troposphere zenith delay for a user interpolated from grid points T_G[m]
- residual troposphere zenith delay for satellite i interpolated from polynomial expansion T_P[m]

$$\delta T^i = \overline{T_h^z} \cdot m_h(\epsilon_i) + (T_P + T_G) \cdot m_{nh}(\epsilon_i)$$

$$T_P = T_{00} + T_{01}(\delta\Phi) + \mathrm{T}_{10}(\delta\lambda) + T_{11}(\delta\Phi)(\delta\lambda)$$

$$T_G = \sum_{k=1}^{4} W_k T_{G_K}$$

Compact SSR Message Types

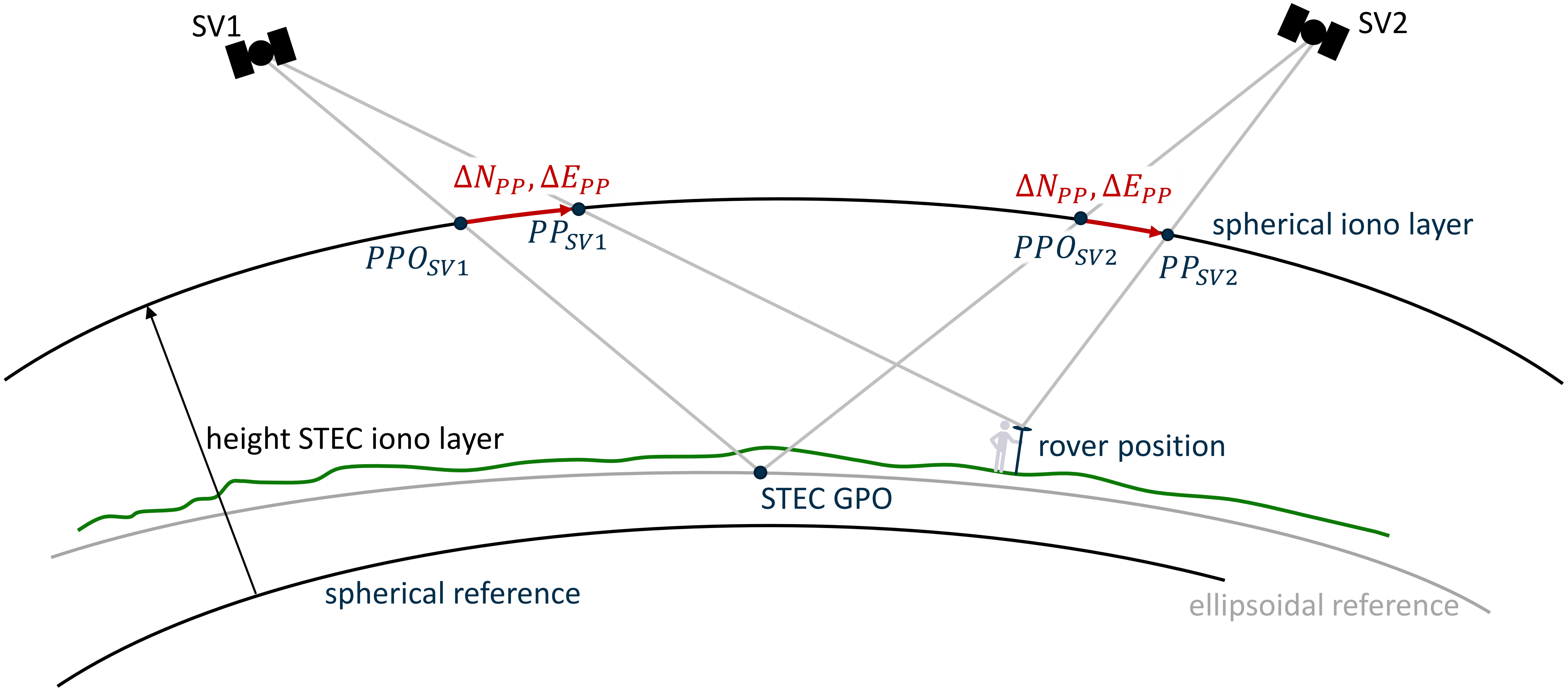
Compact SSR Msg Name	Number		SAPA
Compact SSR Mask	MT4073,1		OCB
Compact SSR GNSS Orbit Correction	MT4073,2		OCB,sys,O
Compact SSR GNSS Clock Correction	MT4073,3		OCB,sys,C
Compact SSR GNSS Satellite Code Bias	MT4073,4		OCB,sys,CB
Compact SSR GNSS Satellite Phase Bias	MT4073,5		OCB,sys,PB
Compact SSR GNSS Satellite Code and Phase Bias	MT4073,6		OCB,sys,B
Compact SSR GNSS URA	MT4073,7		
Compact SSR GNSS STEC Correction	MT4073,8		HPAC,sys,RSI
Compact SSR GNSS Gridded Correction	MT4073,9		HPAC,sys,GRI,GRT
Compact SSR GNSS Service Information	MT4073,10		
Compact SSR GNSS Combined Correction	MT4073,11		
Null Message	MT4073,1		

SSRM2SAPA

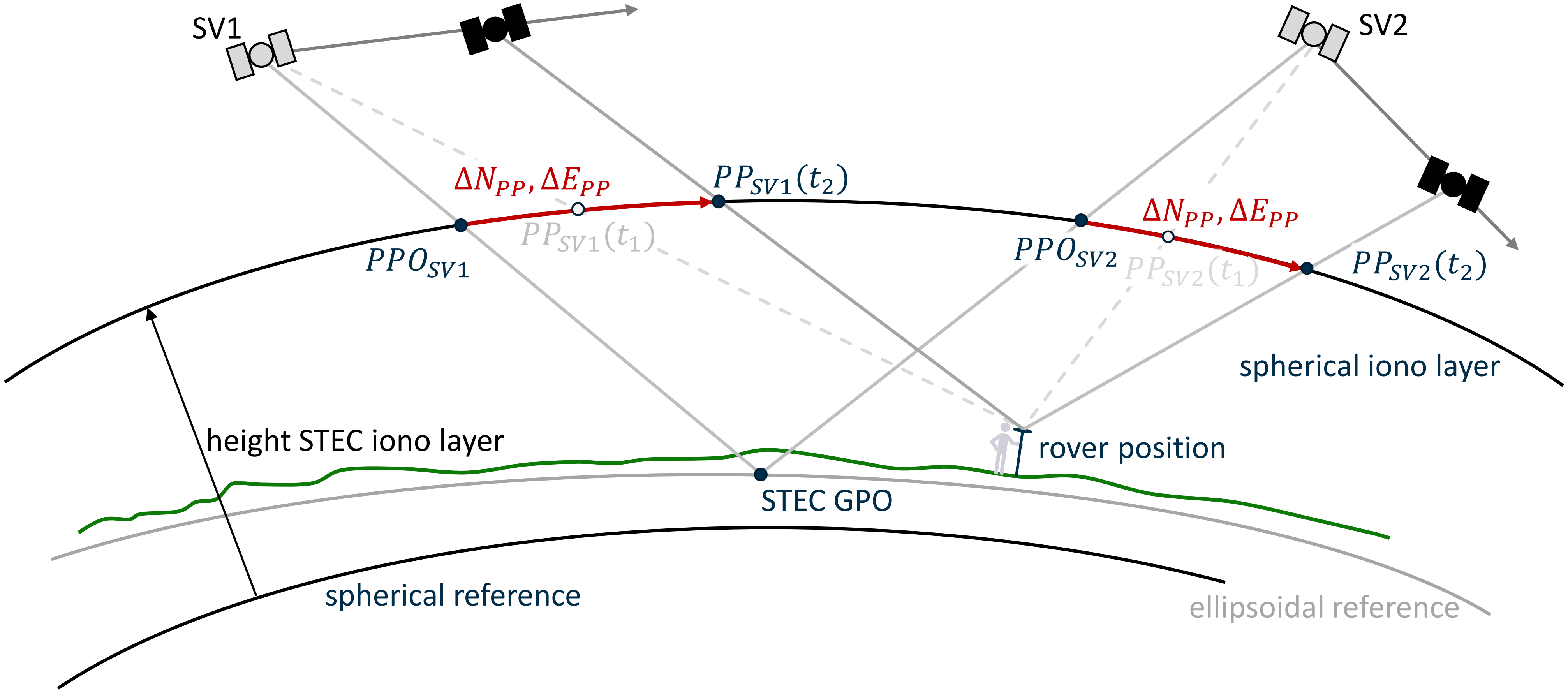
- `sapalib` is developed in cooperation with Neosoft
    - OCB ready and improved with handle structure to control ocb flag
    - HPAC in test
    - GAD ready
- Implementation of `ssrm2sapa_util` functions (interfaces between MC structures and SAPA structures) in progress (OCB ready)
- ToDo `ssrm2sapa.exe`

Thank you.

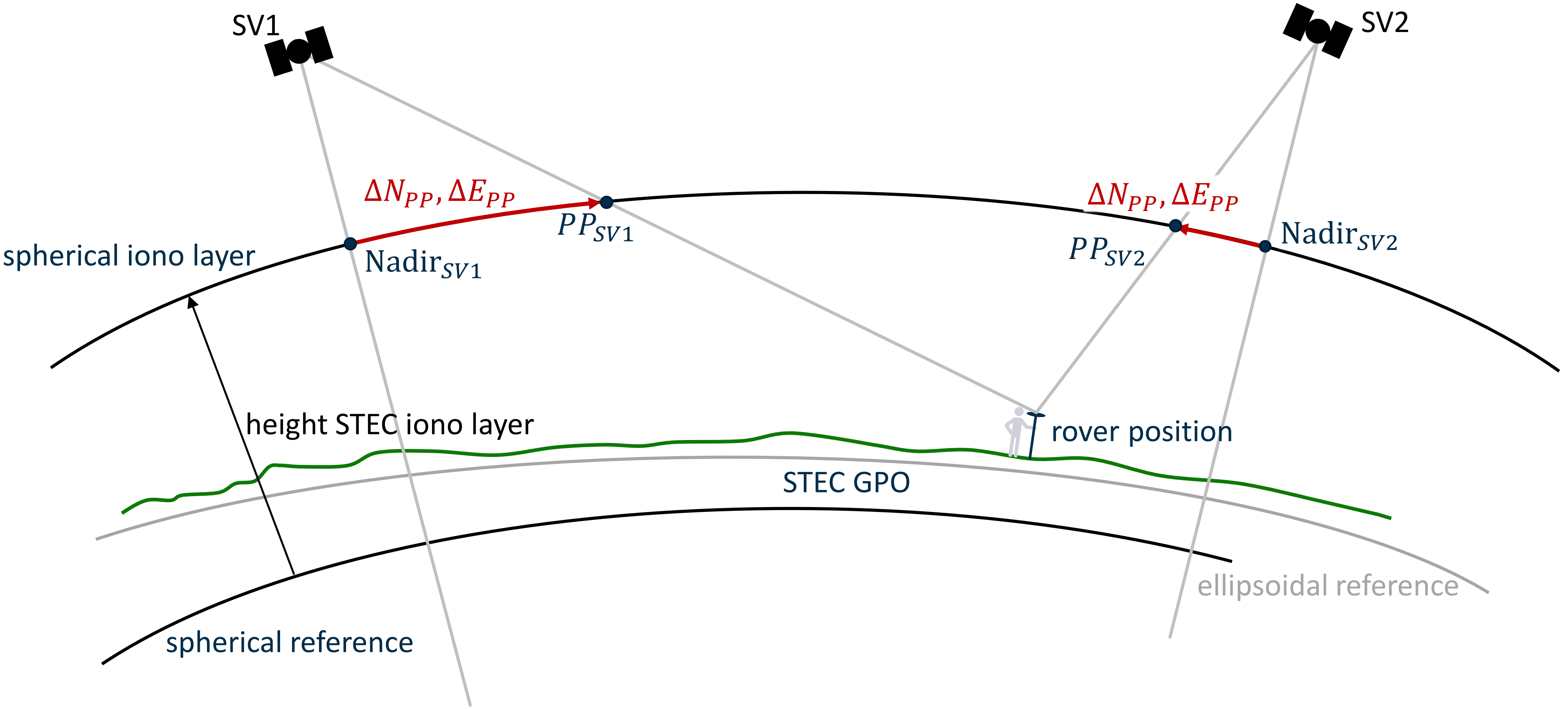
Regional STEC 1/2



Regional STEC 2/2



Global STEC 1/2



Global STEC 2/2