Augmenting Global Real-Time PPP Service With Regional Network For Instantaneous cm-Level Positioning

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PPP-RTK & Open Standards Symposium, 12-13 March, 2012, Frankfurt, Germany,

GFZ Helmholtz-Zentrum Potsdam

Real-Time Positioning Services

Network Real-Time Kinematic (NRTK)

- Using a local/regional reference network
- OBS. DOMAIN Representation

NRTK Service Covers The Whole European/Chinese Territory?

Global Precise Point Positioning Service

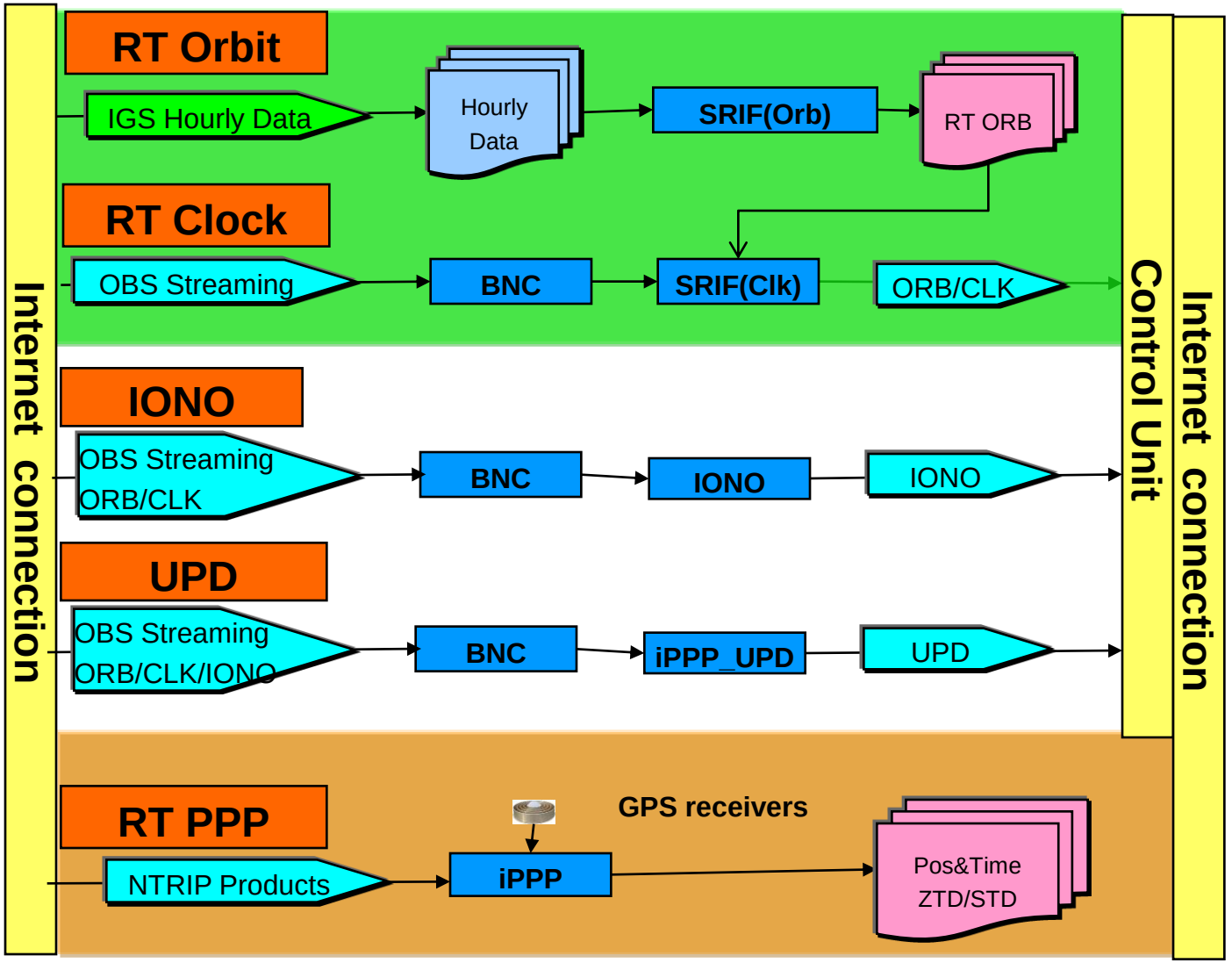
- Using a global reference network
- STATE DOMAIN Representation

Initialization/Re-initialization takes 10-30 Min..

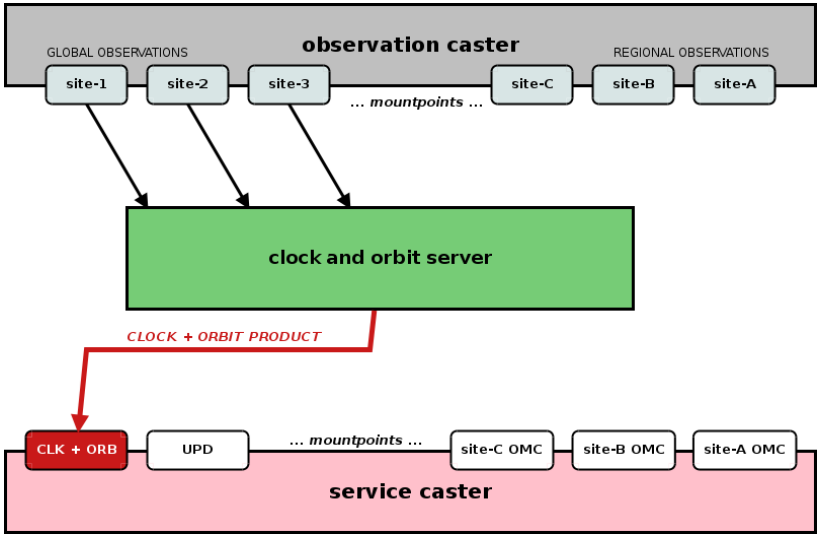
Global PPP + Regional Augmentation For All Real-Time Applications

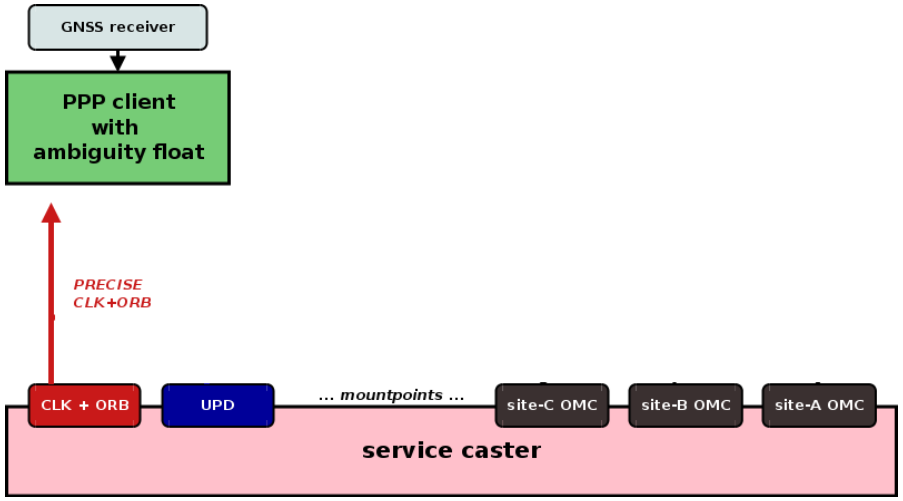
EPOS-RT For Real-Time PPP Service

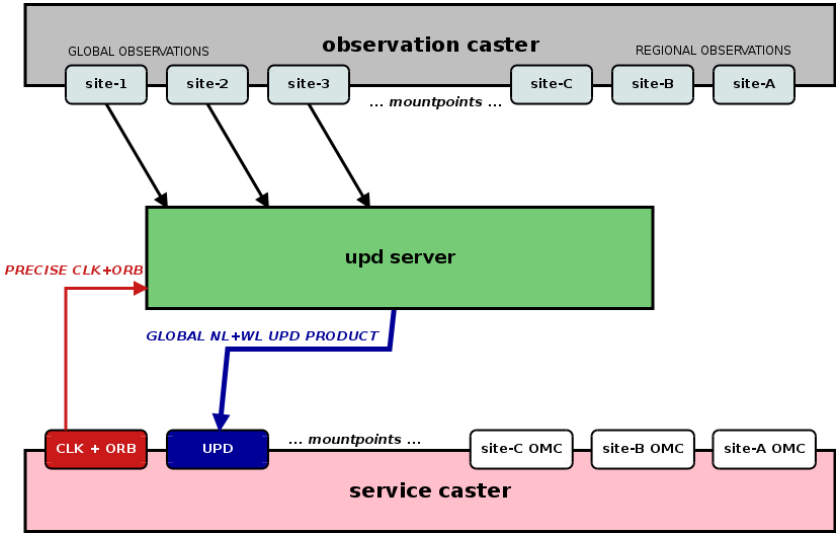
IGS Real-Time Analysis Center at GFZ

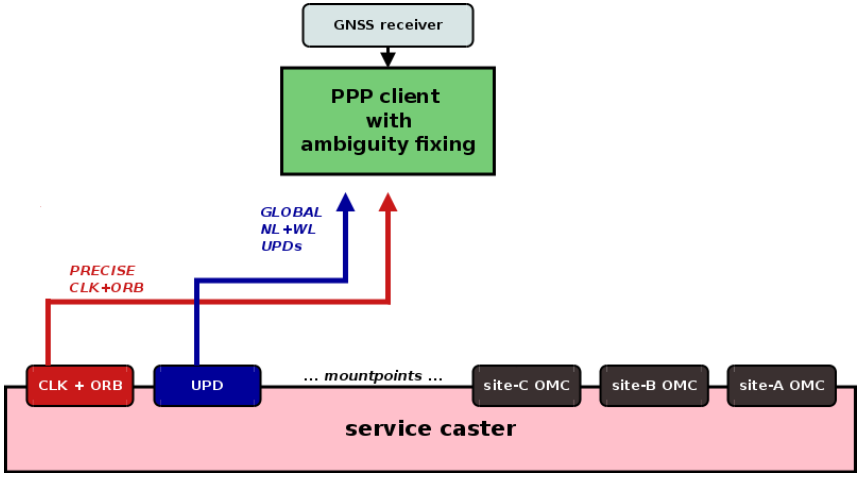


Standard PPP & PPP + AmbFixing









PPP Ambiguity Resolution

Estimation of UPDs

$$b_{mk}^{i} = n_{mk}^{i} + \Delta\phi_m^{\,i} - \Delta\phi_{mk}$$

With Integer Ni

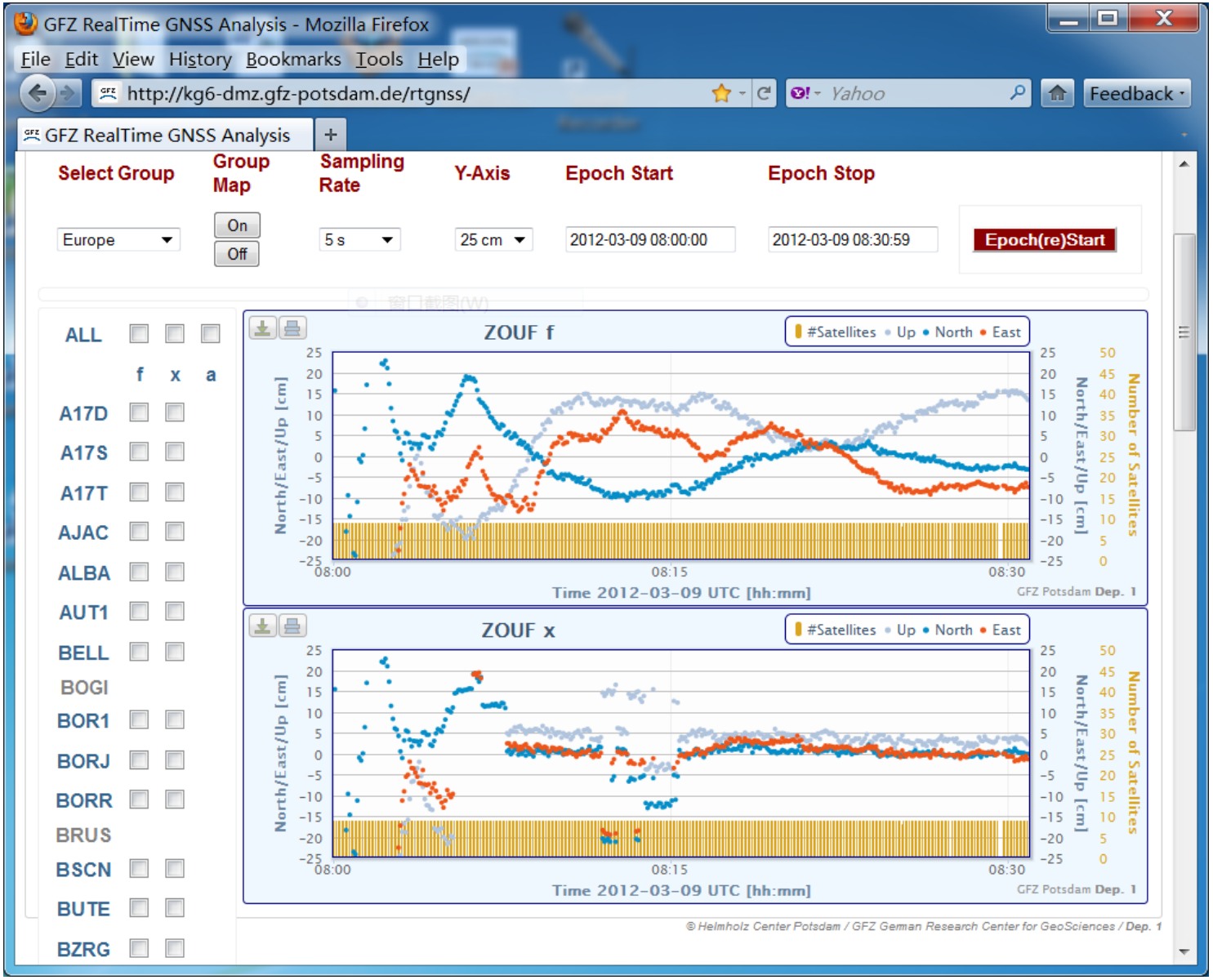
$$\begin{bmatrix} \mathbf{b}_1 \\ \mathbf{b}_2 \\ \vdots \\ \mathbf{b}_n \end{bmatrix} = \begin{bmatrix} \mathbf{I} & & & \mathbf{R}_1 & \mathbf{S}_1 \\ & \mathbf{I} & \mathbf{0} & \mathbf{R}_2 & \mathbf{S}_2 \\ & & \mathbf{I} & \vdots & \vdots \\ & \mathbf{0} & & \vdots & \vdots \\ & & \mathbf{I} & \mathbf{R}_n & \mathbf{S}_n \end{bmatrix} \begin{bmatrix} \mathbf{n}_1 \\ \mathbf{n}_2 \\ \vdots \\ \mathbf{n}_n \\ \Delta\phi_{\mathbf{R}} \\ \Delta\phi_{\mathbf{S}} \end{bmatrix}, \qquad \mathbf{Q_{bb}}$$

$$\begin{bmatrix} \mathbf{b}_1 - \mathbf{n}_1 \\ \mathbf{b}_2 - \mathbf{n}_2 \\ \vdots \\ \mathbf{b}_n - \mathbf{n}_n \end{bmatrix} = \begin{bmatrix} \mathbf{R}_1 & \mathbf{S}_1 \\ \mathbf{R}_2 & \mathbf{S}_2 \\ \vdots & \vdots \\ R_n & \mathbf{S}_n \end{bmatrix} \begin{bmatrix} \Delta\phi_{\mathbf{R}} \\ \Delta\phi_{\mathbf{S}} \end{bmatrix}$$

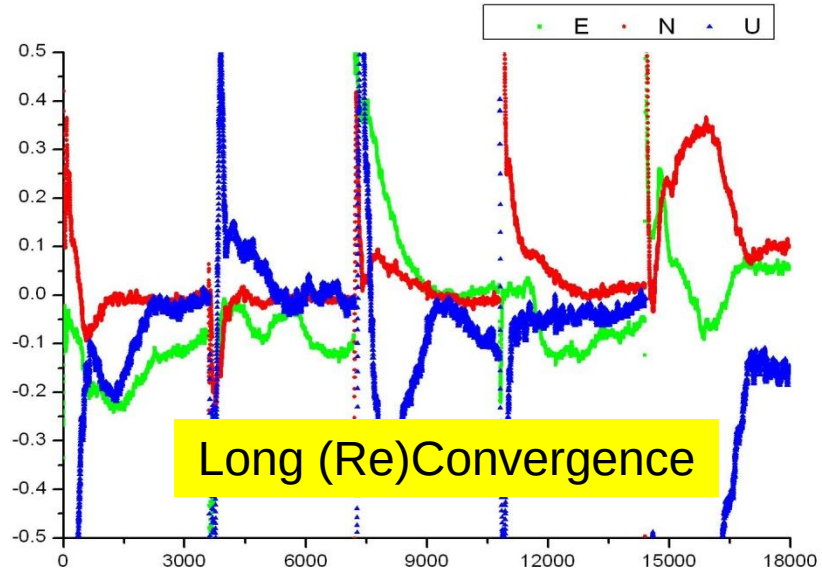
Algorithm

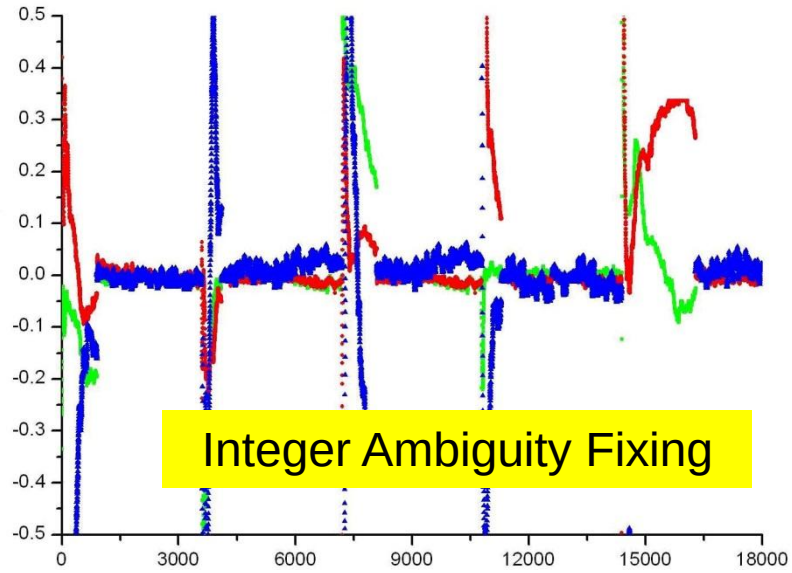
1. Get Initial $\Delta\phi_{mk}$ $\Delta\phi_m^{\,i}$
2. Fix Integer Ambiguities n_{mk}^{i}
3. Remove IA, Solve For $\Delta\phi_{mk}$ $\Delta\phi_m^{\,i}$
4. Repeat Above Procedure

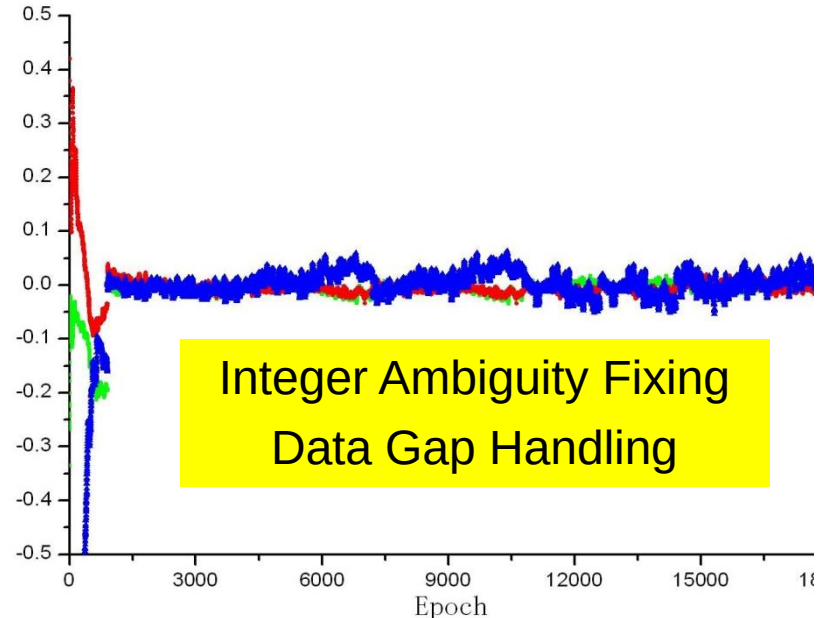
Typical Performances

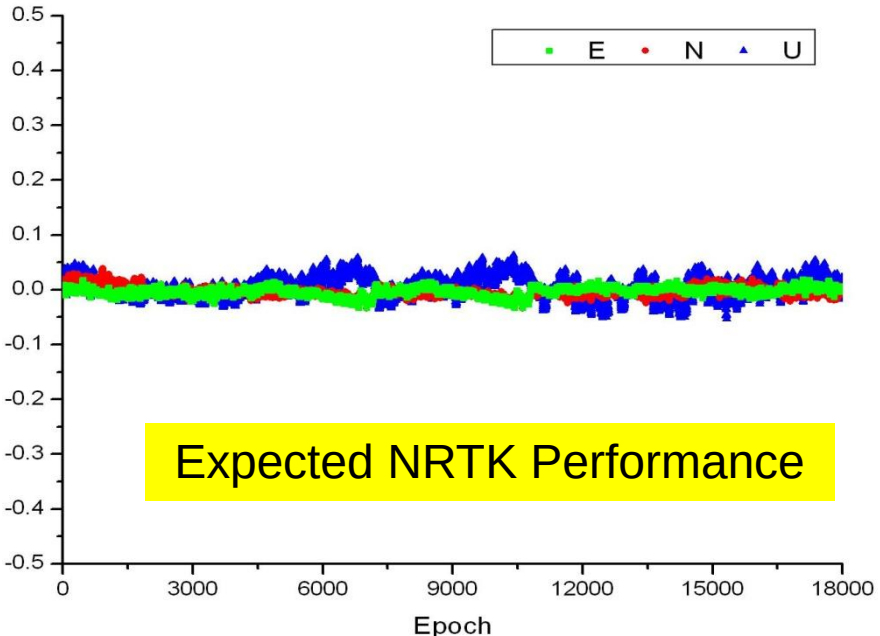


Typical Performances









Regional Augmentation

Regional Augmentation vs Network RTK

- Global PPP Service Is Needed
- Using UnDifferenced Obs. Corrections – Break Down Rec.&Sat. Connections
- Casted Station-By-Station – No Communication Bottleneck
- Network Solution Not A Must – Unlimited Number Of Reference Stations

Principal: Unambiguous OMC

- **OMC of Station k to Satellite i**

$$omc_k^i = L_k^i - \tilde{\rho}_k^i$$
$$= \delta S_k^i - \delta t^i + \delta t_k + \delta I_k^i$$
$$+ \delta T_k^i + n_k^i + f_k - f^i$$

δS_k^i Orbit Bias

f_k UPD Receiver

f^i UPD Satellite

- **Unambiguous OMC (Ambiguity Known)**

$$l_k^i = omc_k^i - n_k^i$$
$$= \delta S_k^i - \delta t^i + \delta t_k + \delta I_k^i + \delta T_k^i + f_k - f^i$$

Principal: Unambiguous OMC

- **Interpolated User Correction**

Interpolated Correction

$$\bar{l}_u^i = \sum_{k=1}^{3} \alpha_k (\delta S_k^i + \delta I_k^i + \delta T_k^i) + \sum_{k=1}^{3} \alpha_k (\delta t_k + \delta f_k) - \delta t^i - \delta f^i$$

$$\text{With } \alpha_1 + \alpha_2 + \alpha_3 = 1$$

User Obs. Equ.

$$l_u^i = \delta S_u^i + \delta I_u^i + \delta T_u^i + \delta t_u + \delta f_u - \delta t^i - \delta f^i + n_u^i + u_u^i \delta x_u$$

Cor. Obs. Equ.

$$\approx 0 \quad = \text{Contant} \quad = n_u^i \quad = u_u^i \delta x_u$$

- **Corrected Obs. Equ == PPP With Integer SD-Ambiguities**
- **How To Get The Integer UD-Ambiguities For L1&L2 ?**

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Integer UD Ambiguities

- NRTK With UD-Corrections

  Based On Fixed DD-Ambiguities

- PPP Augmentation,

  Based On Fixed UD-Ambiguities

Unambigous UDOMC From PPP

- After PPP For All Stations, We Have

$$b_k^i = n_k^i + f_k - f^i$$

- Solve for f_k , f^i, then n_k^i as explained
- With n_k^i , UD OMCs are derived.

- n_k^i Can Be Biased Because f_k , f^i Are Usually Biased By Integers

Unambigous UDOMC From PPP

- **Assume that f_i, f^k Are Biased By Integers**

$$\begin{bmatrix} \bar{l}_u^1 \\ \bar{l}_u^2 \\ \bar{l}_u^3 \end{bmatrix} = \left(\begin{bmatrix} l_1^1 & l_2^1 & l_3^1 \\ l_1^2 & l_2^2 & l_3^2 \\ l_1^3 & l_2^3 & l_3^3 \end{bmatrix} - \begin{bmatrix} \delta f_1 - \delta f^1 & \delta f_2 - \delta f^1 & \delta f_3 - \delta f^1 \\ \delta f_1 - \delta f^2 & \delta f_2 - \delta f^2 & \delta f_3 - \delta f^2 \\ \delta f_1 - \delta f^3 & \delta f_2 - \delta f^3 & \delta f_3 - \delta f^3 \end{bmatrix} \right) \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{bmatrix}$$

- **Biases in the Interpolated Corrections**

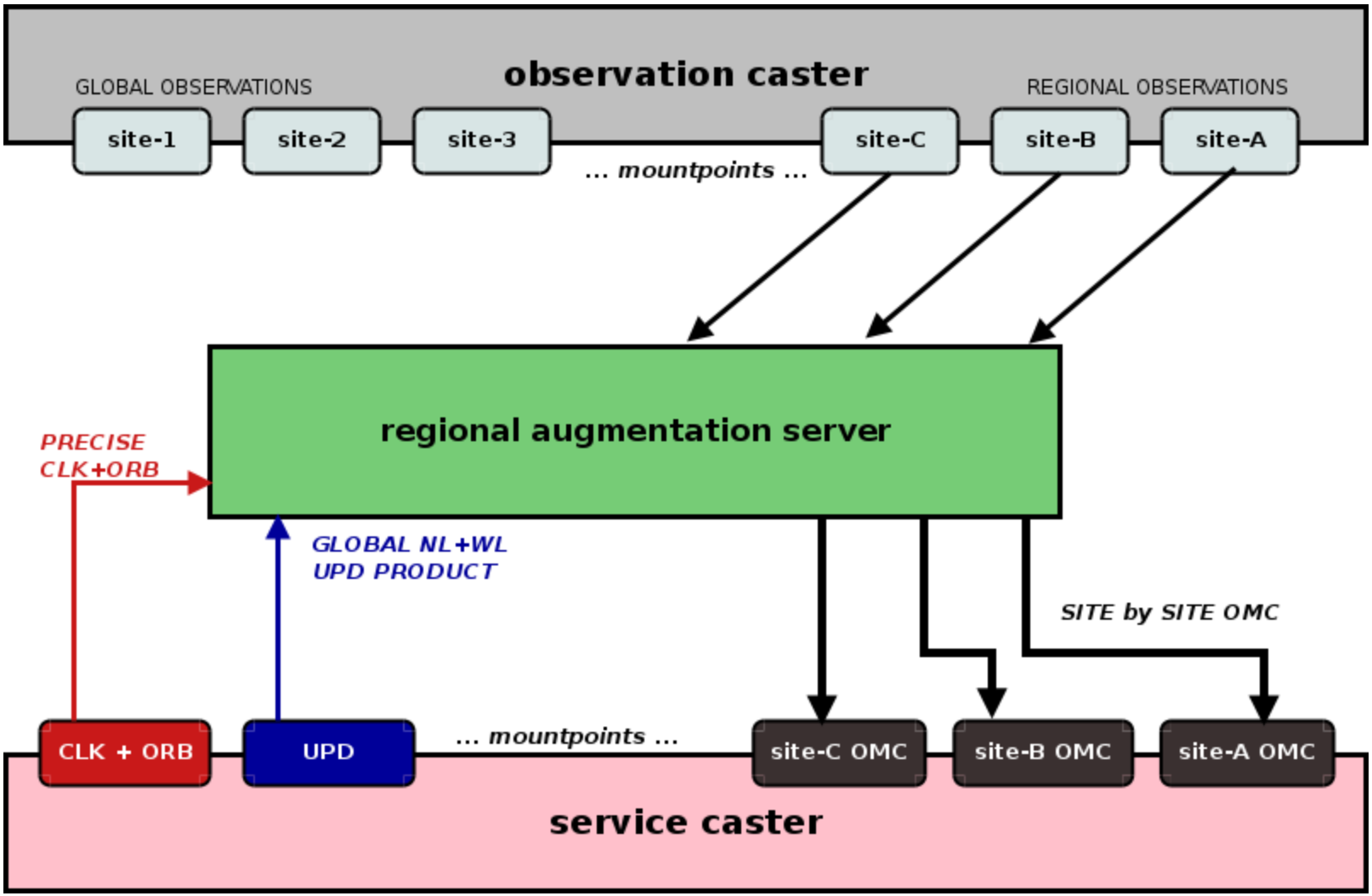
$$\begin{bmatrix} \delta\bar{l}_u^1 \\ \delta\bar{l}_u^2 \\ \delta\bar{l}_u^3 \end{bmatrix} = \sum_{i=1}^{3} \alpha_i \delta f_i \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix} - \begin{bmatrix} \delta f^1 \\ \delta f^2 \\ \delta f^3 \end{bmatrix}$$

Satellite-specific, constant for all related epochs

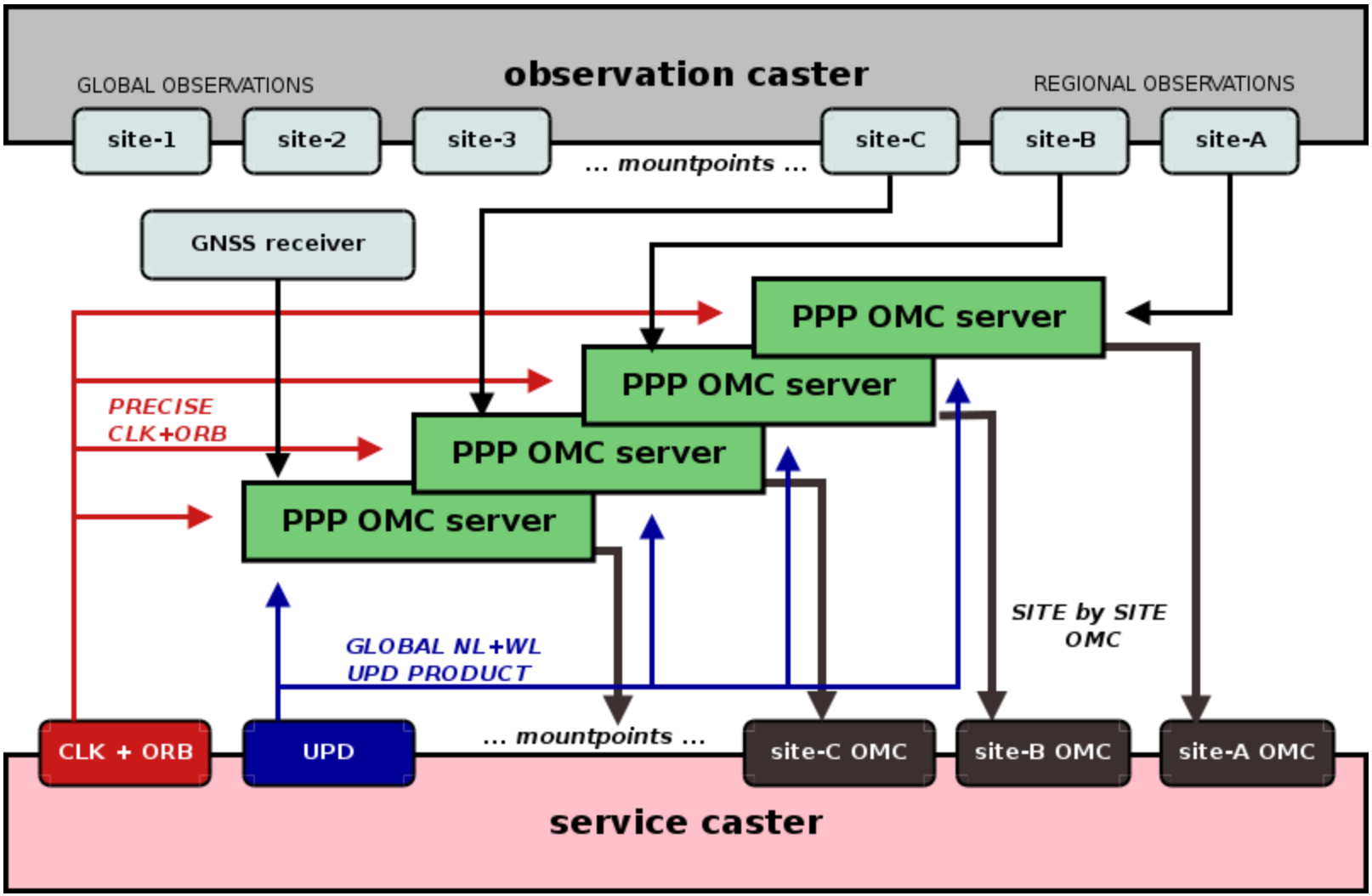
A constant for all satellites

- The 1st. a constant for all sats, and the 2nd, a integer constant for each sat, both will be absorbed by ambiguities
- SD ambiguities are natural integer.

Generation Of Augmentation Info.

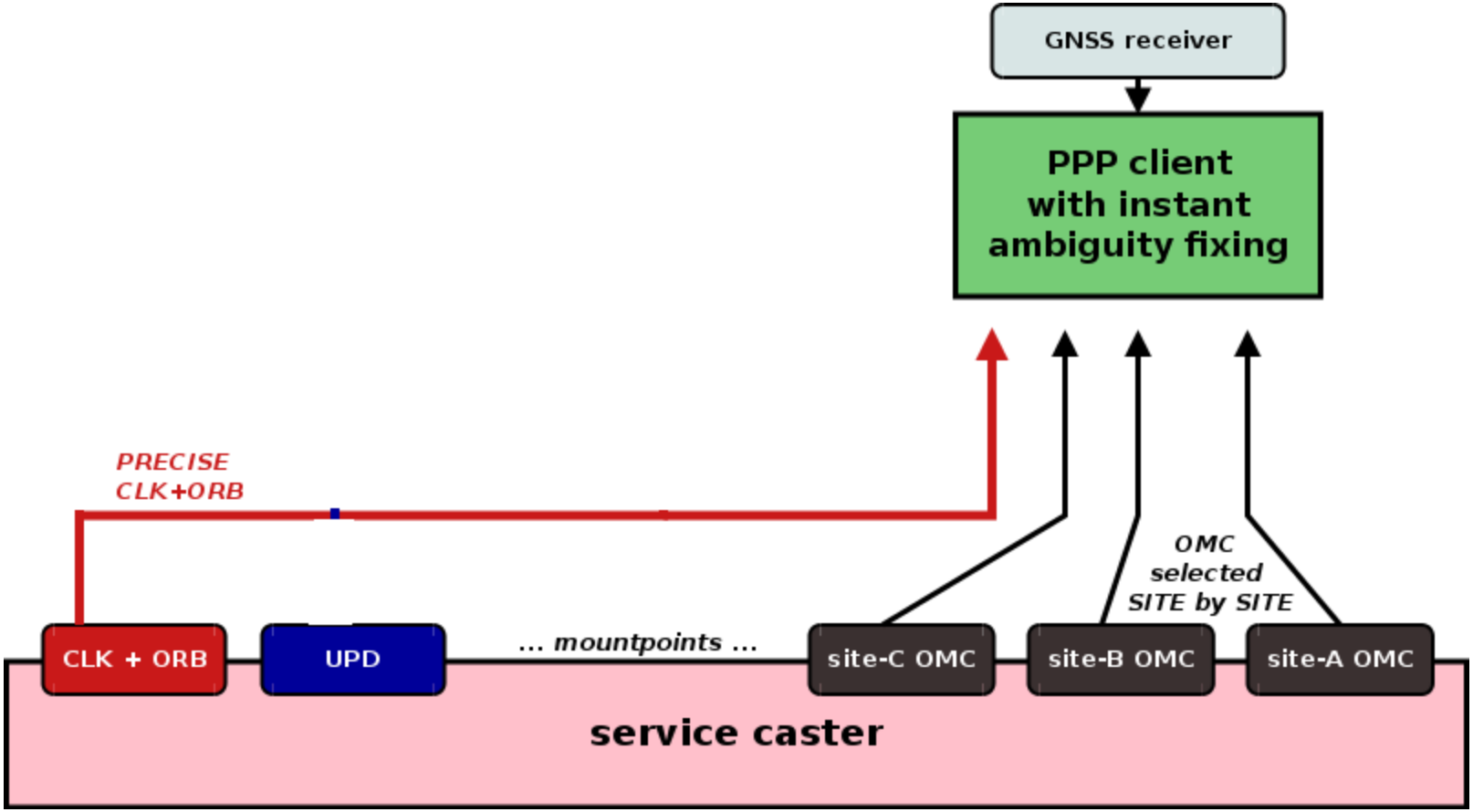


Generation Of Augmentation Info.



- Network Solution Not A Must

PPP+Regional Augmentation Client



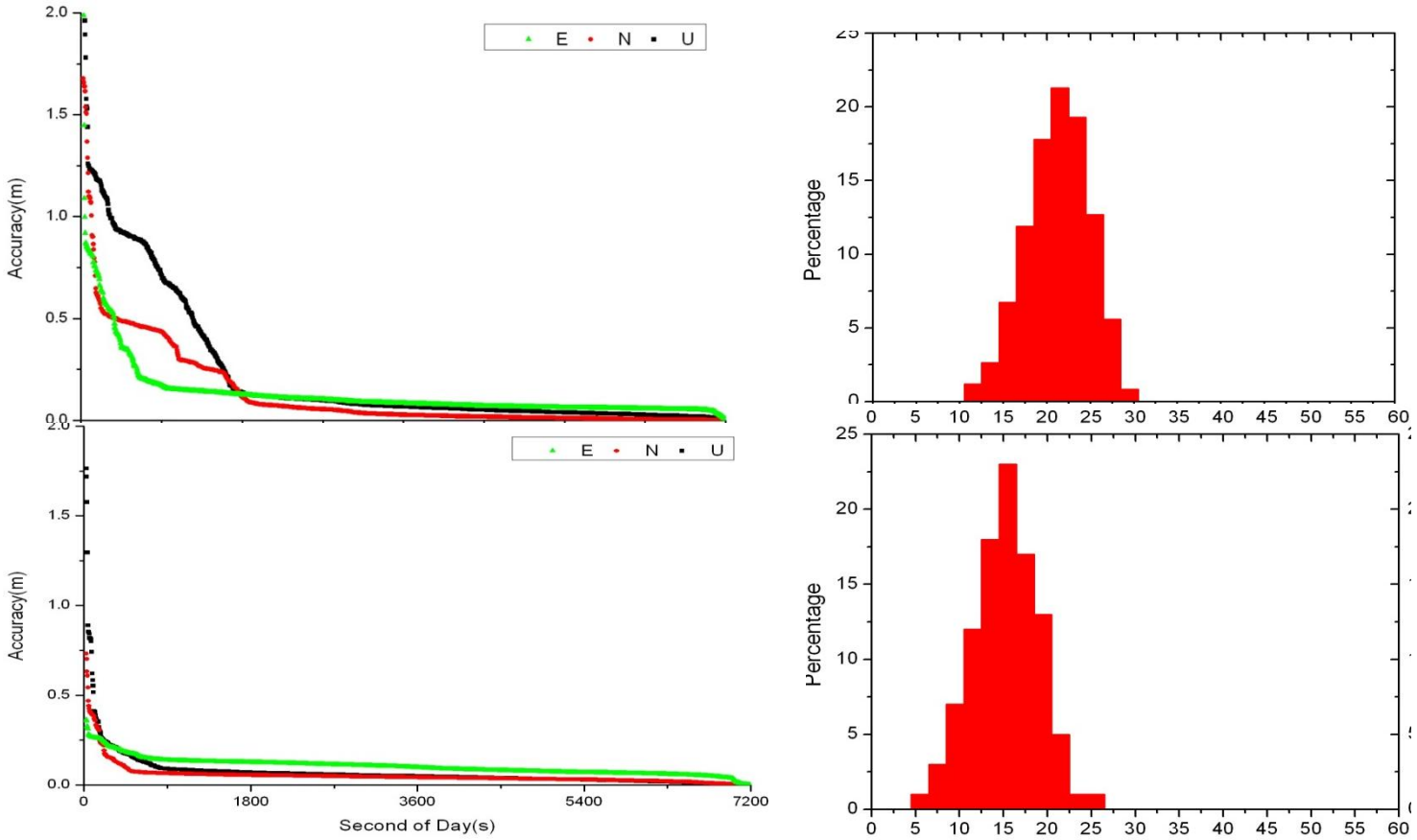
PPP With Iono. Constraints (Ref)

- **PPP with Raw Observations**
  - Ionospheric Trace Delays Are Estimated
- **Ionospheric Constraints**
  - Spatial Constraint (Gradients)
  - Temporal Constraint (Random-Walk Process)
  - Ionospheric Correction Constraint (Pseudo-obs.)

ION 2012 Student Award Winner, Mr. Xingxing LI

IONO. Model, Presented By Dr Hongping Zhang

PPP With Iono. Constraints (Ref)



Improvements

- Faster Convergence, 30 to 20 min < 10 cm
- Faster Ambiguity-Fixing, 20 to 15 min
- Static Station, 10 min, With Known Position, 5 min

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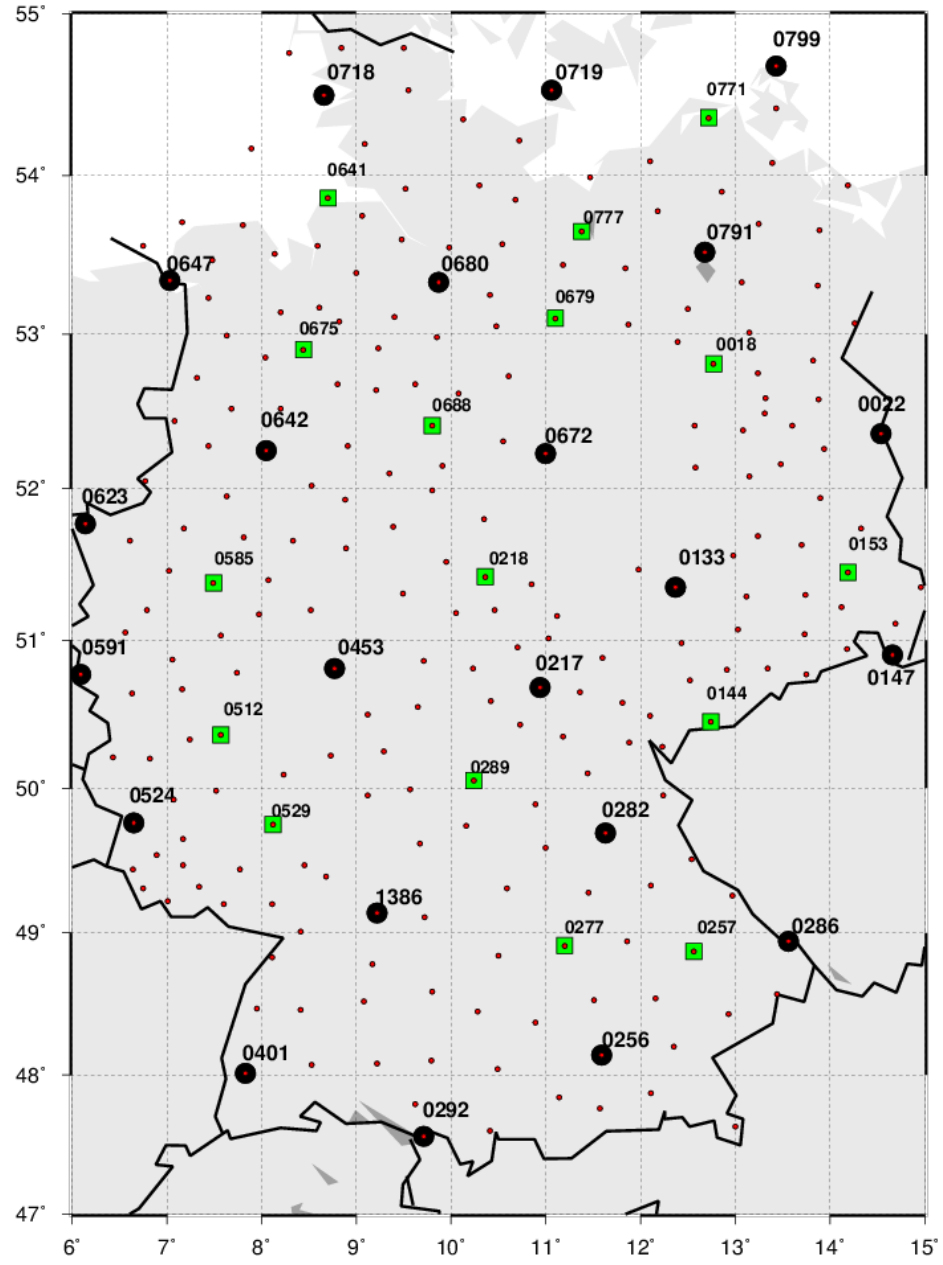
PPP With Iono. Constraints (Usr)

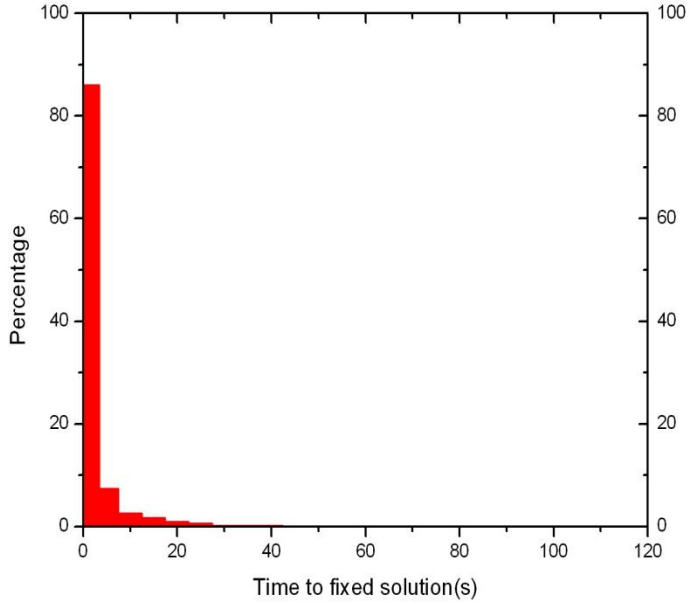
- **PPP with Raw Observations**
  - Corrections From Ref. Stations Applied
  - Remaining Ionospheric Trace Delays Estimated
- **Ionospheric Constraints**
  - Spatial Constraint (Gradients)
  - Temporal Constraint (Random-Walk Process)
- **Improvements**
  - Ambiguity-Fixing At User-End
  - Larger Inter-Station Distance

Real-Time Validation (SAPOS)

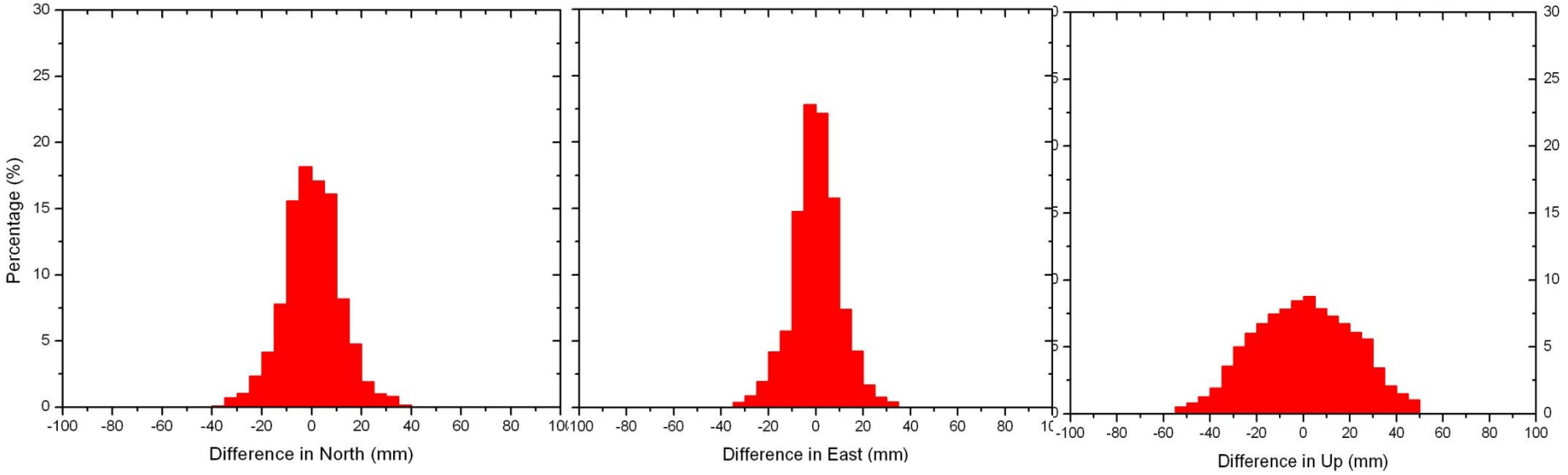


- **DATA**
  - SAPOS Real-Time Data of about 200 stations (2012) among them about 20 GREF stations
  - Various receiver types
  - 1 seconds sampling rate
- **Reference Network**
  - Selected 22 reference stations
  - Inter-station distance 180 km
  - 17 user stations (green squares)
- **Software**
  - iPPP in C++ for PPP + UPD + Regional Augmentation

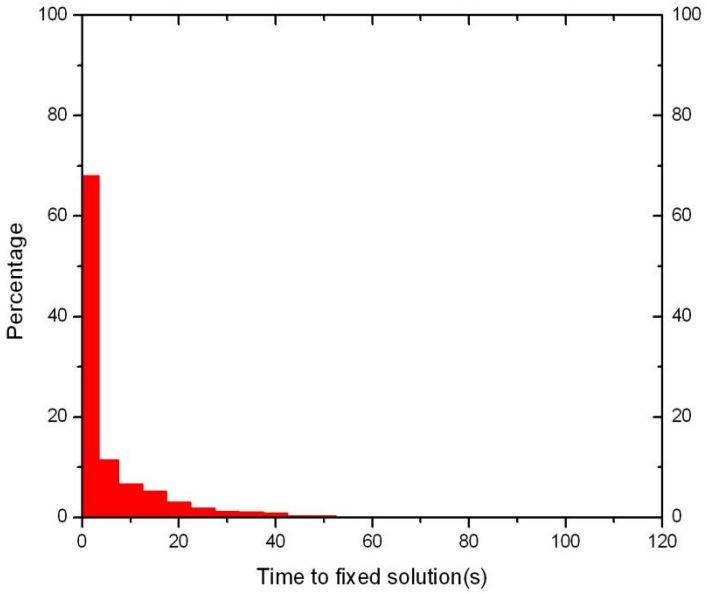
PPP With L1+L2+Iono. Constraints



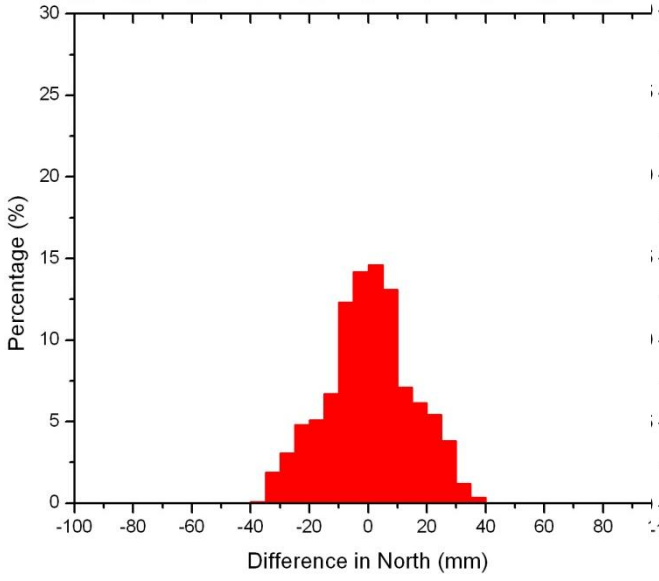
- Reset The Estimator Every Minute
- 87% Fixed With 1 Epoch, On Average Two Epochs
- 12, 10 and 25 mm in ENU

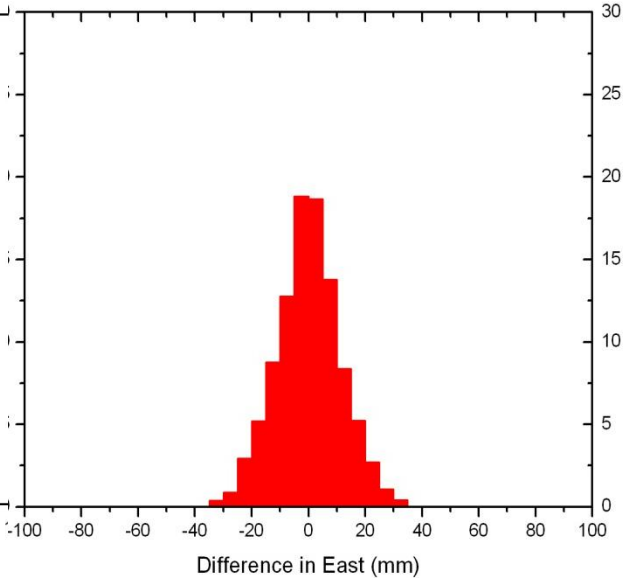


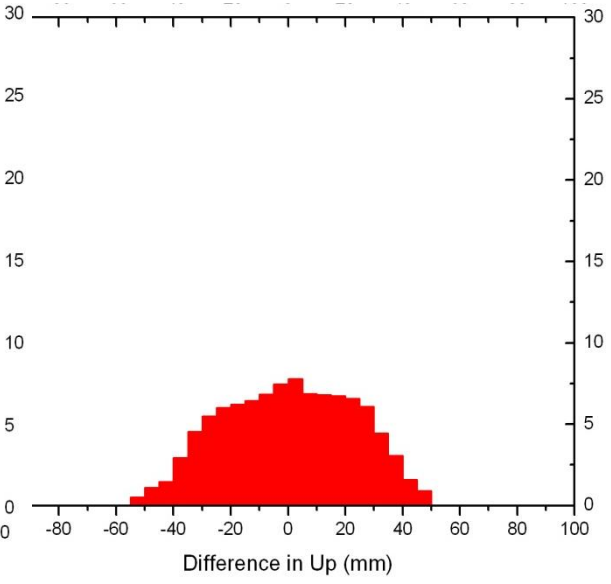
PPP With Lw+Lc Obs.



- Reset The Estimator Every Minute
- 68% Fixed With 1 Epoch, On Average Two Epochs
- 15, 10 and 30 mm in ENU

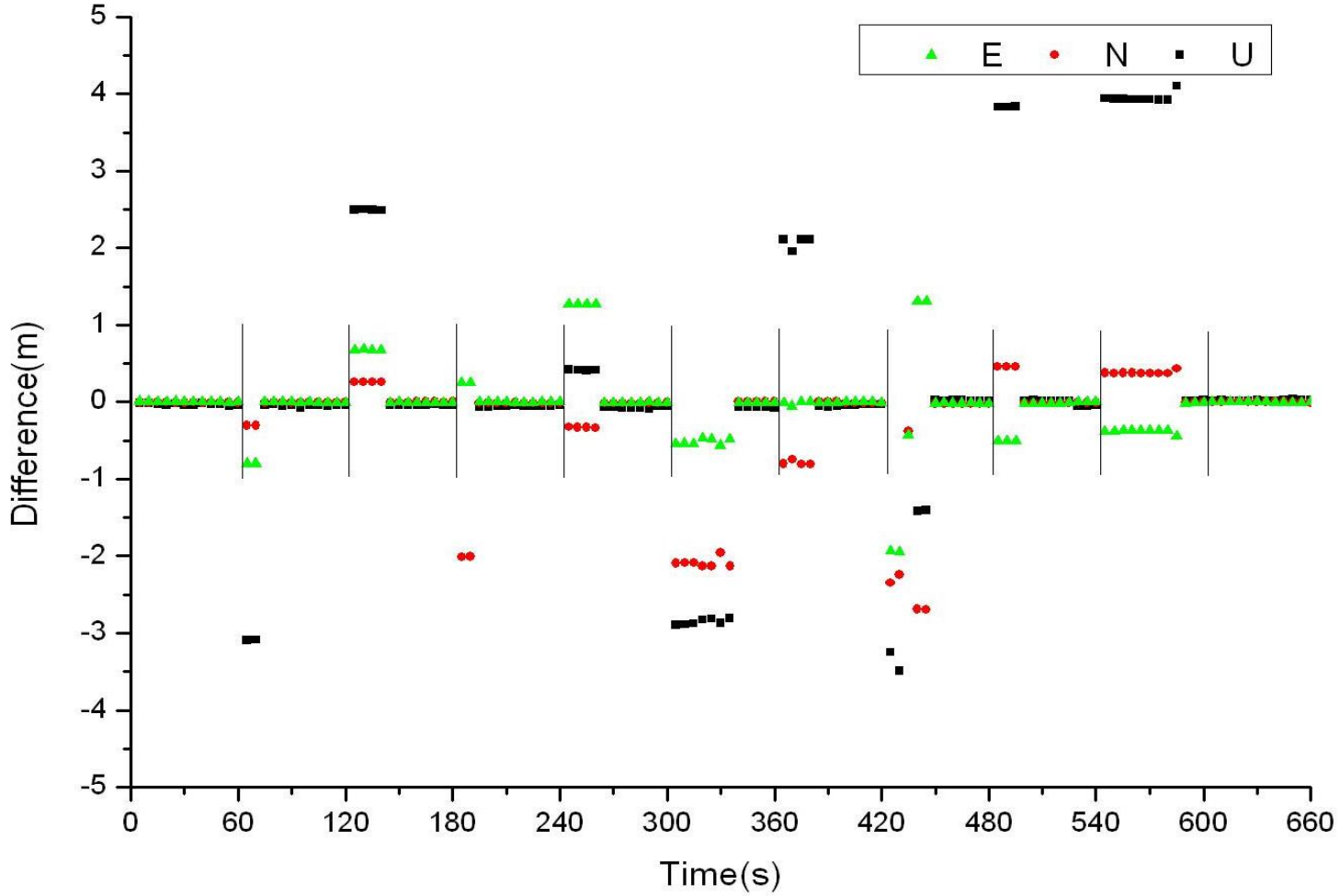






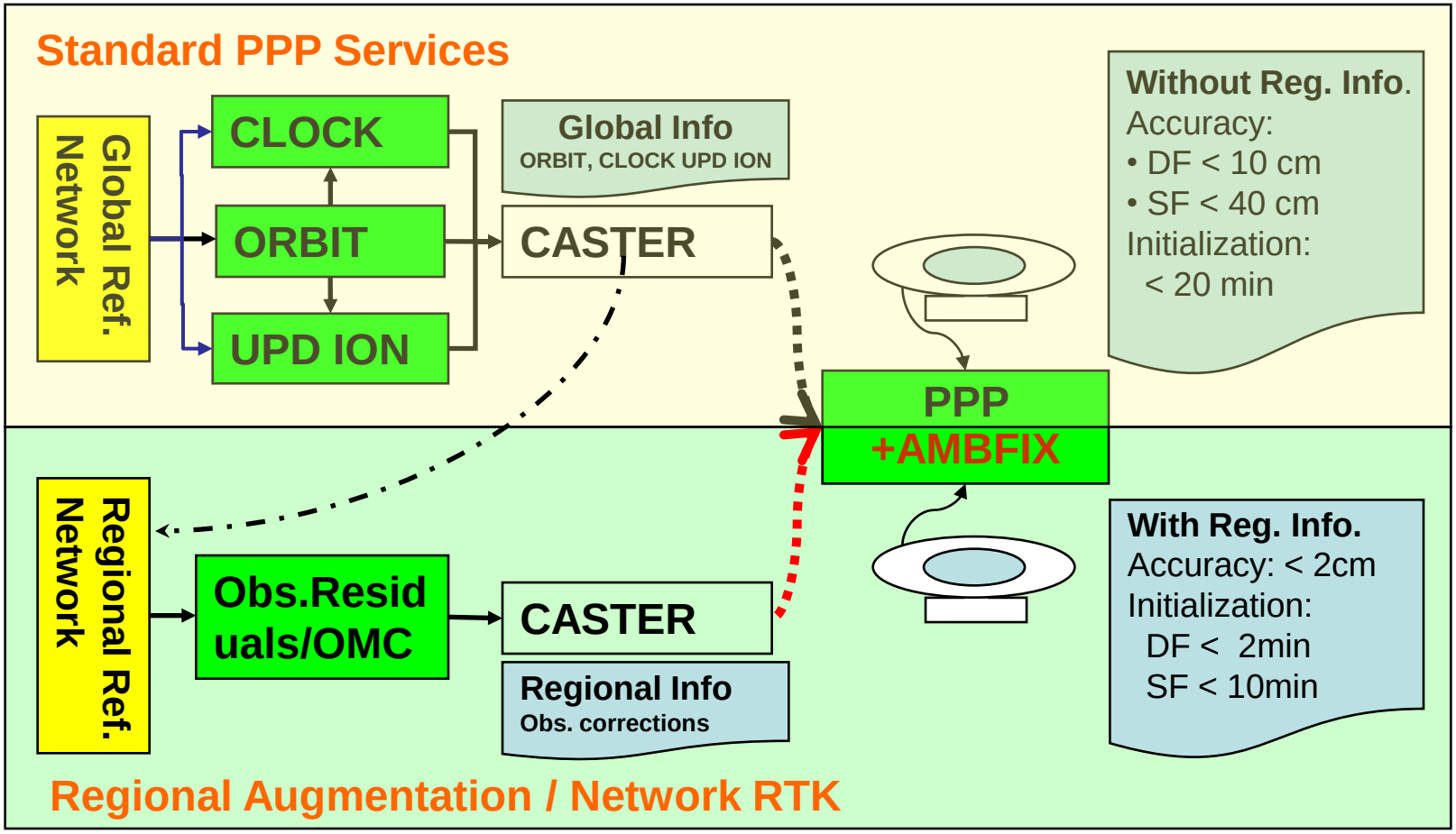
Example Of Real-Time Results

- Every Minute Reset The Estimator, Initial Coordinates from SPP

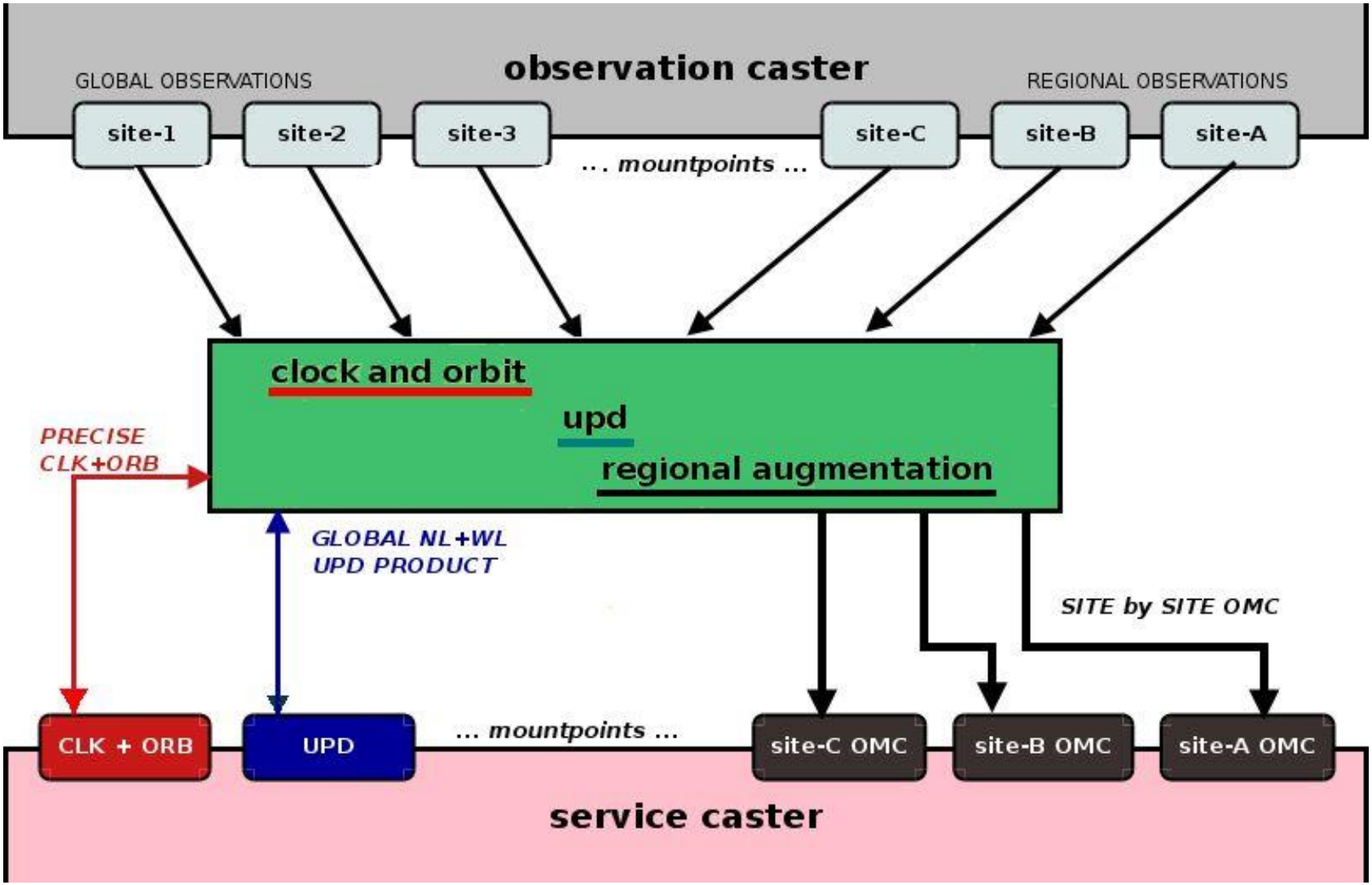


Example Of Real-Time Results

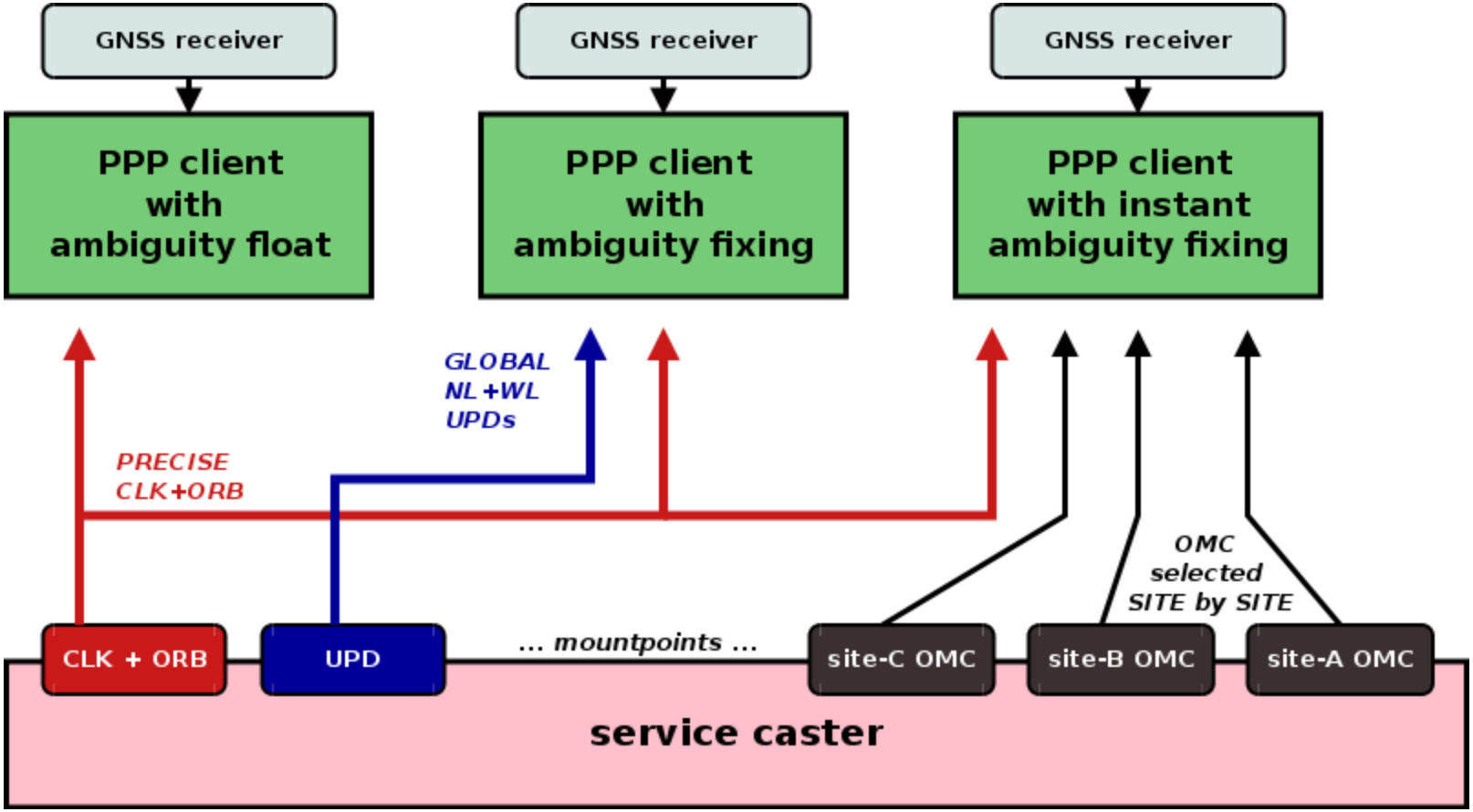
Augmentation of PPP Service



Global Real-Time Precise Point Positioning With Regional Augmentation


observation caster
GLOBAL OBSERVATIONS
REGIONAL OBSERVATIONS
site-1
site-2
site-3
site-C
site-B
site-A
... mountpoints ...
clock and orbit
upd
regional augmentation
PRECISE
CLK+ORB
GLOBAL NL+WL
UPD PRODUCT
SITE by SITE OMC
CLK + ORB
UPD
... mountpoints ...
site-C OMC
site-B OMC
site-A OMC
service caster

PPP Clients


GNSS receiver
GNSS receiver
GNSS receiver
PPP client with ambiguity float
PPP client with ambiguity fixing
PPP client with instant ambiguity fixing
GLOBAL NL+WL UPDs
PRECISE CLK+ORB
OMC selected SITE by SITE
CLK + ORB
UPD
... mountpoints ...
site-C OMC
site-B OMC
site-A OMC
service caster

Performance Of The Augmented PPP Service

- **Without Regional Augmentation**
  - **Open Ocean, …**
  - **5-10 cm, after 30 min., 3-5 cm after Ambiguity-Fixing (15 min)**
- **With Regional Augmentation**
  - **Developed Cities, …**
  - **1-2 cm, within 1-2 min. depends on …**
- **Also For Single-Frequency And Low-Cost Receivers**

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Thanks

Thanks To SAPOS, BKG, IGS
For Providing Real-Time Data !

Thanks for Your Attention !

For Details And More Real-Time Results (PPP, PPP+AR, PPP+RA)

http://kg6-dmz.gfz-potsdam.de/rtgnss/