# Analysis of the transformed clocks approach for dealing with scale-induced bias in the generation of ETRS89 clock and orbit corrections to broadcast ephemeris

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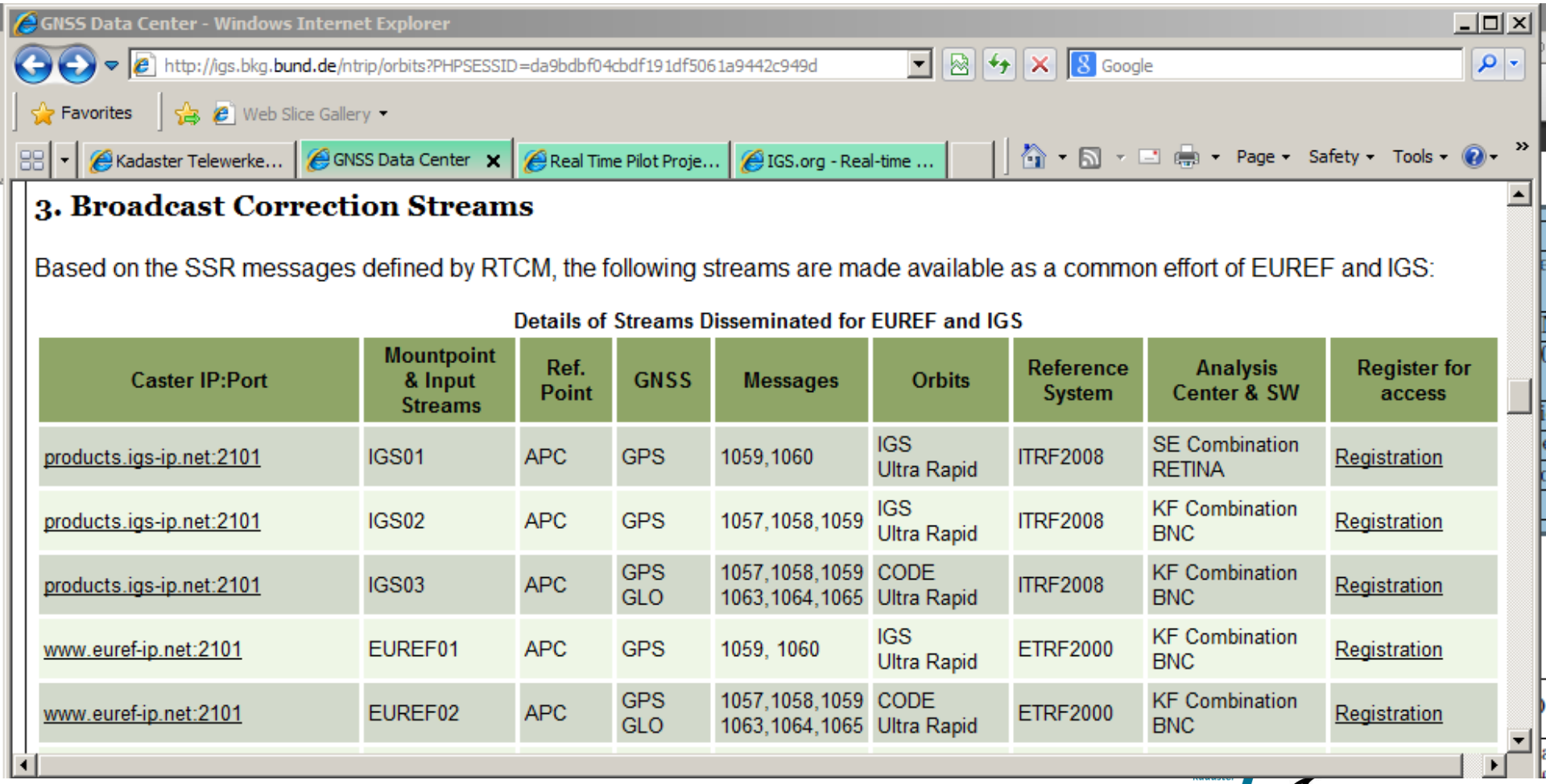
# Outline

- **EUREF Orbit and Clock corrections**
- Scale induced bias
  - Problem description
  - Approaches to deal with bias
    - Unscaled
    - Scale-absorbed
    - Transformed clocks (Approach used for EUREF RT Products)
- Results
  - Transformed clocks
  - Scale absorbed
- Conclusions
- Outlook

# EUREF Products



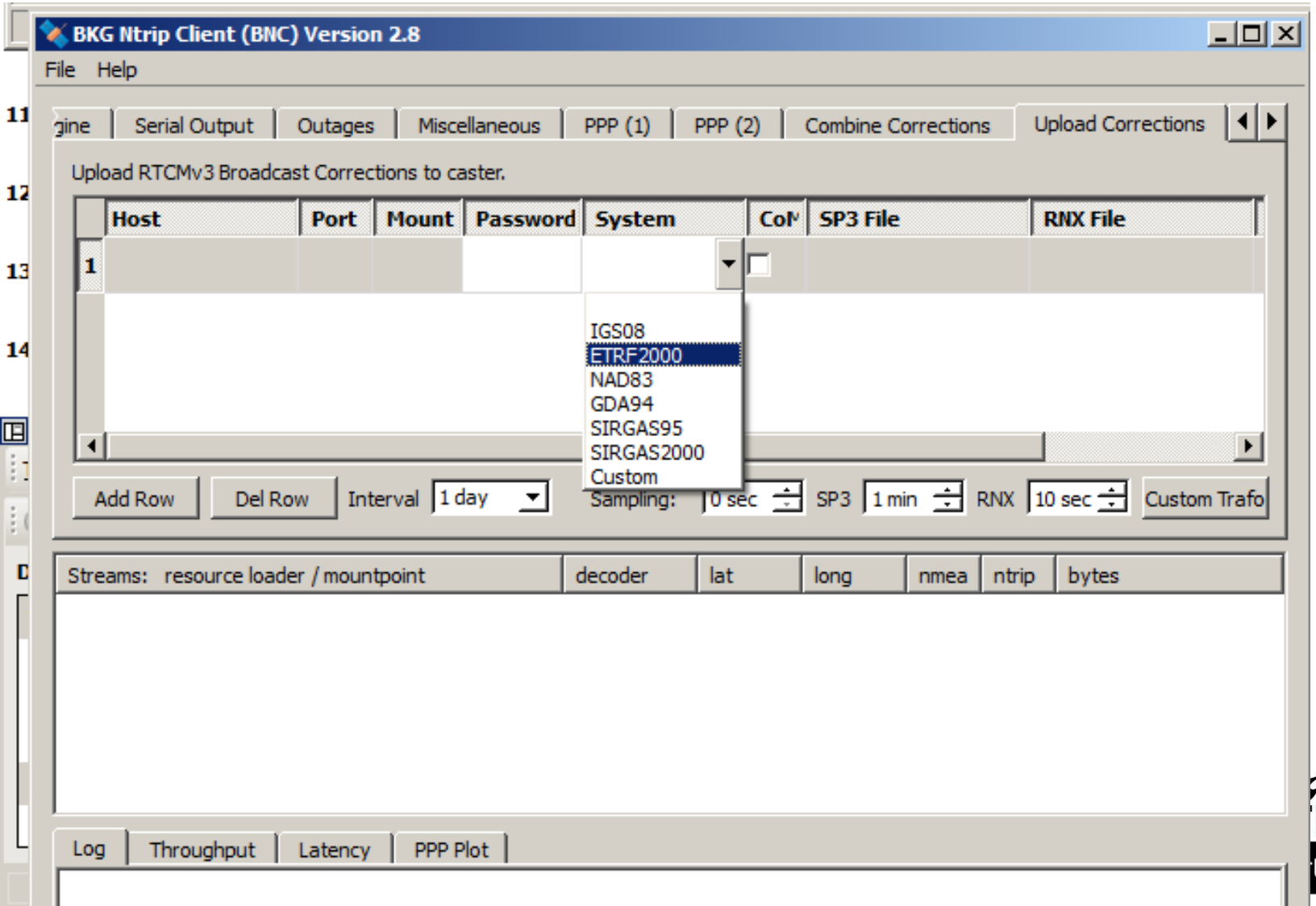

### 3. Broadcast Correction Streams

Based on the SSR messages defined by RTCM, the following streams are made available as a common effort of EUREF and IGS:

**Details of Streams Disseminated for EUREF and IGS**

| Caster IP:Port | Mountpoint & Input Streams | Ref. Point | GNSS | Messages | Orbits | Reference System | Analysis Center & SW | Register for access |
|---|---|---|---|---|---|---|---|---|
| products.igs-ip.net:2101 | IGS01 | APC | GPS | 1059,1060 | IGS Ultra Rapid | ITRF2008 | SE Combination RETINA | Registration |
| products.igs-ip.net:2101 | IGS02 | APC | GPS | 1057,1058,1059 | IGS Ultra Rapid | ITRF2008 | KF Combination BNC | Registration |
| products.igs-ip.net:2101 | IGS03 | APC | GPS GLO | 1057,1058,1059 1063,1064,1065 | CODE Ultra Rapid | ITRF2008 | KF Combination BNC | Registration |
| www.euref-ip.net:2101 | EUREF01 | APC | GPS | 1059, 1060 | IGS Ultra Rapid | ETRF2000 | KF Combination BNC | Registration |
| www.euref-ip.net:2101 | EUREF02 | APC | GPS GLO | 1057,1058,1059 1063,1064,1065 | CODE Ultra Rapid | ETRF2000 | KF Combination BNC | Registration |

# Generated with BKG NTRIP Client (BNC)



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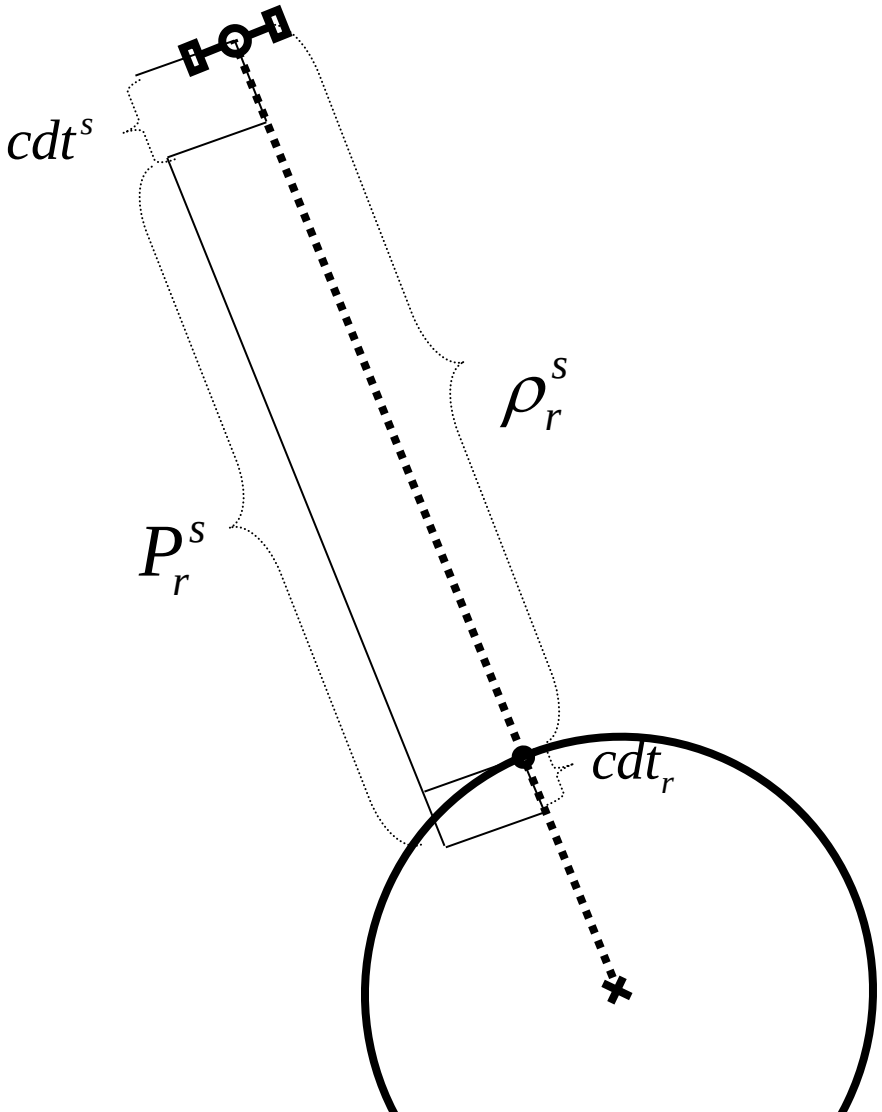
# Scale induced bias explained:
# 1- Simplified observation equation




Assume atmospheric and hardware delays and other error sources absent, then:

$$P_r^s = c(\tau_r^s - dt^s + dt_r)$$

$$= \rho_r^s + c(dt_r - dt^s)$$

With

$P_r^s$ Observation

$c$ Signal propagation speed

$\tau_r^s$ Travel time

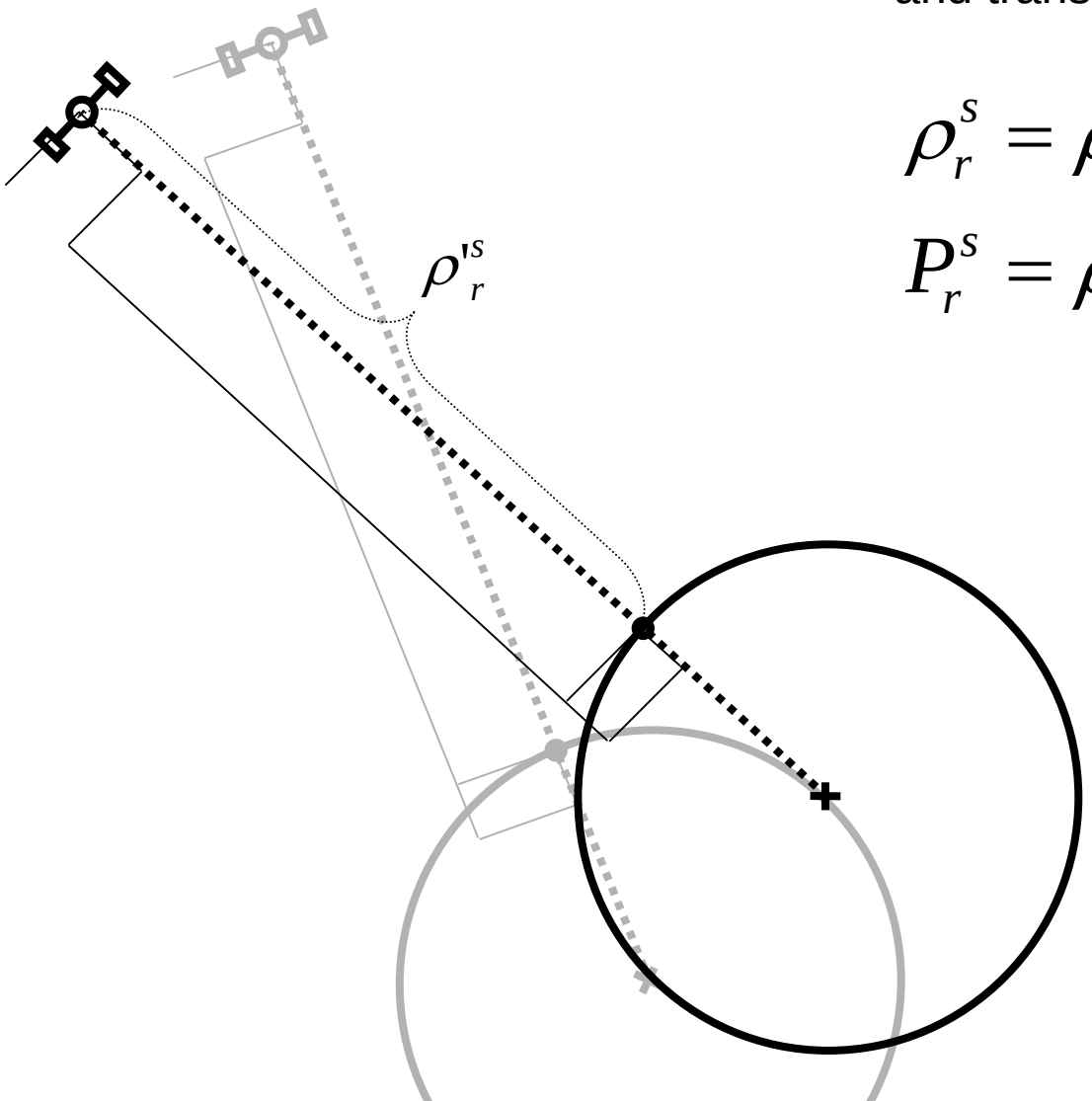
$\rho_r^s$ Receiver satellite range

$dt^s$ Satellite clock error

$dt_r$ Receiver clock error

# 2 – Translation and rotation of reference frame

$x' = d + Rx$ ($d$: translation vector $R$: rotation matrix)




Parameters are invariant for rotation and translation

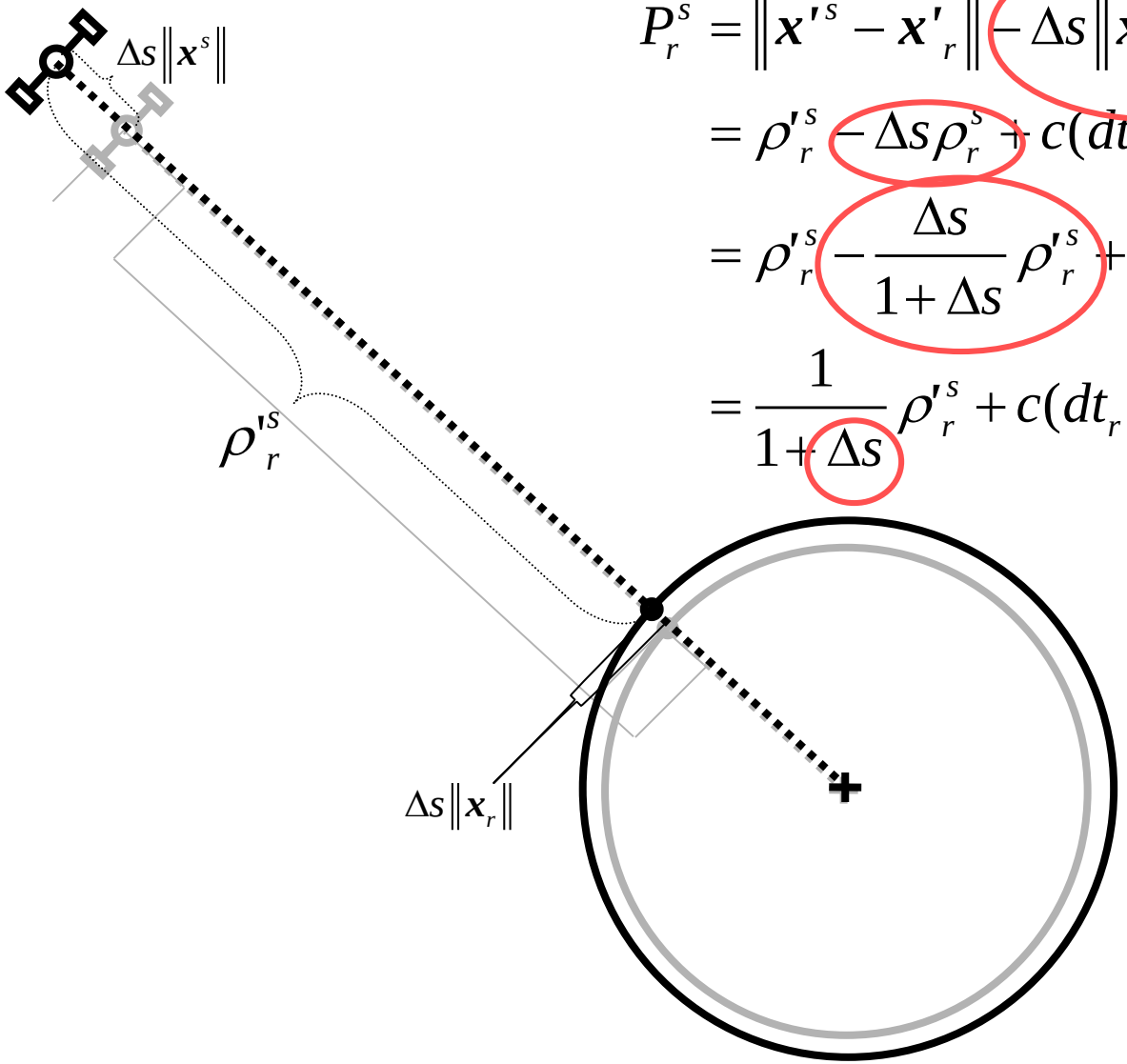
$$\rho^{s}_{r} = \rho'^{s}_{r}$$

$$P^{s}_{r} = \rho'^{s}_{r} + c(dt_r - dt^s)$$

# 3 – Translation, rotation and scaling of reference frame

$x' = d + (1+\Delta s)Rx$ ($\Delta s$: increment to scale)

Scale affects computed receiver satellite range: $\rho_r^s = \frac{1}{1+\Delta s}\rho'^s_r$




$$P_r^s = \left\|x'^s - x'_r\right\| - \Delta s\left\|x^s - x_r\right\| + c(dt_r - dt^s)$$

$$= \rho'^s_r - \Delta s\rho_r^s + c(dt_r - dt^s)$$

$$= \rho'^s_r - \frac{\Delta s}{1+\Delta s}\rho'^s_r + c(dt_r - dt^s)$$

$$= \frac{1}{1+\Delta s}\rho'^s_r + c(dt_r - dt^s)$$

Ignored in processing algorithms: *Scale induced bias*



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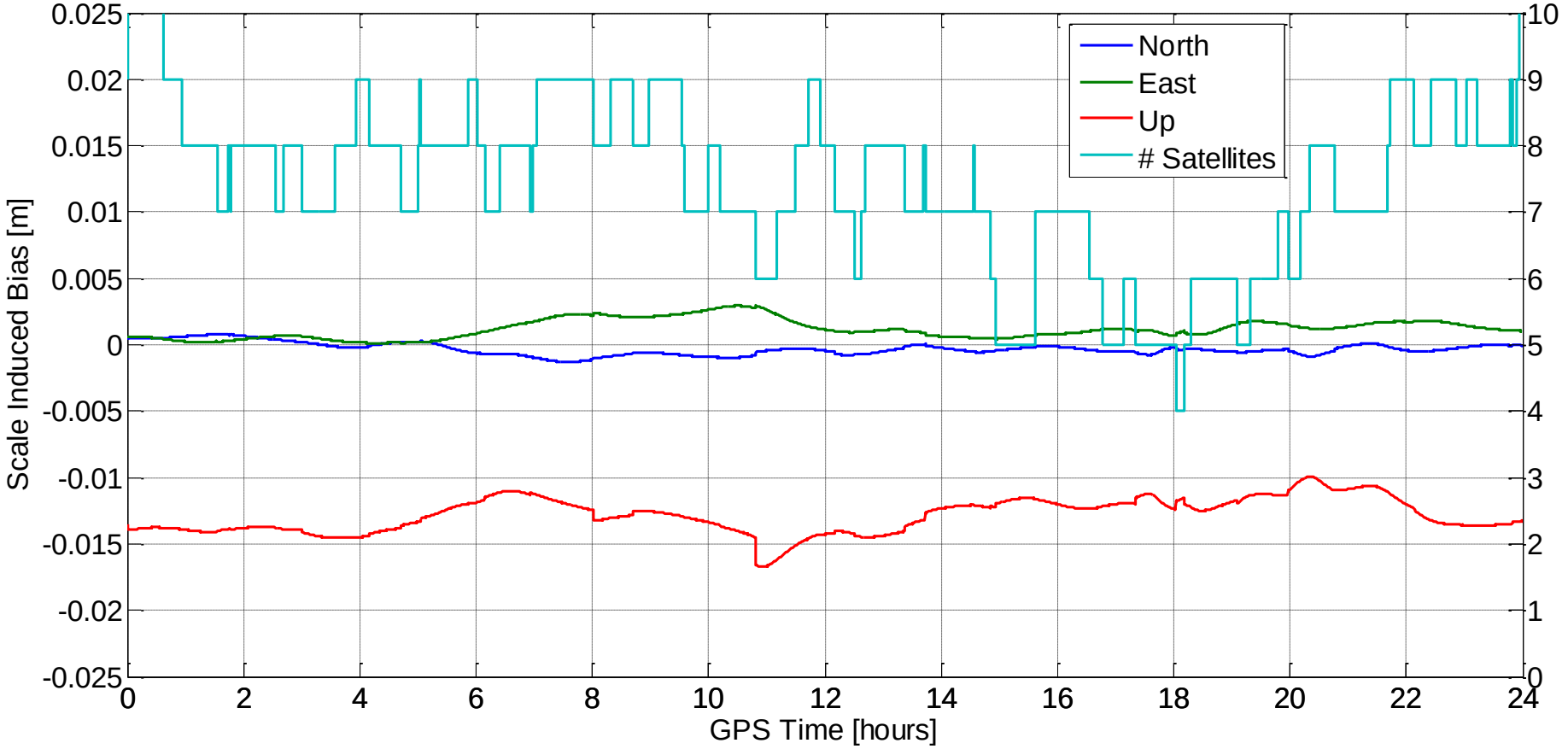
# Example effect of scale induced bias
# May 22nd 2013, station LAGO Portugal




Scale induced bias = B – A, with:

A: Result obtained with global products and applying 14-parameter transformation (IGS01)

B: Result obtained with regional products



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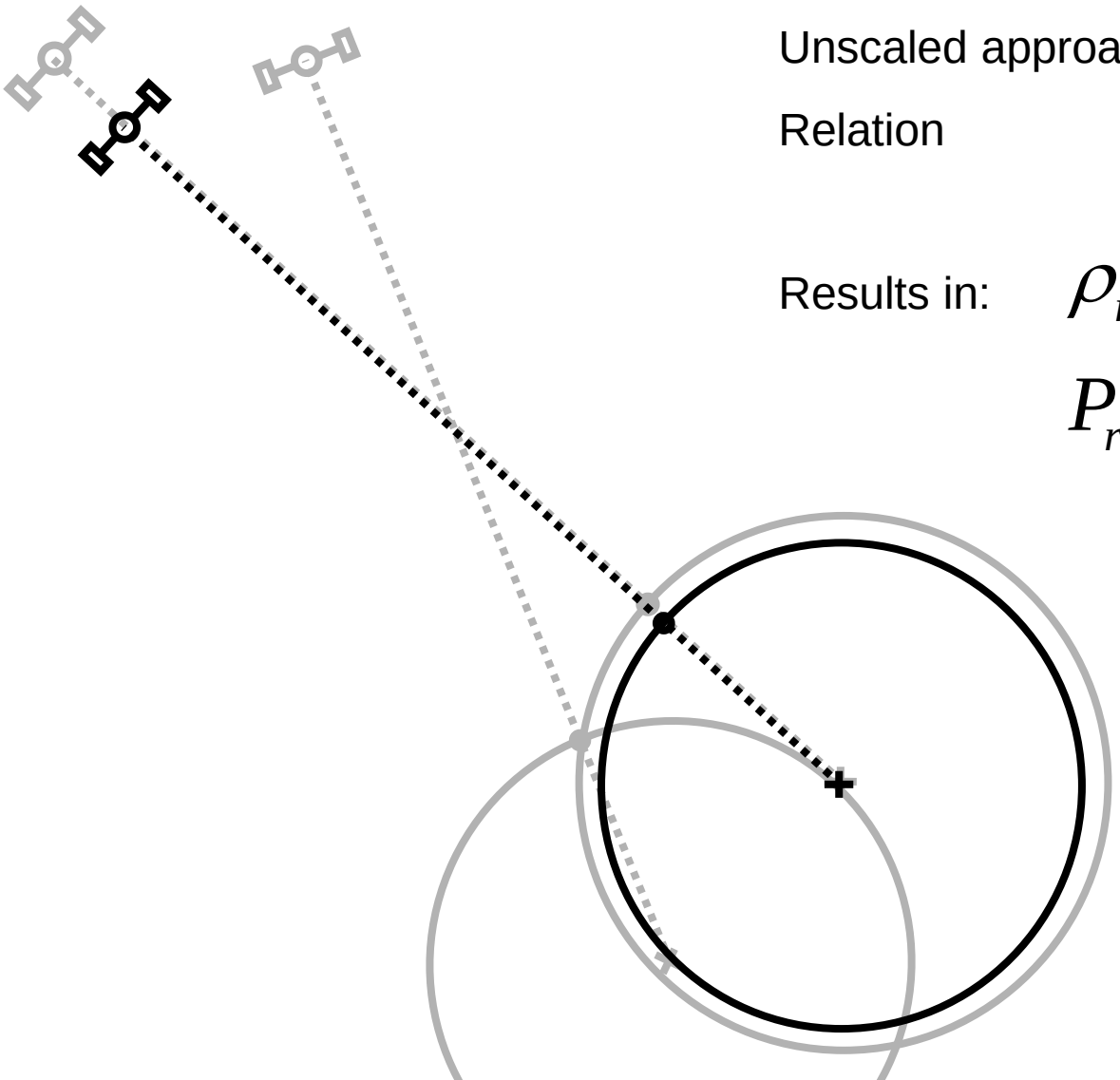
# Unscaled approach



Usual transformation $x' = d + (1 + \Delta s) Rx$

Unscaled approach $x'' = d + Rx$

Relation $x' = x'' + \Delta s Rx$

Results in: $\rho_r^s = \rho''^s_r$

$$P_r^s = \rho''^s_r + c(dt_r - dt^s)$$



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# Scale absorbed approach

Usual transformation $x' = d + (1+\Delta s)Rx$

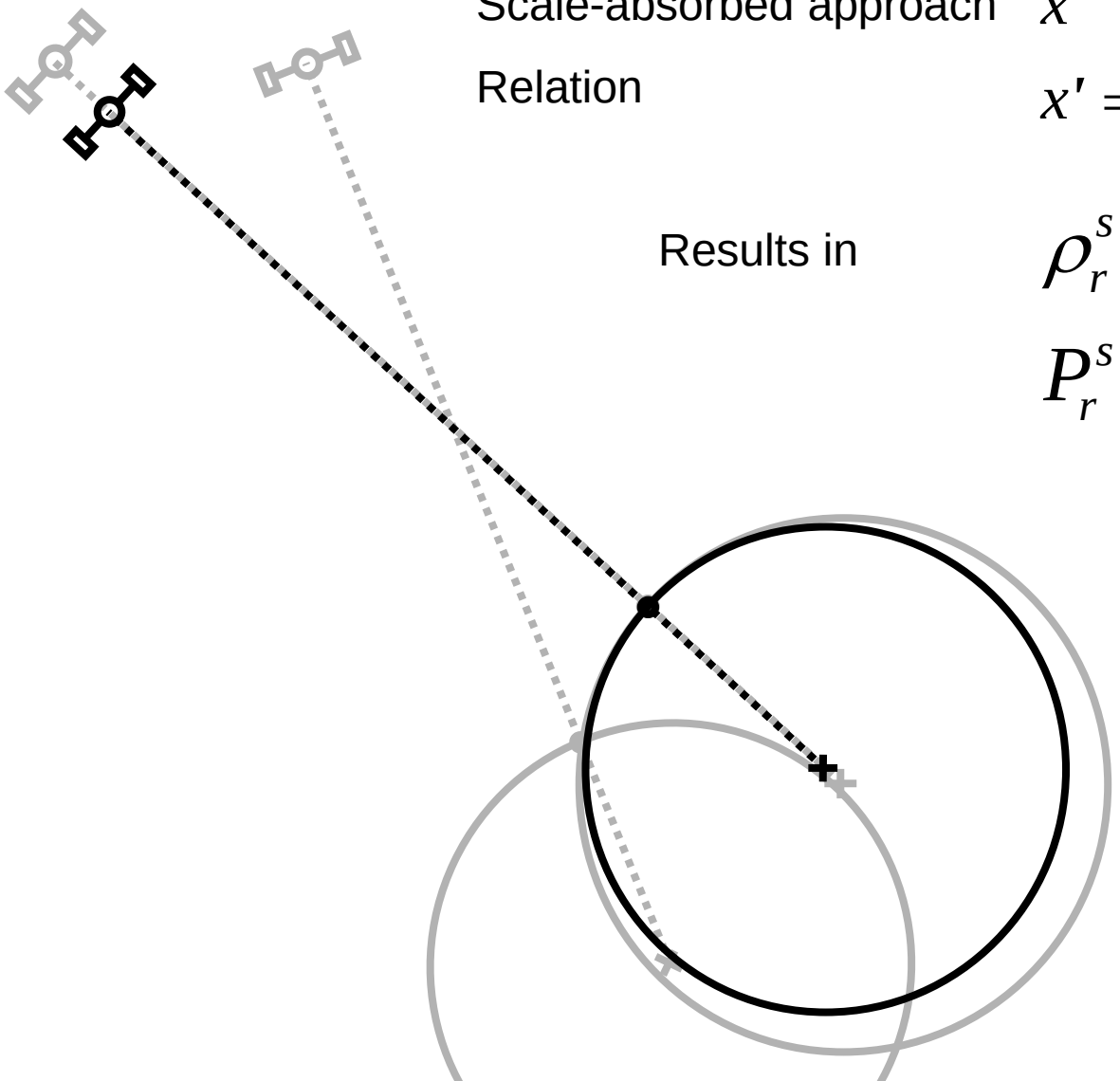
Scale-absorbed approach $x'' = d'' + Rx \;\; ; \;\; d'' = d + \Delta s R x_*$

Relation $x' = x'' + \Delta s R(x - x_*)$

Results in

$$\rho_r^s = \rho''^s_r$$

$$P_r^s = \rho''^s_r + c(dt_r - dt^s)$$



# Transformed clocks approach

Usual transformation

$$x' = d + (1+\Delta s)Rx$$

Results in:

$$P_r^s = \rho'^s_r - \frac{\Delta s}{1+\Delta s}\rho'^s_r + c(dt_r - dt^s)$$

Transformed clocks approach

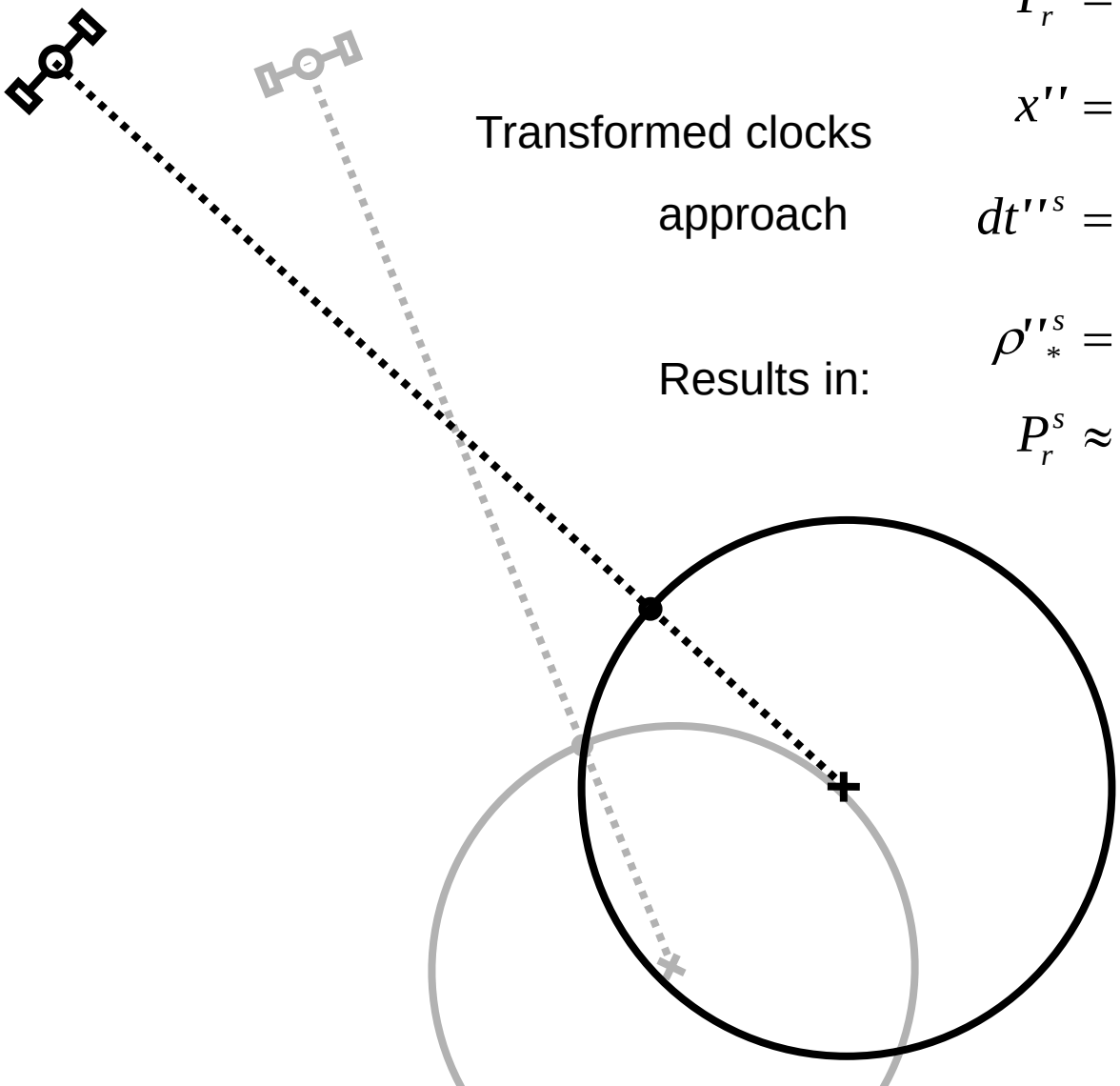
$$x'' = d + (1+\Delta s)Rx$$

$$dt''^s = dt^s + \frac{1}{c}\frac{\Delta s}{1+\Delta s}\rho''^s_*$$

Results in:

$$\rho''^s_* = \left\| x''^s - x''_* \right\|$$

$$P_r^s \approx \rho''^s_r + c(dt_r - dt''^s)$$



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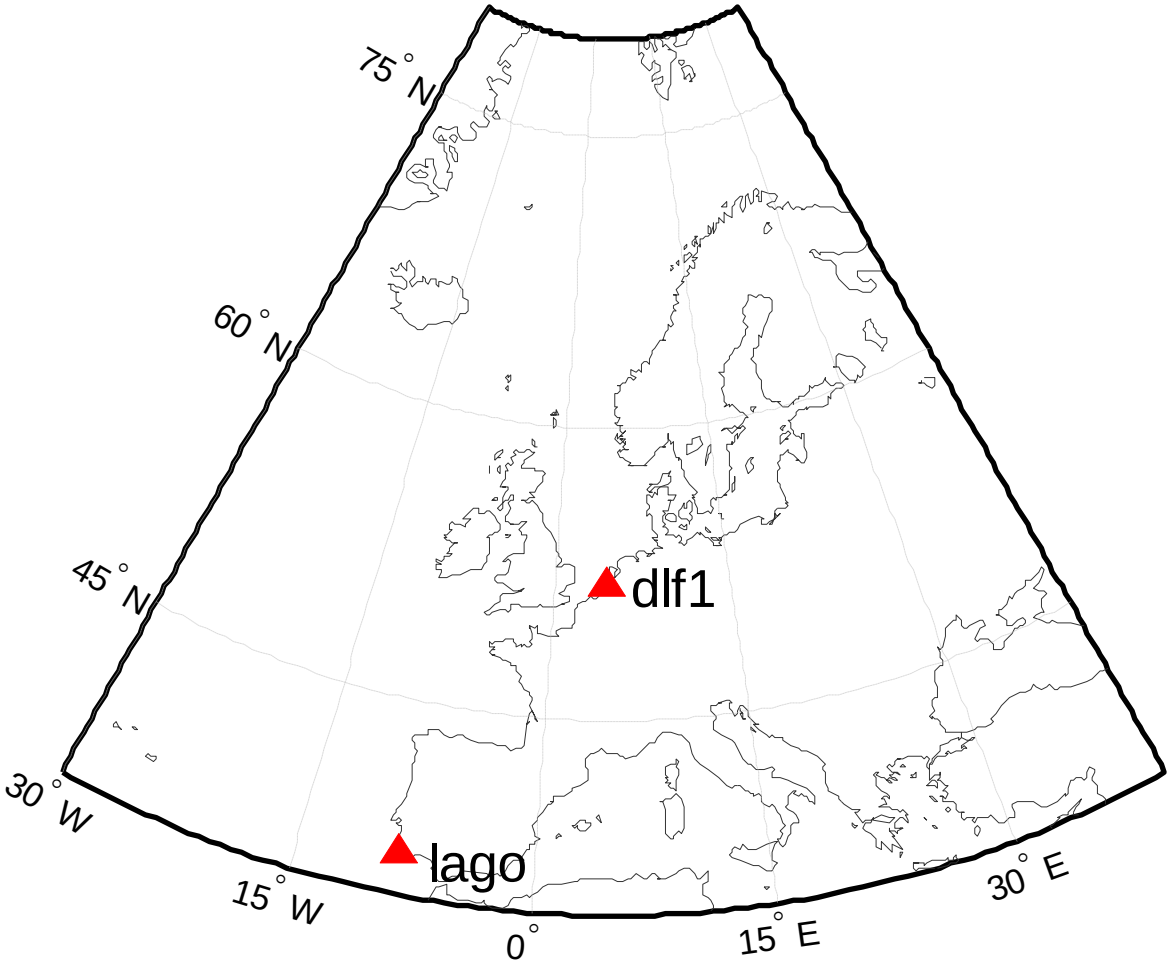
# Processed Stations



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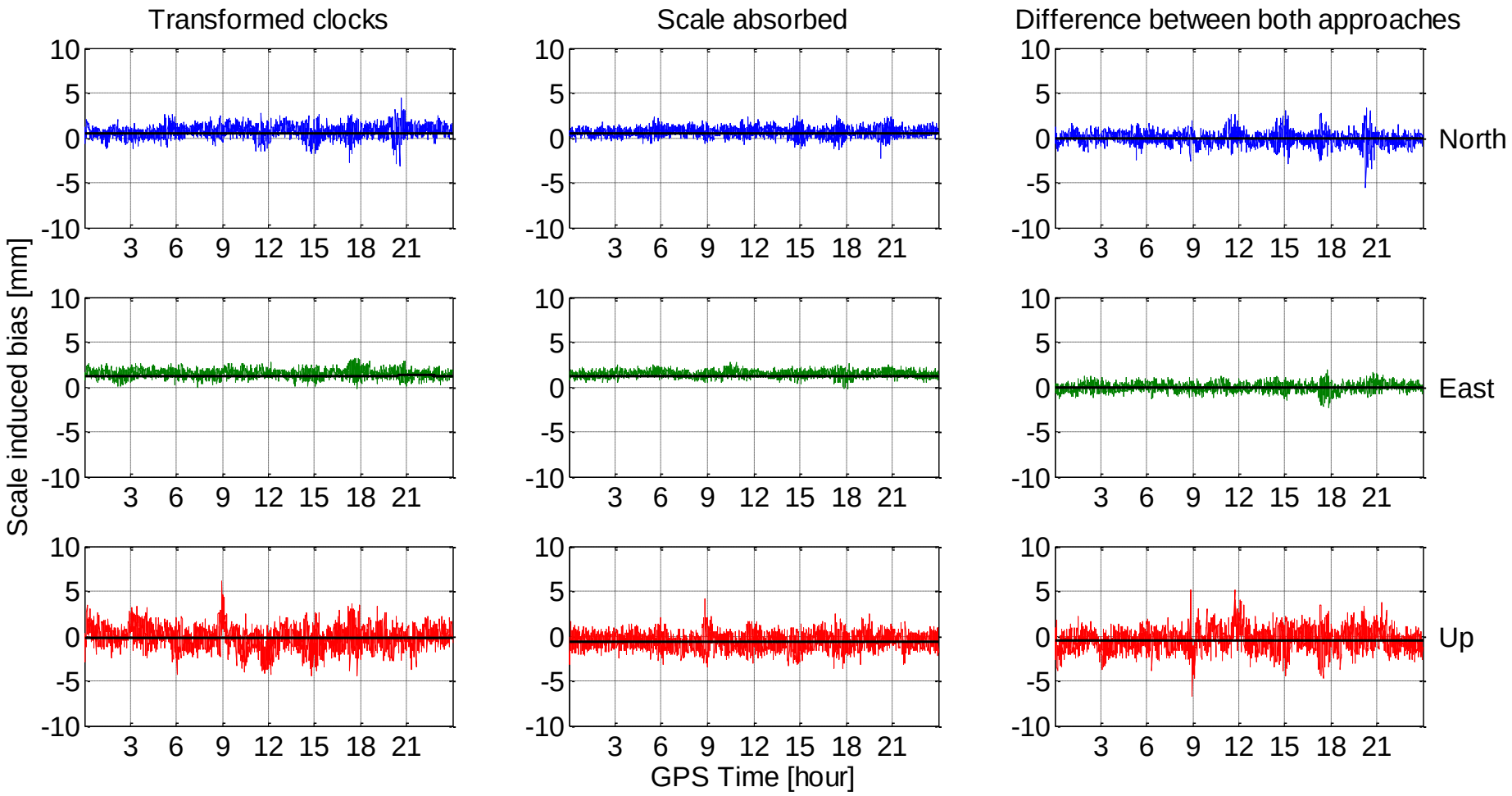
Curtin DF-PPP
Station DLF1, 23-May-2013, 30 second sampling rate
Global product: IGS01, Regional products: Created with BNC 2.8




—— result when creating regional product with Curtin PPP



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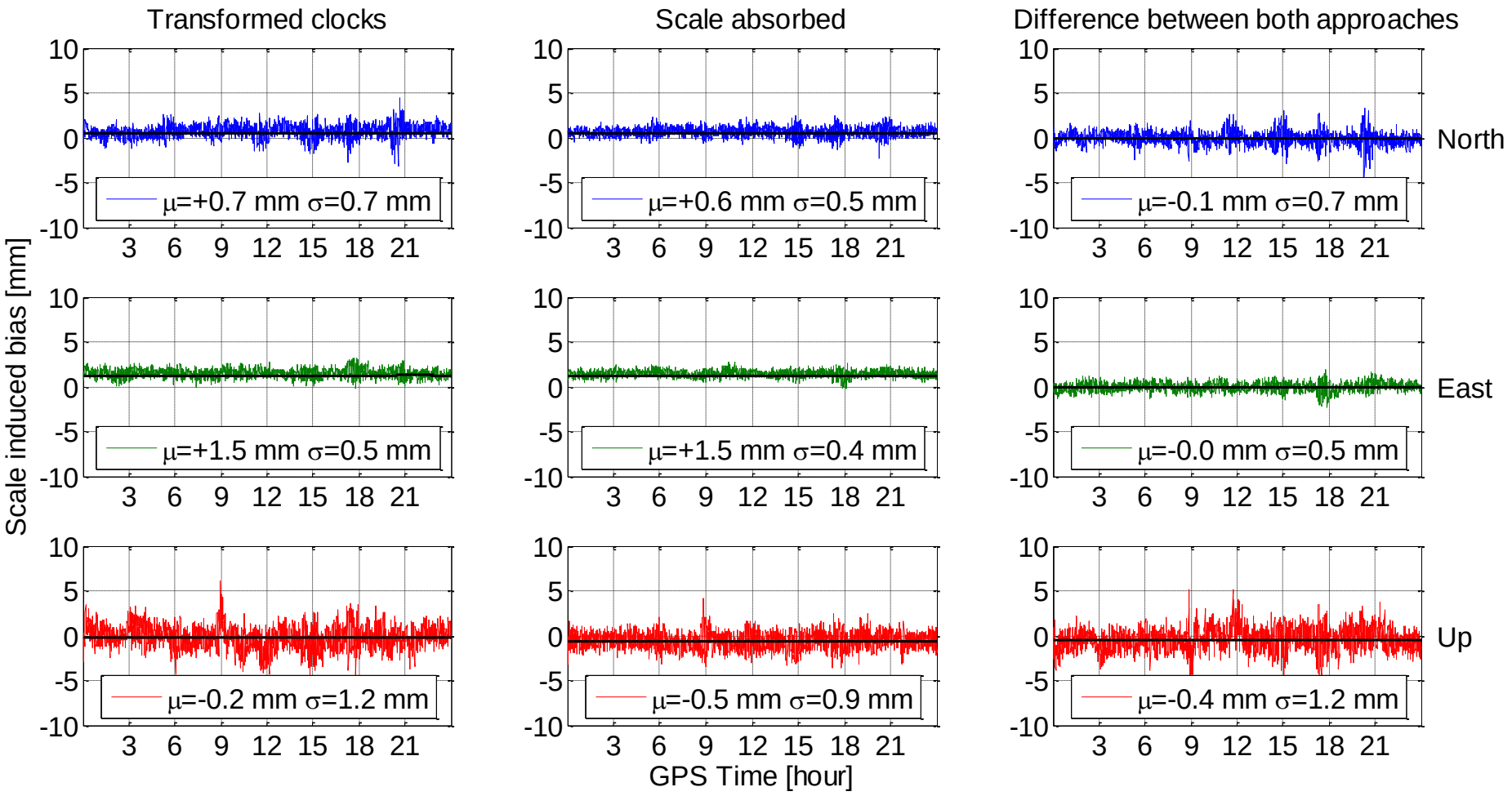


—— result when creating regional product with Curtin PPP



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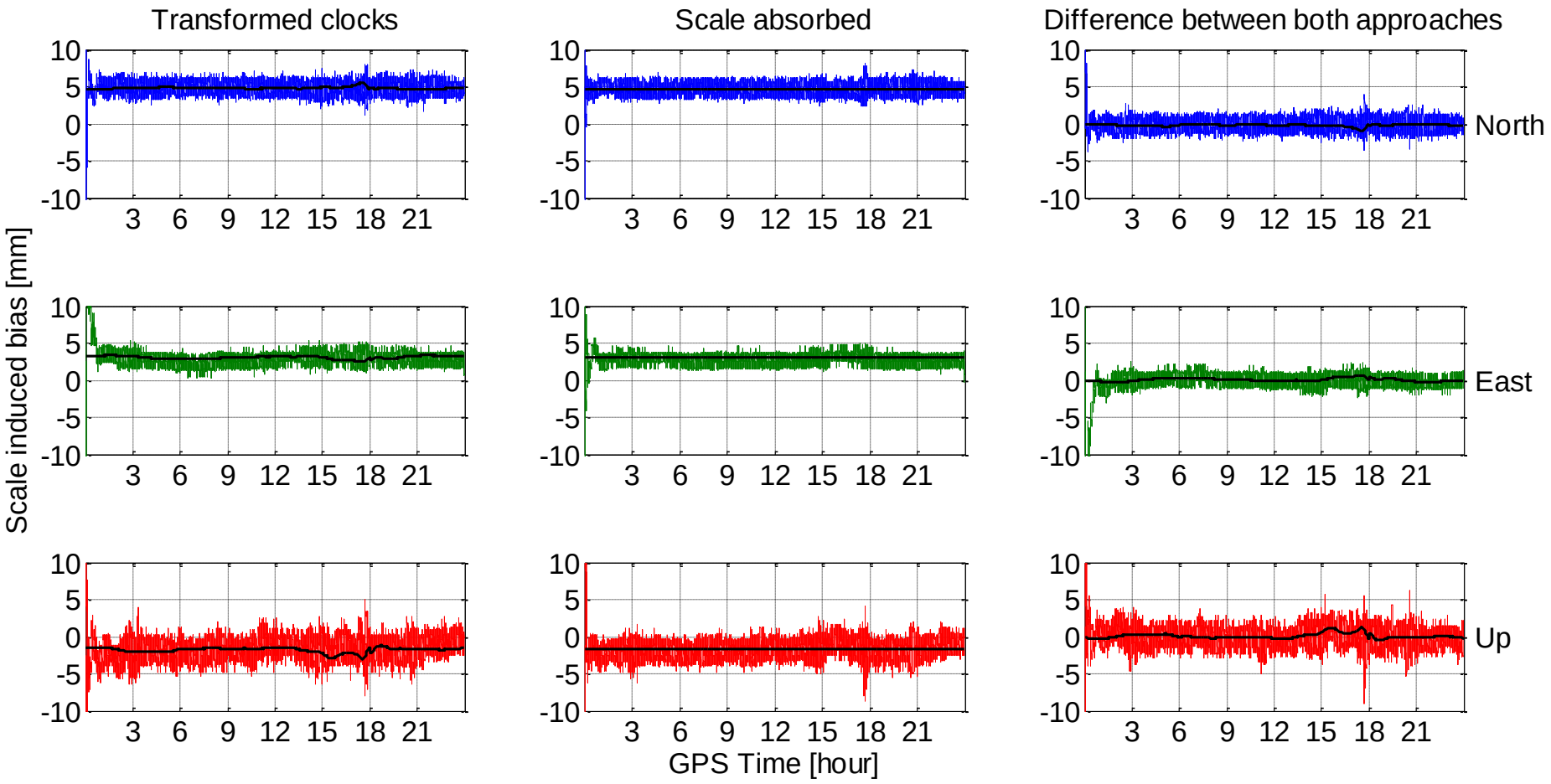
BNC DF-PPP, (Modified to have identical observations for all approaches)
Station LAGO, 23-May-2013 , 1 second sampling rate
Global product: IGS01, Regional products: Created with BNC 2.8

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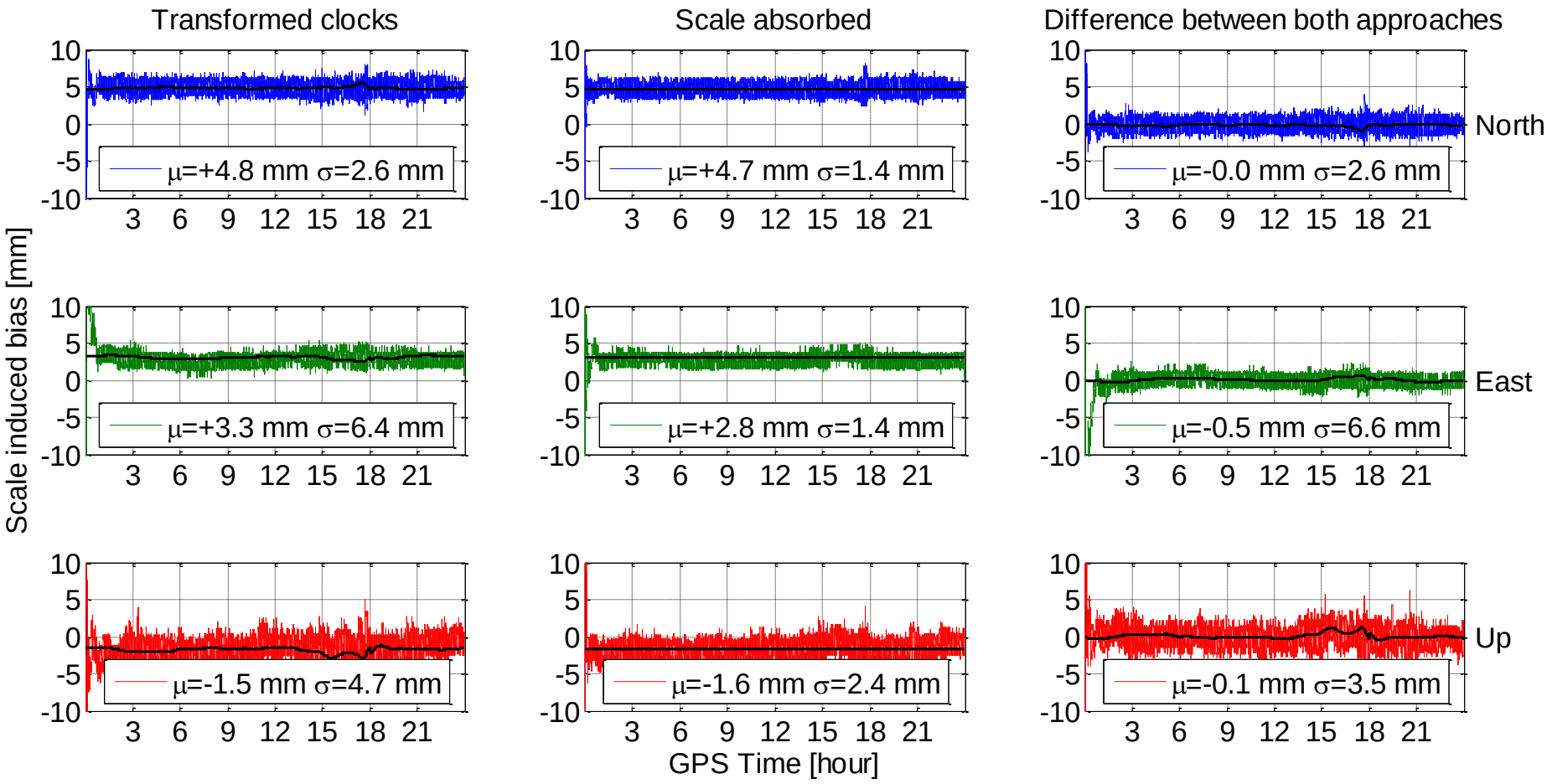


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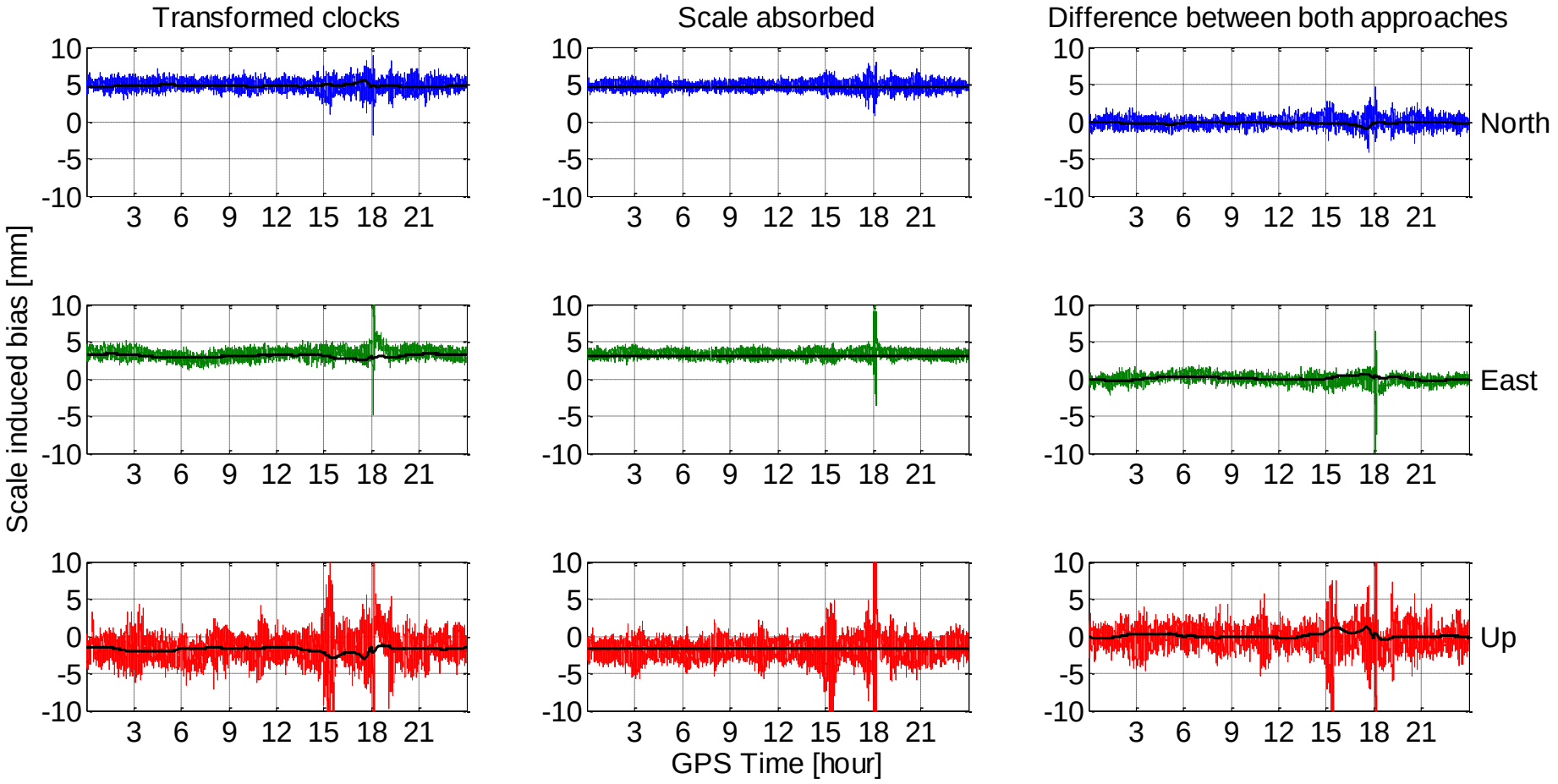


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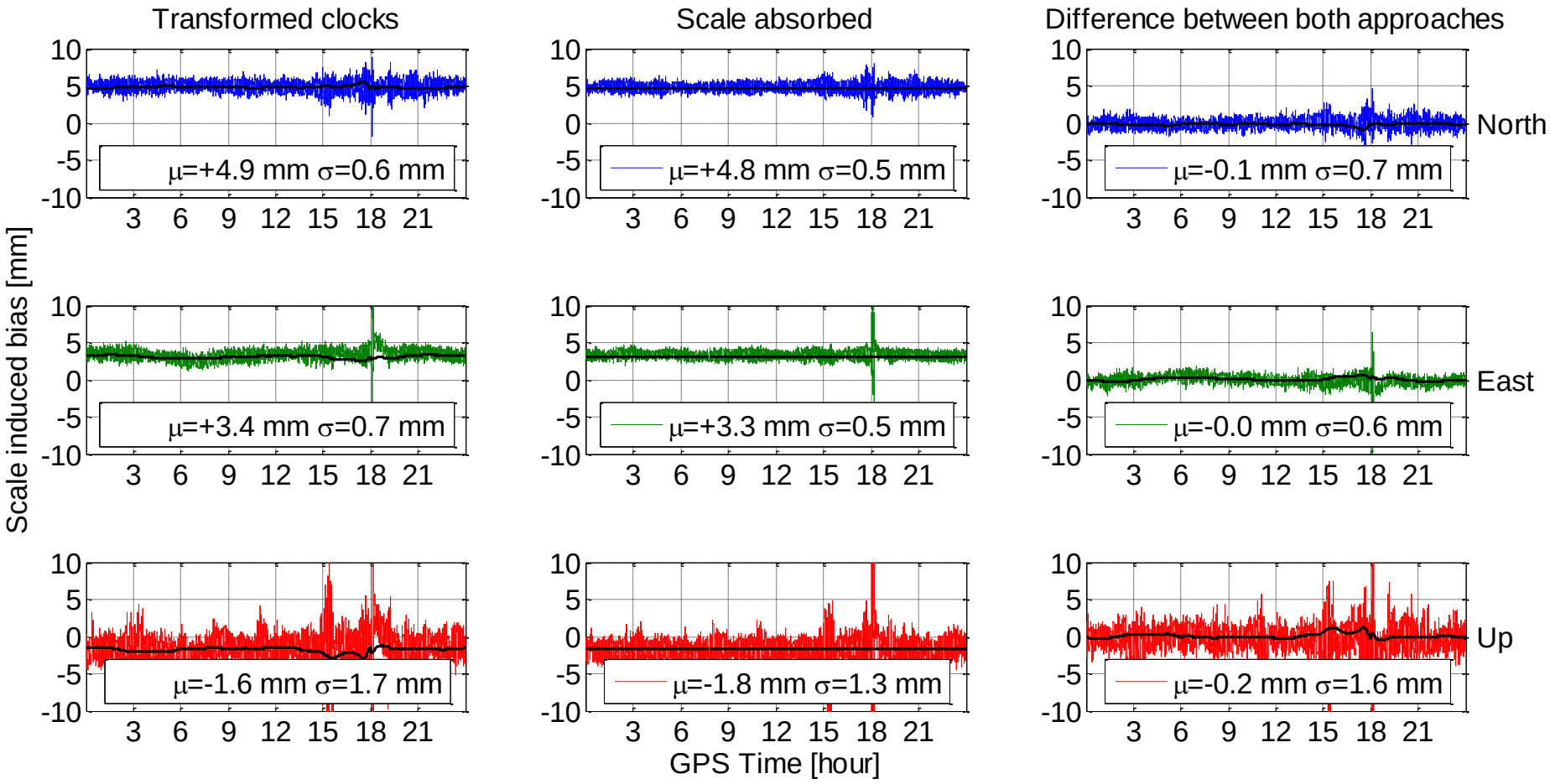


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# Conclusions

- Transformed clocks approach reduces scale induced bias to sub centimeter level for ETRS89

- Remaining bias at same level as Scale absorbed approach
  - However transformed clocks approach
    - geometry dependent
    - requires additional computation on server side
    - clock correction has no meaning in terms of time

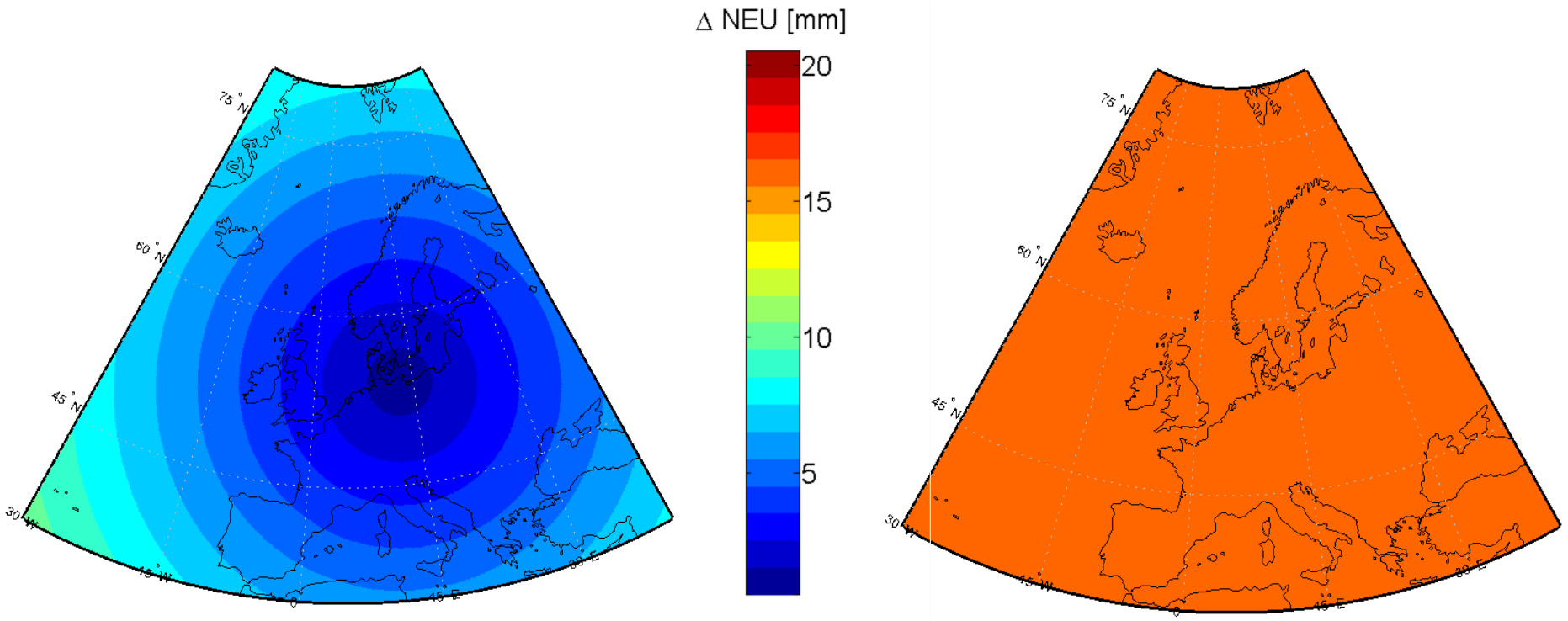
# Outlook

| EUREF products in | 2012 | 2013 | 2014a? | 2014b? |
|---|---|---|---|---|
| Approach | None | Transformed clocks | Scale absorbed | Unscaled |
| Scale induced bias 1-May-2013 | 10-15 mm | -7 – +7 mm | -7 – +7 mm | 15 mm in Up |
| Location dependent | Yes | Yes | Yes | No |
| Geometry dependent | Yes | Yes | No | No |
| Predictable | No | No | Yes | Yes |

# Scale induced bias may 2014 (next EUREF symposium)

- Scale absorbed

Unscaled



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