PPP using satellite positions in regional reference frames

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Contents

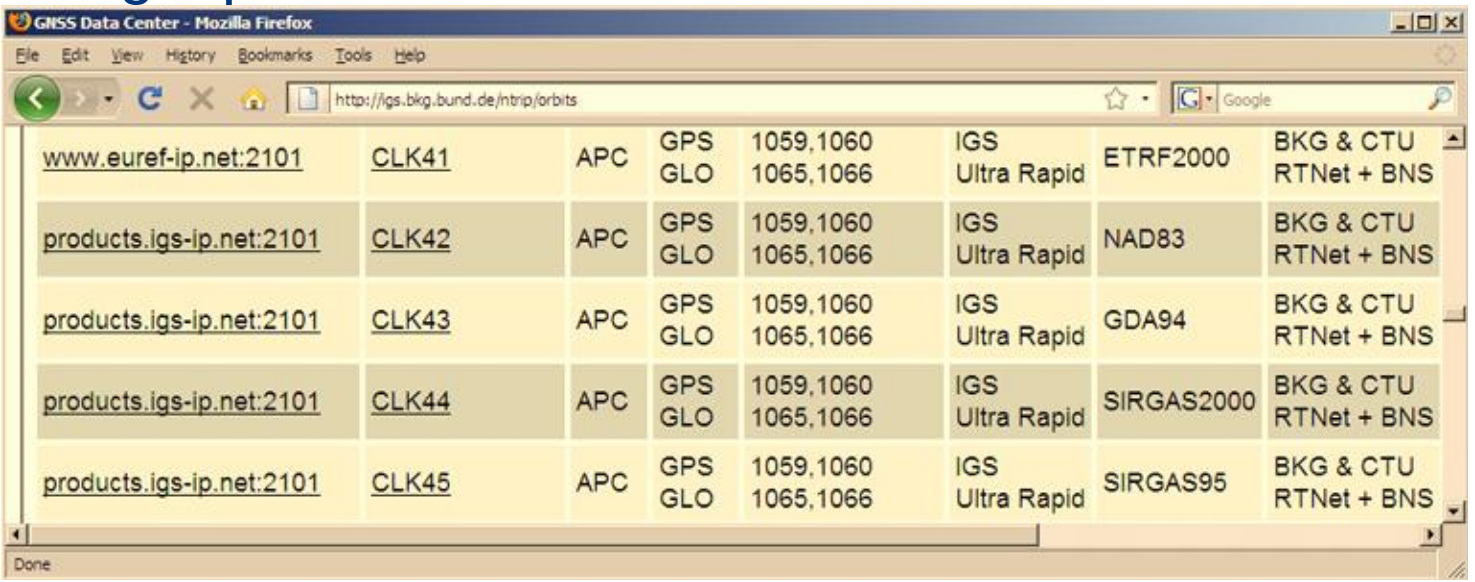
- GNSS positioning and reference frames
- Limitations of existing approaches
- Proposed improved approaches
- Discussion

Limitations of PPP vs (network-)RTK

- Precise results only possible with final IGS-products
  - IGS RT Orbit and clock corrections
  - OmniSTAR
  - StarFire
- Convergence time
  - PPP-RTK?
- User position is in ITRF
  - RTCM transformation messages 1021-1027?
  - Provide satellite positions in RRF

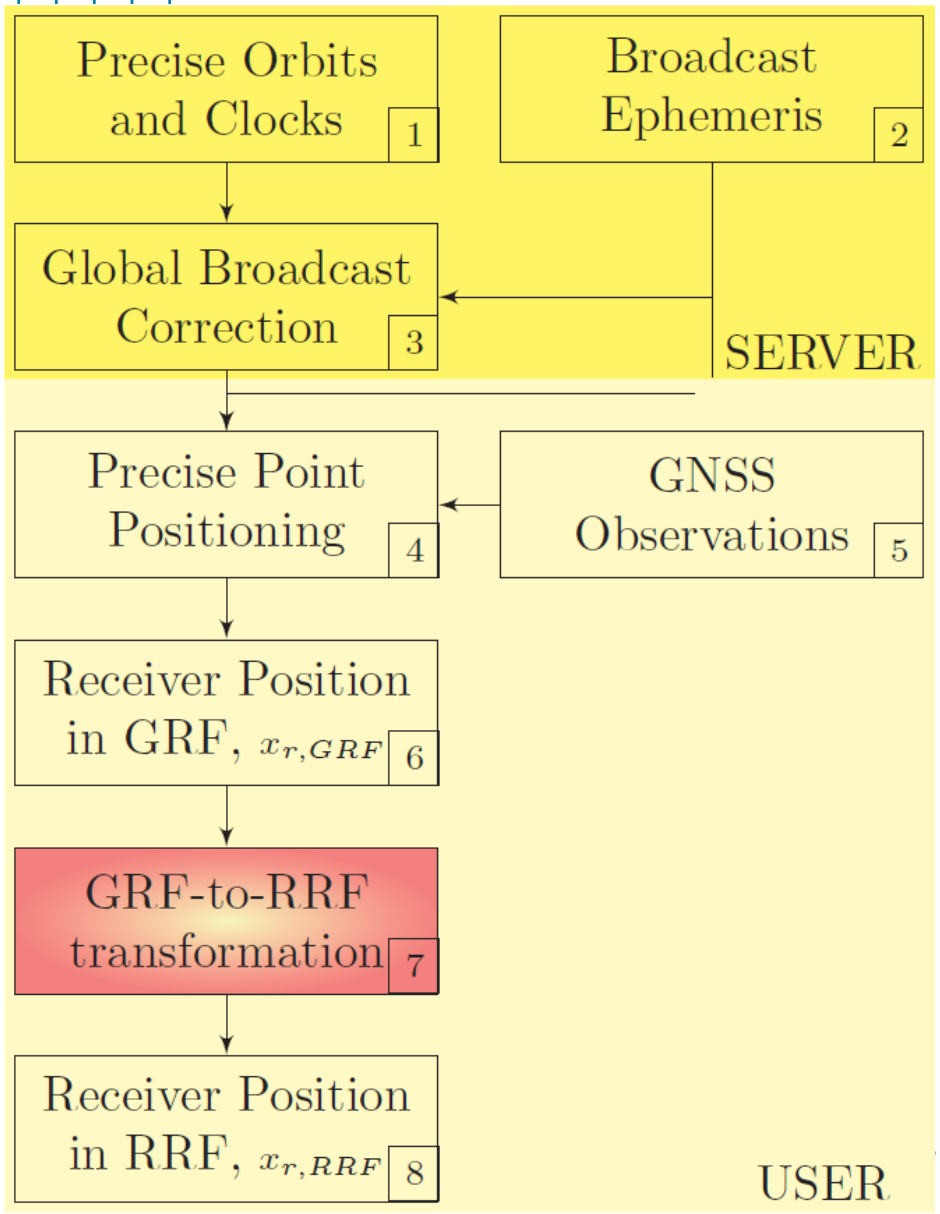
Satellite positions in regional reference frames

- 1998, trfspn3n utility, also see: J. Kouba, The GPS Toolbox ITRF Transformations, GPS Solutions 2002
- Now: Real-Time Orbit and Clock corrections via NTRIP from igs-ip

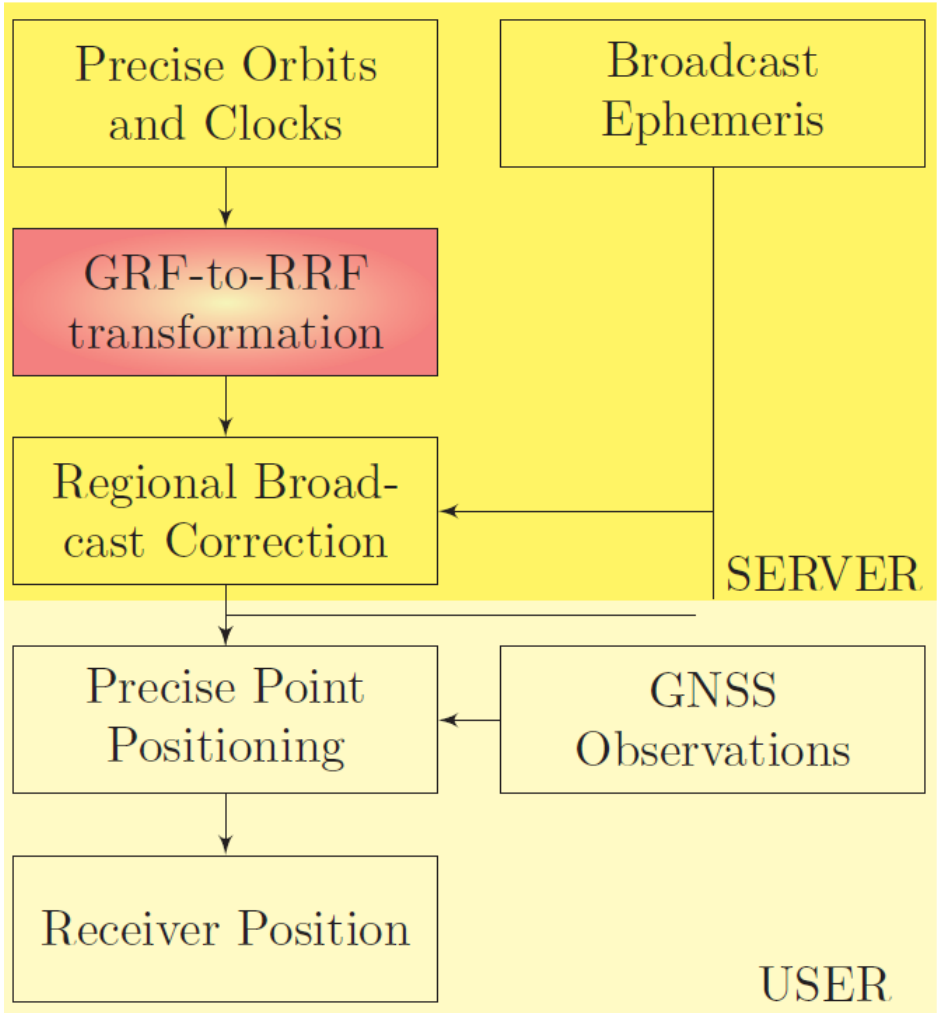


www.euref-ip.net:2101	CLK41	APC	GPS GLO	1059,1060 1065,1066	IGS Ultra Rapid	ETRF2000	BKG & CTU RTNet + BNS
products.igs-ip.net:2101	CLK42	APC	GPS GLO	1059,1060 1065,1066	IGS Ultra Rapid	NAD83	BKG & CTU RTNet + BNS
products.igs-ip.net:2101	CLK43	APC	GPS GLO	1059,1060 1065,1066	IGS Ultra Rapid	GDA94	BKG & CTU RTNet + BNS
products.igs-ip.net:2101	CLK44	APC	GPS GLO	1059,1060 1065,1066	IGS Ultra Rapid	SIRGAS2000	BKG & CTU RTNet + BNS
products.igs-ip.net:2101	CLK45	APC	GPS GLO	1059,1060 1065,1066	IGS Ultra Rapid	SIRGAS95	BKG & CTU RTNet + BNS

GBC



RBC



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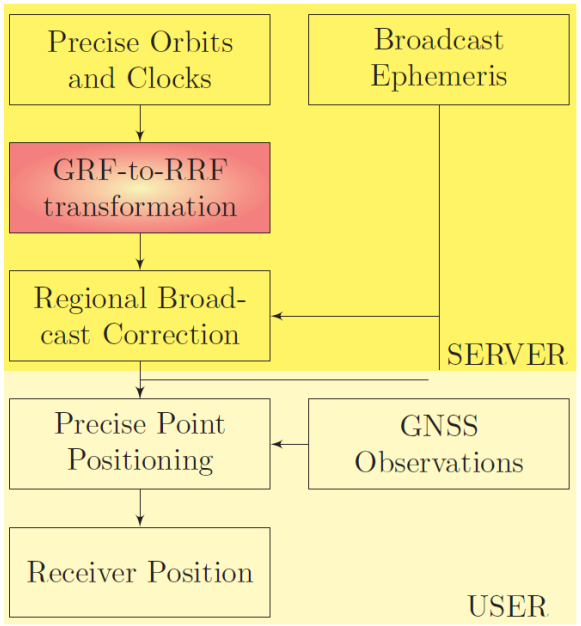
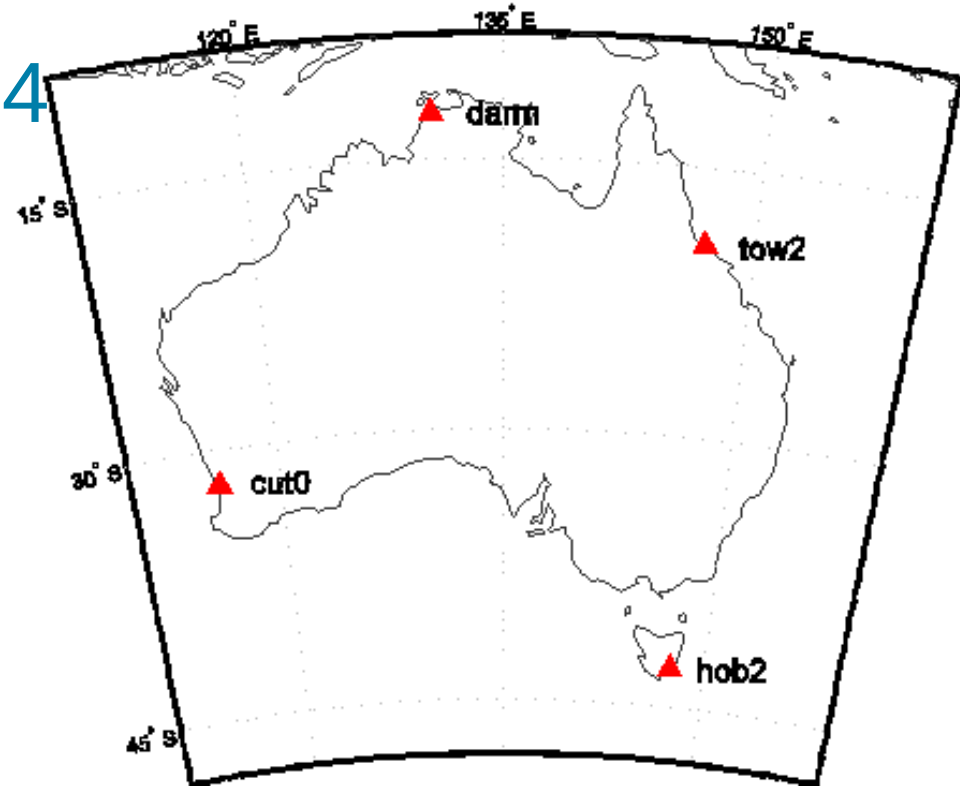
Case study – GDA94



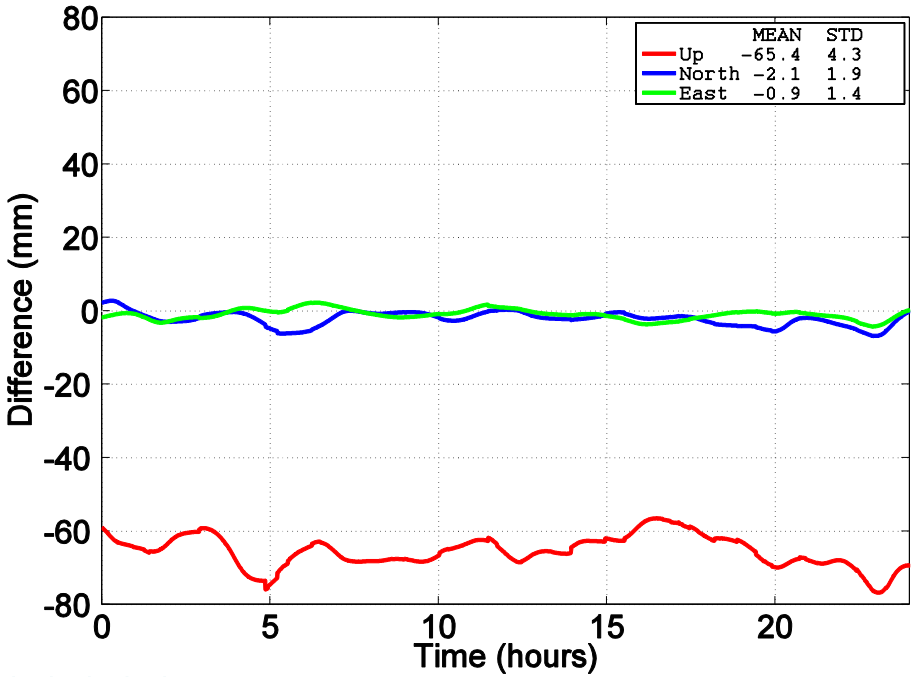


- Reproduced CLK43 (GDA94-RBC) from CLK11 (IGS05-GBC) product
- Processed 4 Stations in Australia using both products
- Following results are for station CUT0, Perth, Australia

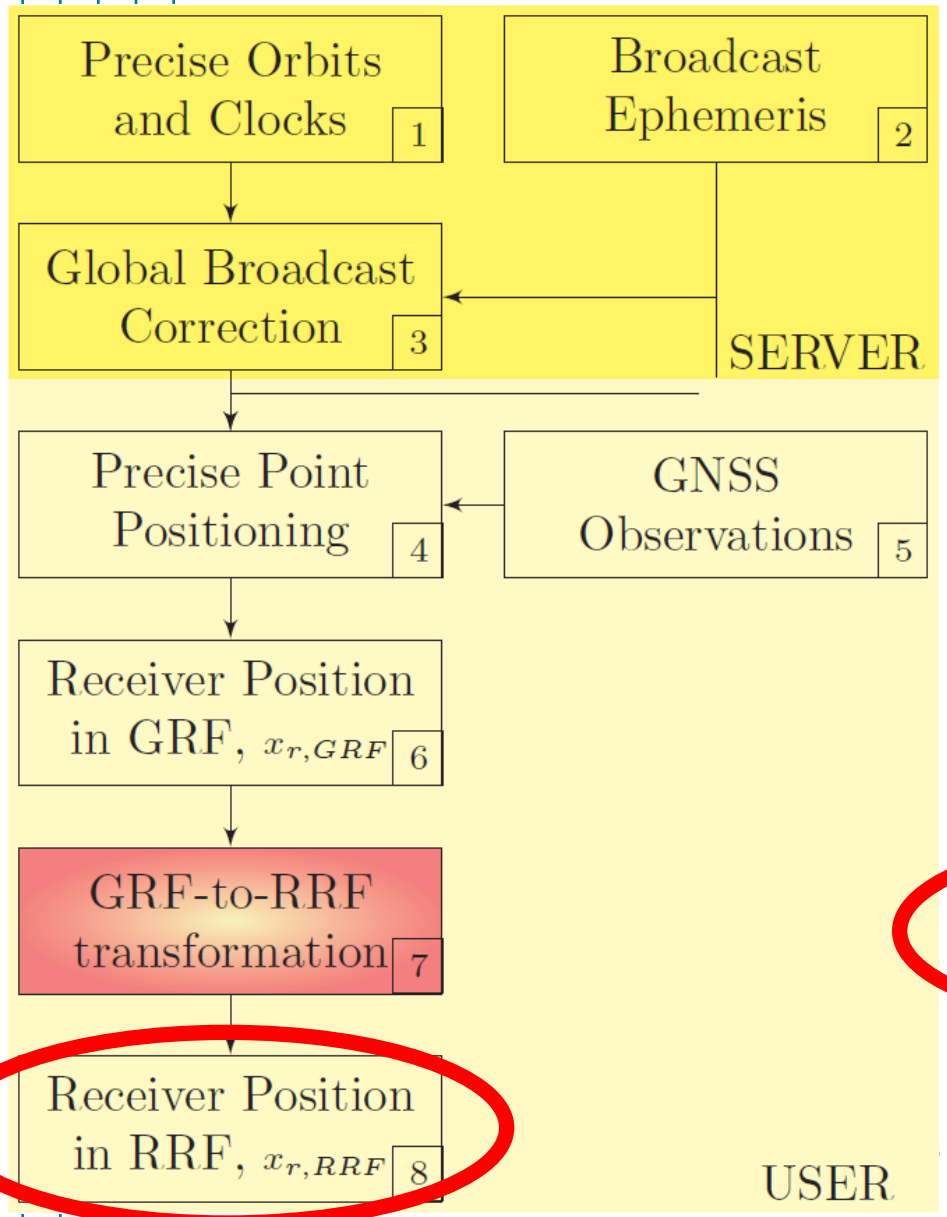
Case study – GDA94

- Differences using GBC and RBC

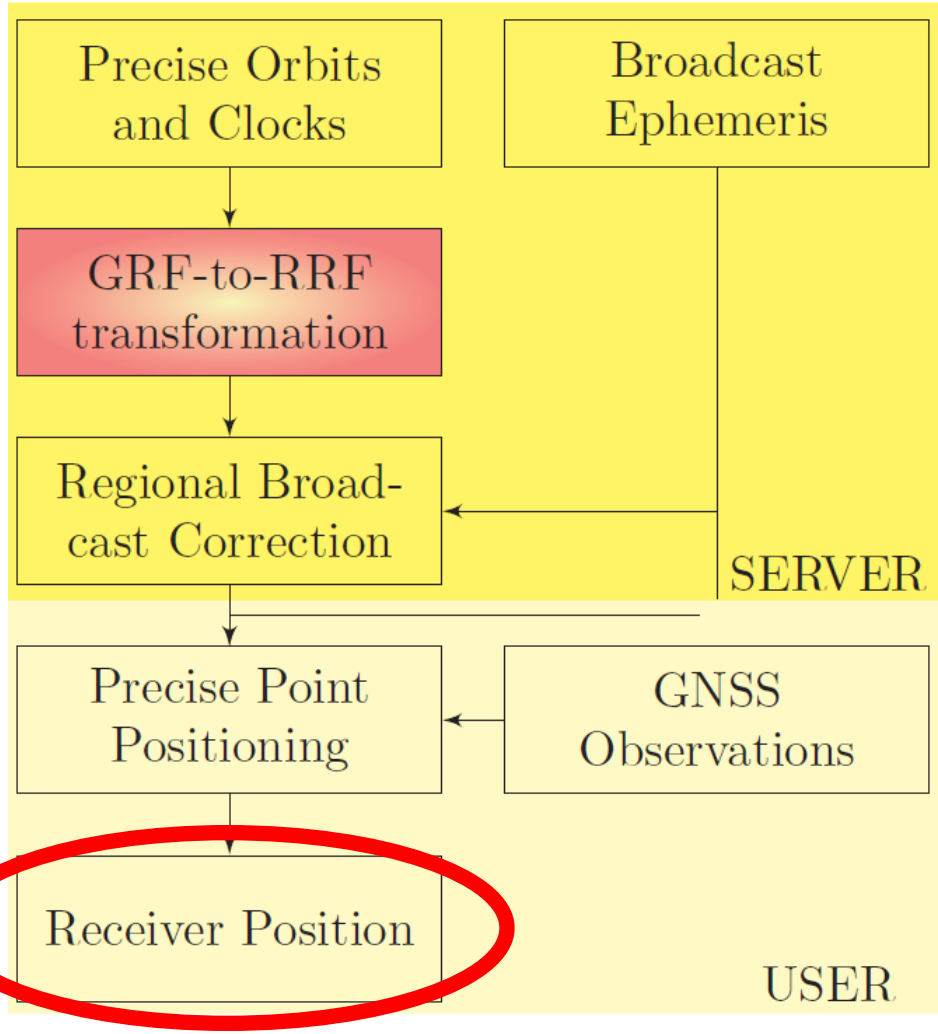
Single-Frequency



GBC



RBC



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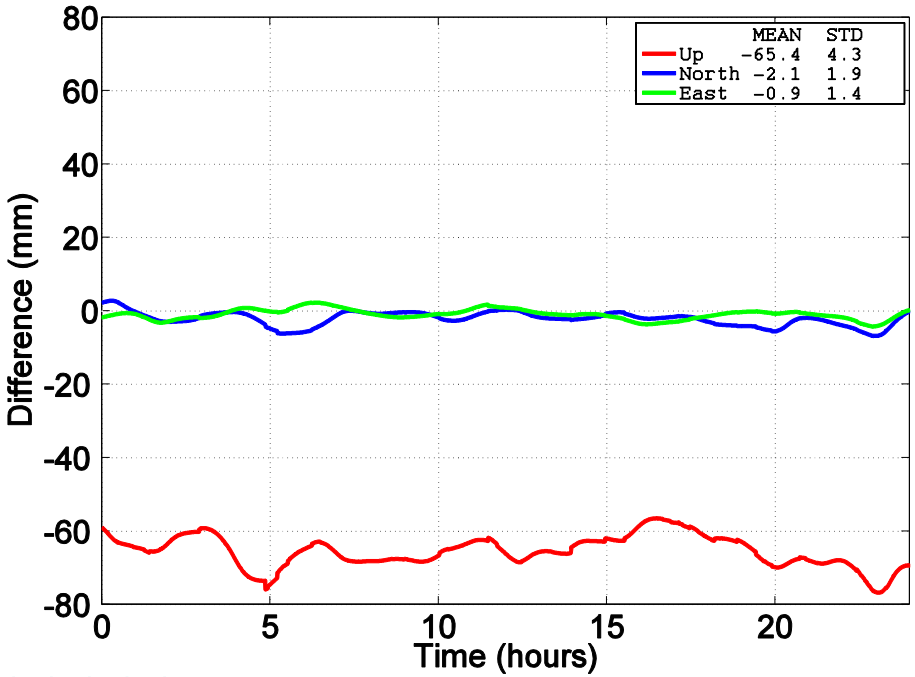
Case study – GDA94

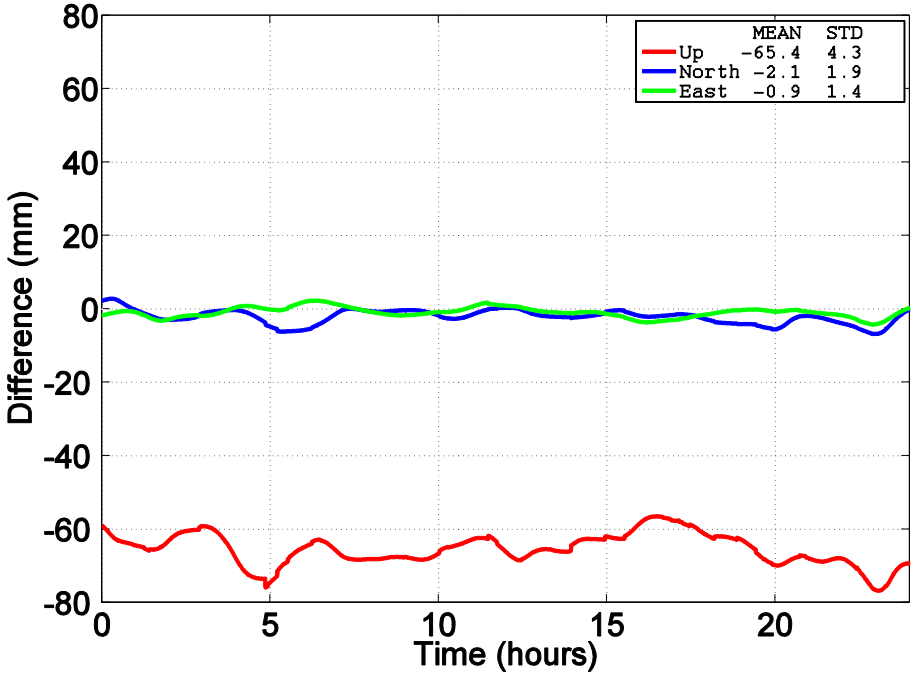
- Differences using GBC and RBC Single-Frequency



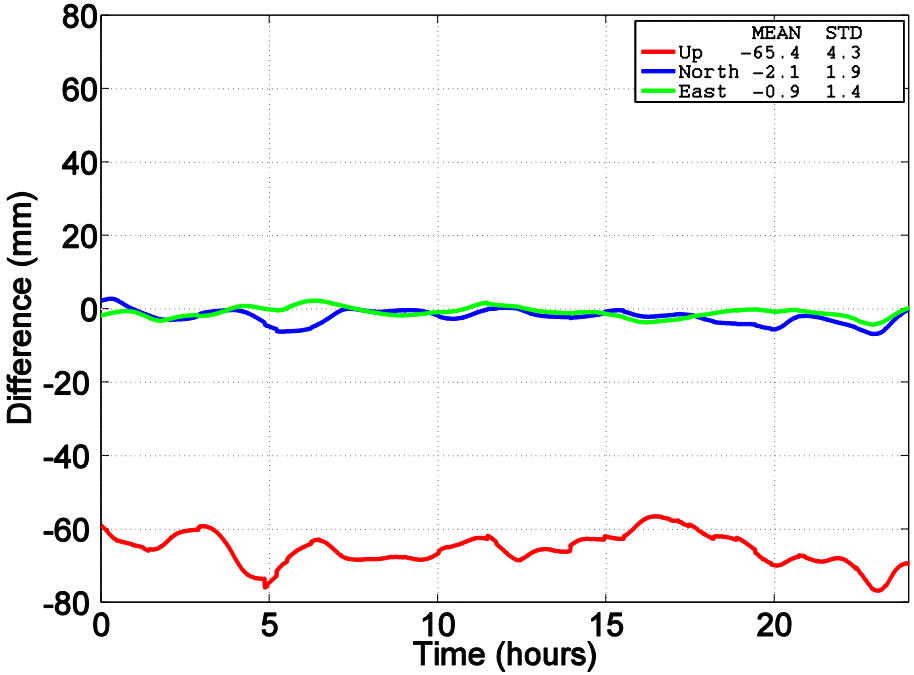
Case study – GDA94

- Differences using GBC and RBC

Single-Frequency



Dual-Frequency



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Limitations of existing approaches

- Observation equations:

$$p_r^s = \rho_r^s - dt^s + dt_r + m_r^s \tau_r + I_{r,j}^s$$

$$\phi_r^s = \rho_r^s - dt^s + dt_r + m_r^s \tau_r - I_{r,j}^s + w_j M_{r,j}^s$$

s	Satellite index	dt	Clock error [m]
r	Receiver index	m	Mapping function
j	Frequency index	τ	Zenith tropospheric delay [m]
p	Code observation [m]	I	Slant ionospheric delay [m]
ϕ	Phase observation [m]	w	Wavelength [m]
ρ	Receiver-satellite range [m]	M	Phase ambiguity (non-integer)

- Parameters in red are affected by transformation

Observations have a different scale than the reference system

- Scale is main contributor

$$p_r^s = \rho_r^s - dt^s + dt_r + m_r^s \tau_r + I_{r,j}^s$$

$$\phi_r^s = \rho_r^s - dt^s + dt_r + m_r^s \tau_r - I_{r,j}^s + w_j M_{r,j}^s$$

- Relation receiver-satellite range in GRF and RRF

$$\rho_{r,GRF}^s = \left\| x_{GRF}^s - x_{r,GRF} \right\|$$

$$= \frac{1}{\lambda} \left\| x_{RRF}^s - x_{r,RRF} \right\|$$

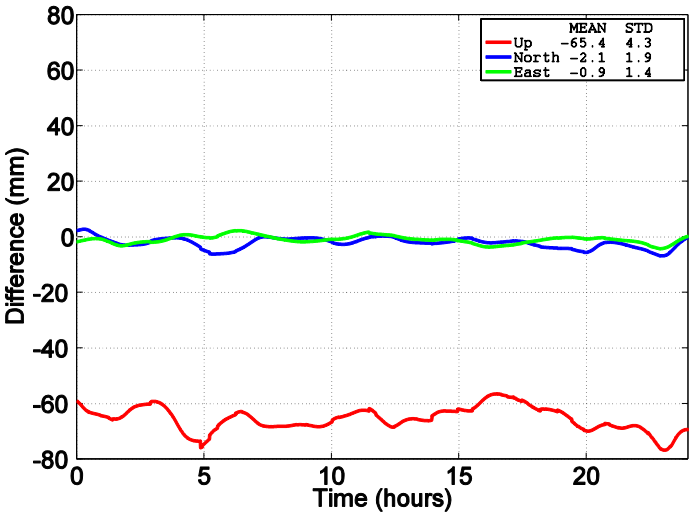
$$= \frac{1}{\lambda} \rho_{r,RRF}^s$$

Observations have a different scale than the reference system

- Scale is main contributor
  - For GDA94 at May 1st 2010:

    $$\lambda = 1 + 1.17 * 10^{-9}$$

  - Effect on ρ_r^s = 20.000 km of ignoring scale in algorithm: -0.23 meter
- Troposphere is second largest contributor, when ellipsoidal heights are used in a-priori ZTD computation

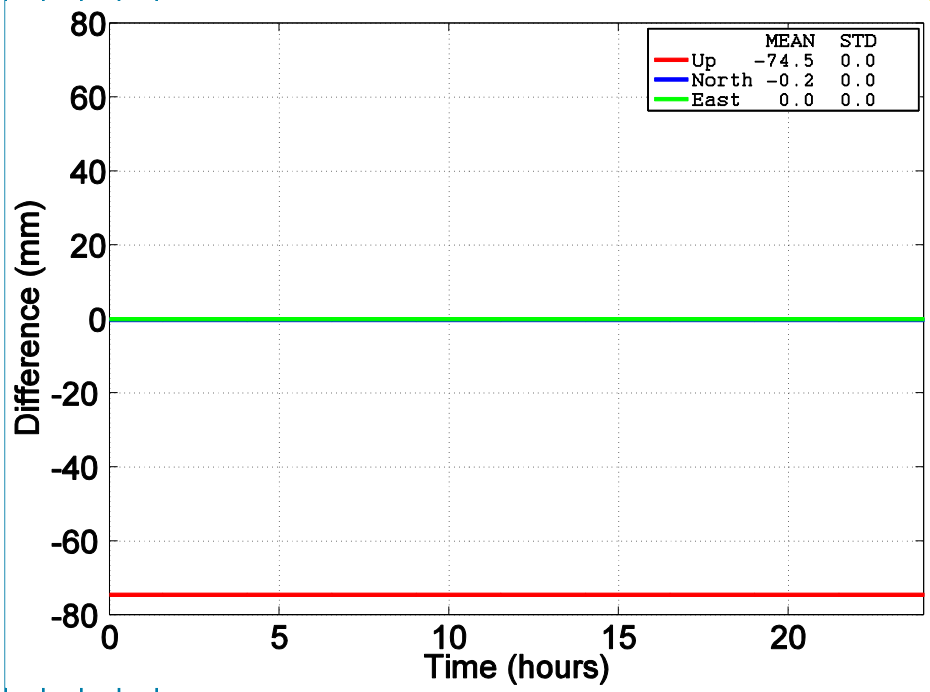


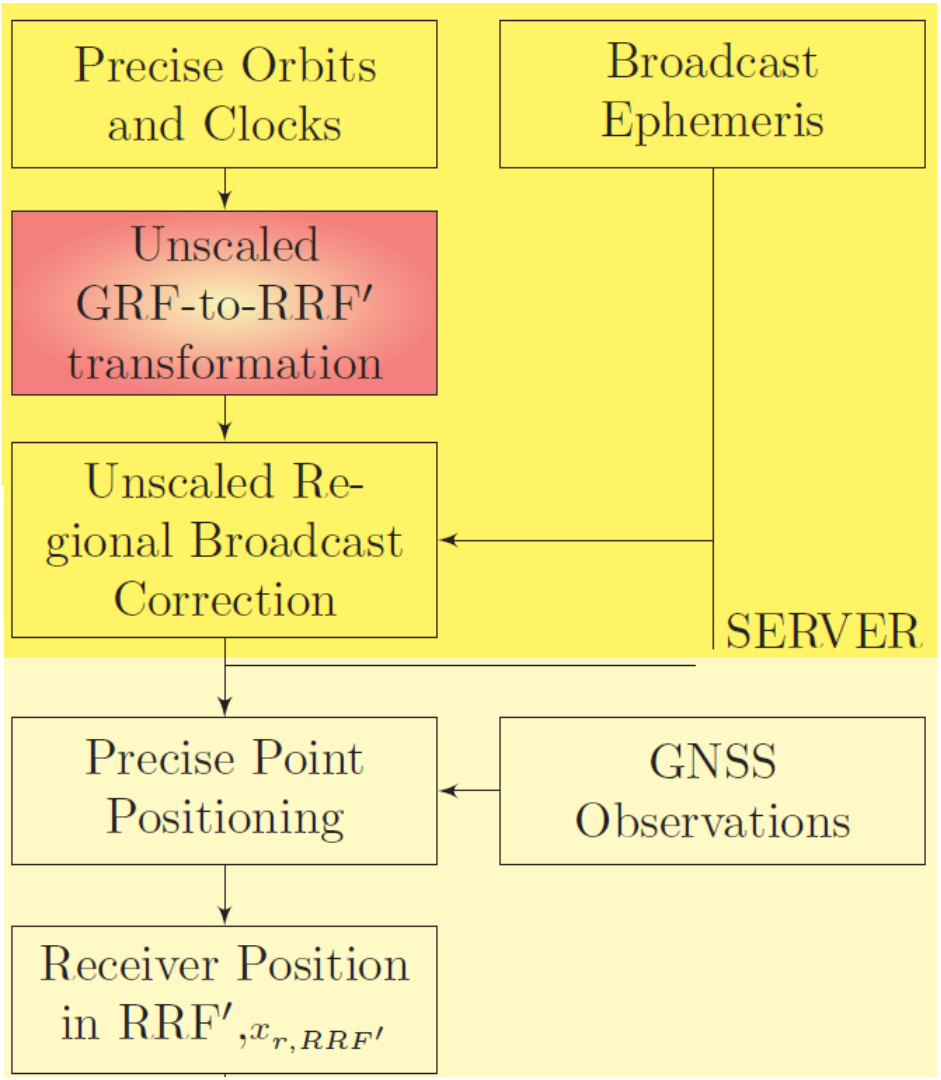
Observations have a different scale than the reference system

- How to deal with this without modifying PPP algorithm
  - Unscaled RBC
    - Ignore scale in transformation
  - ‘Scale-absorbed’ RBC
    - Adapt transformation parameters
- Both approaches allow for prediction of scale-induced error

Unscaled RBC

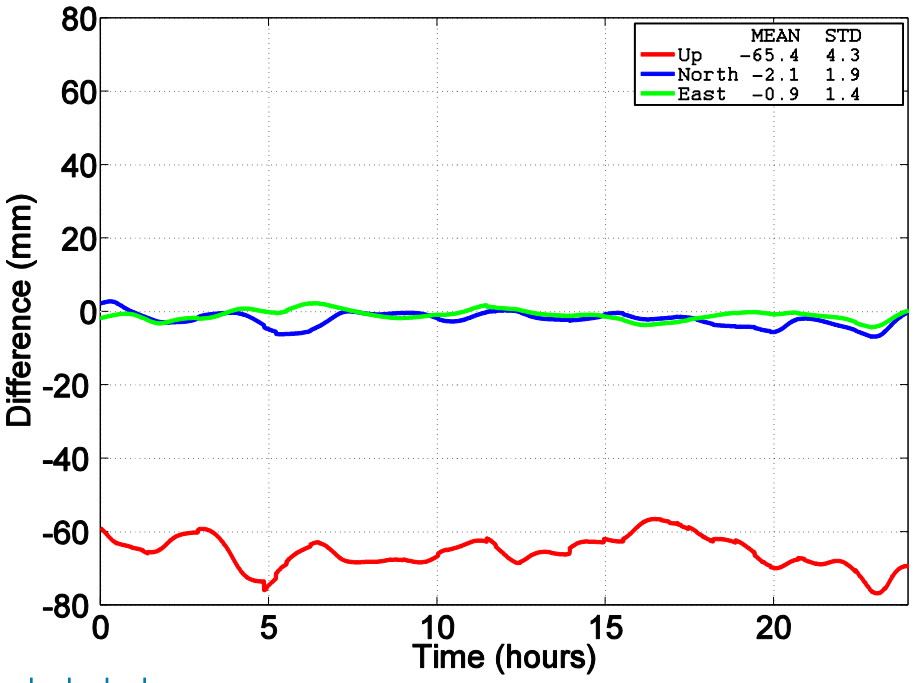
- Results

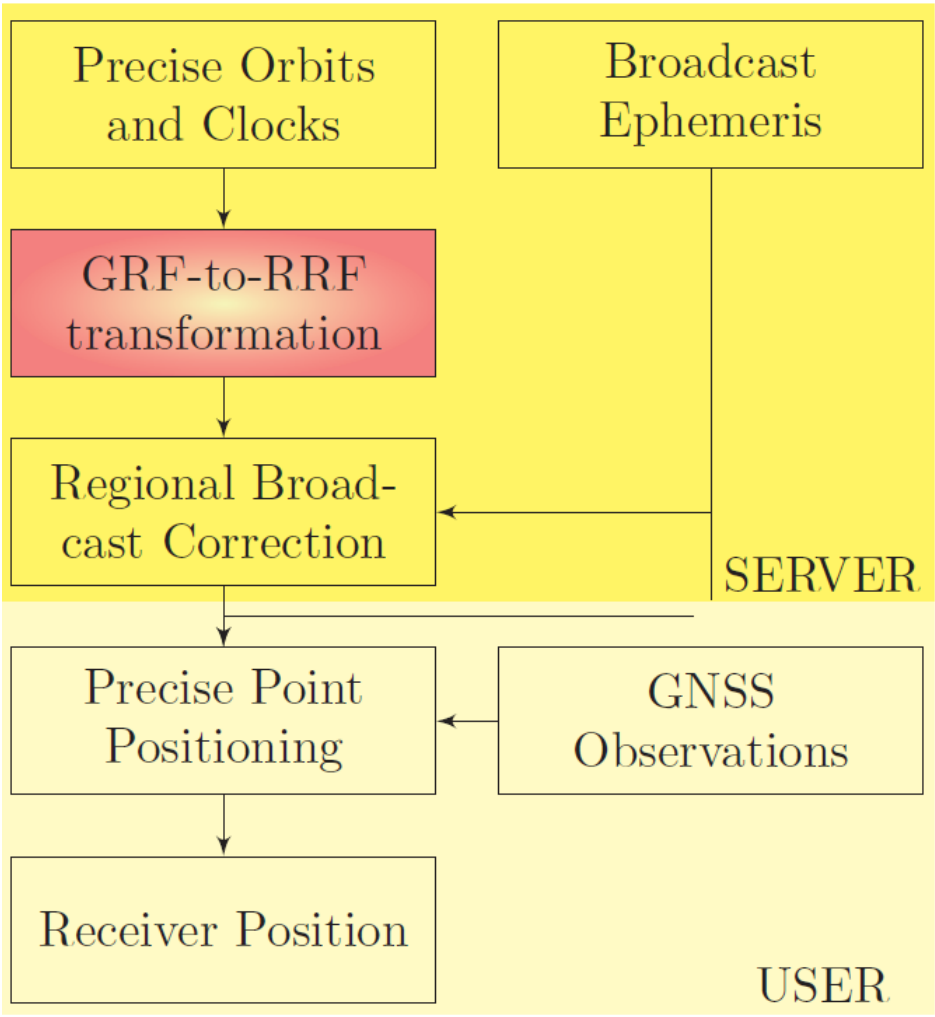




Existing RBC

- Results





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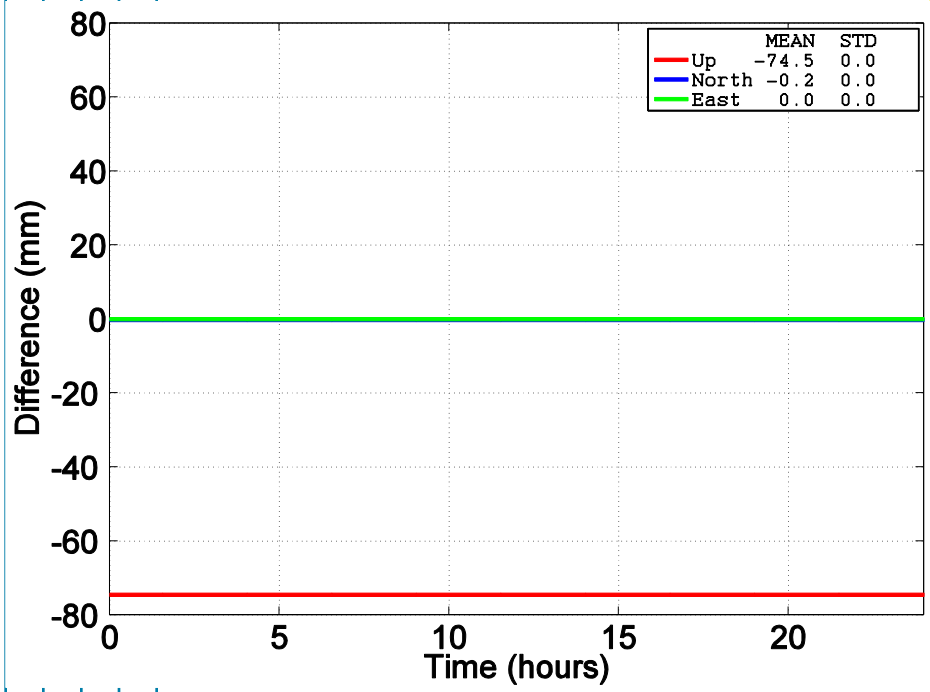
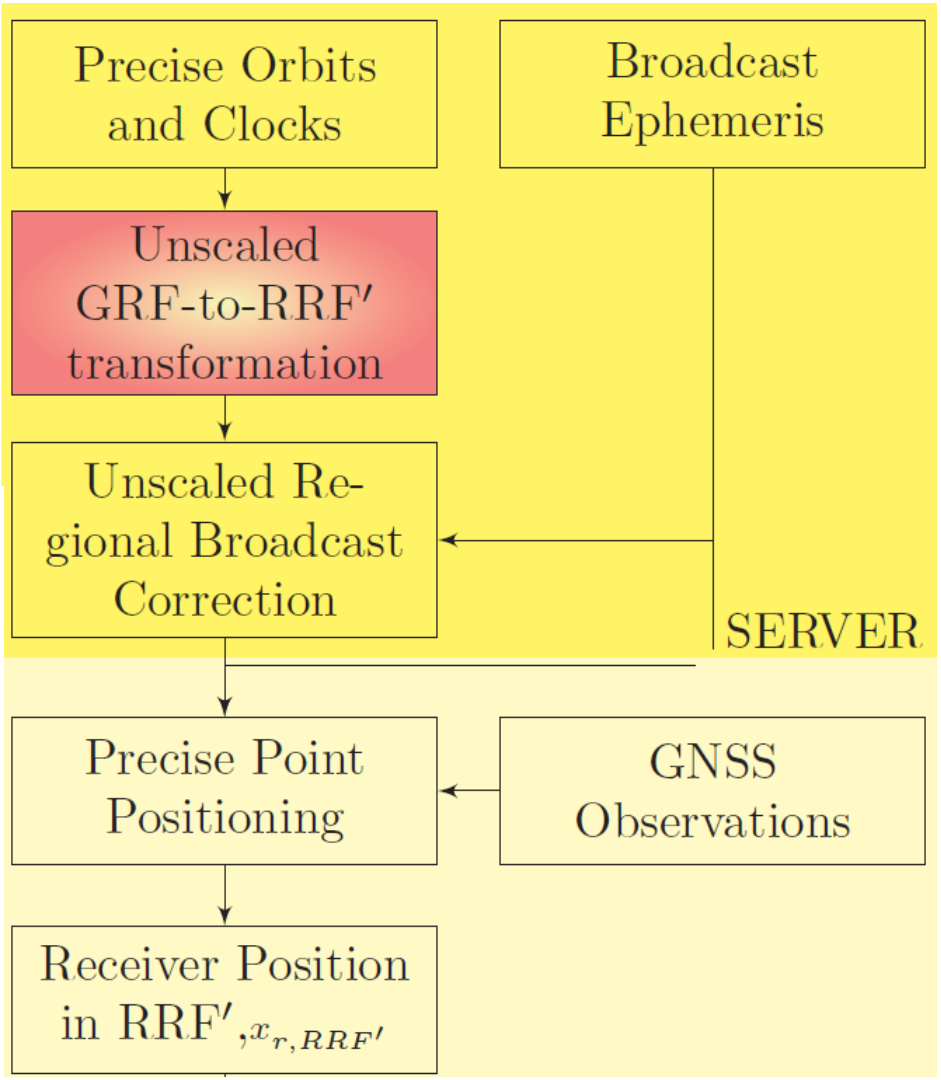
Unscaled RBC

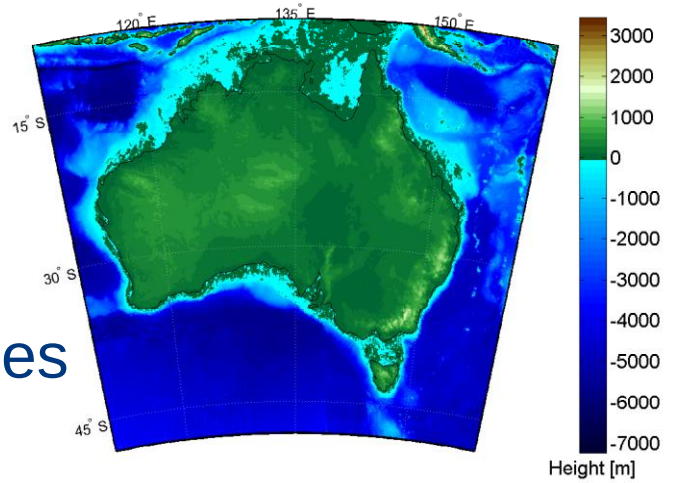
- Results

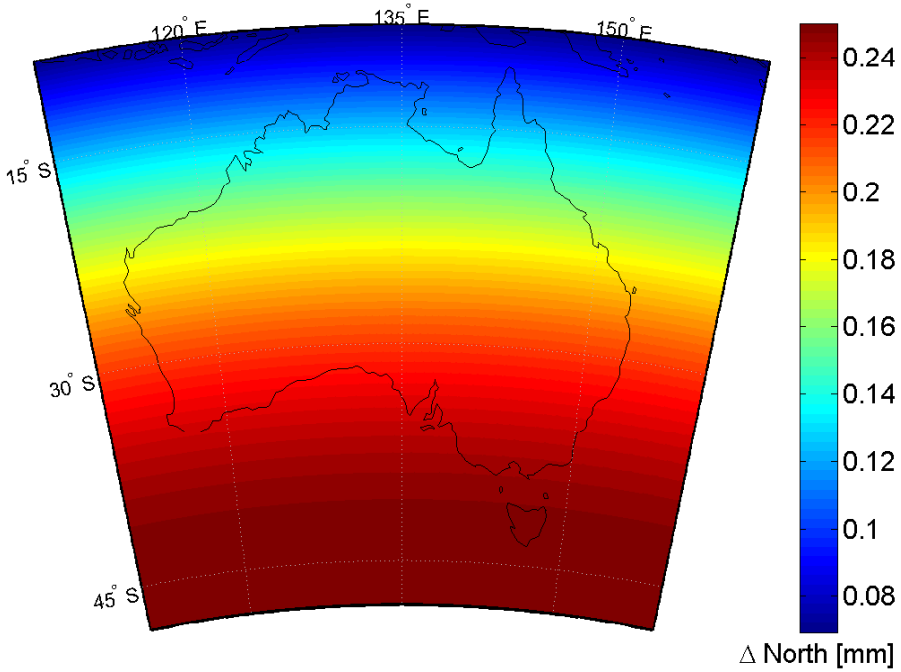


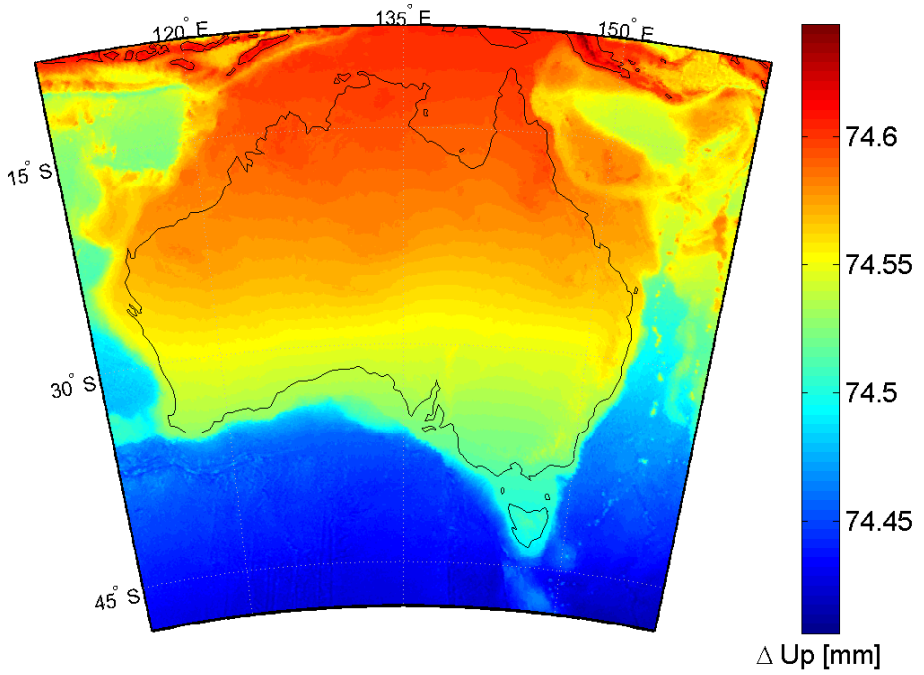


Unscaled RBC

- Prediction of scale-induced biases







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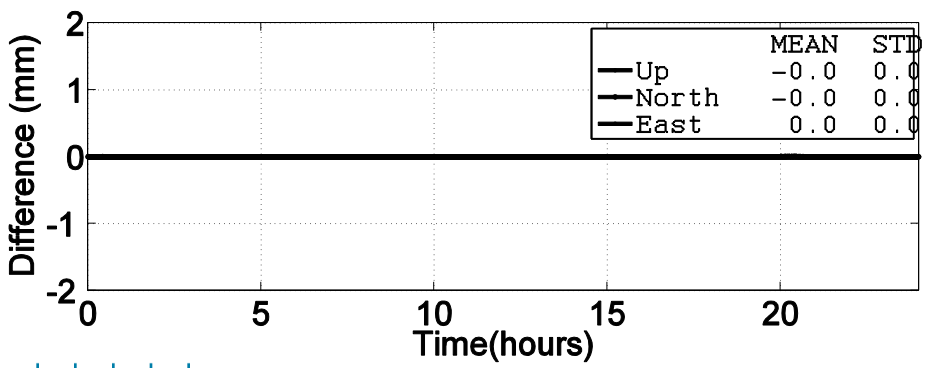
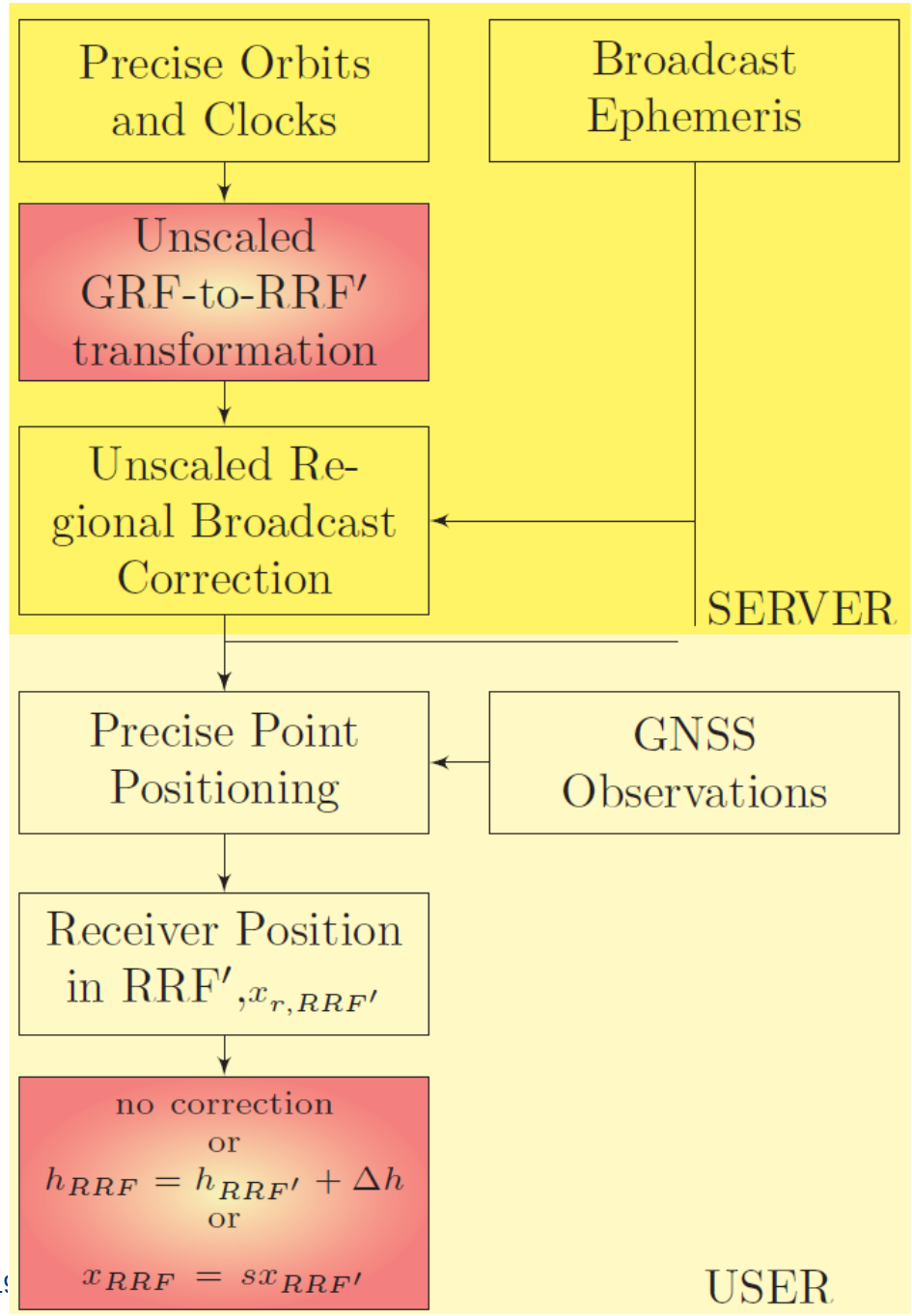
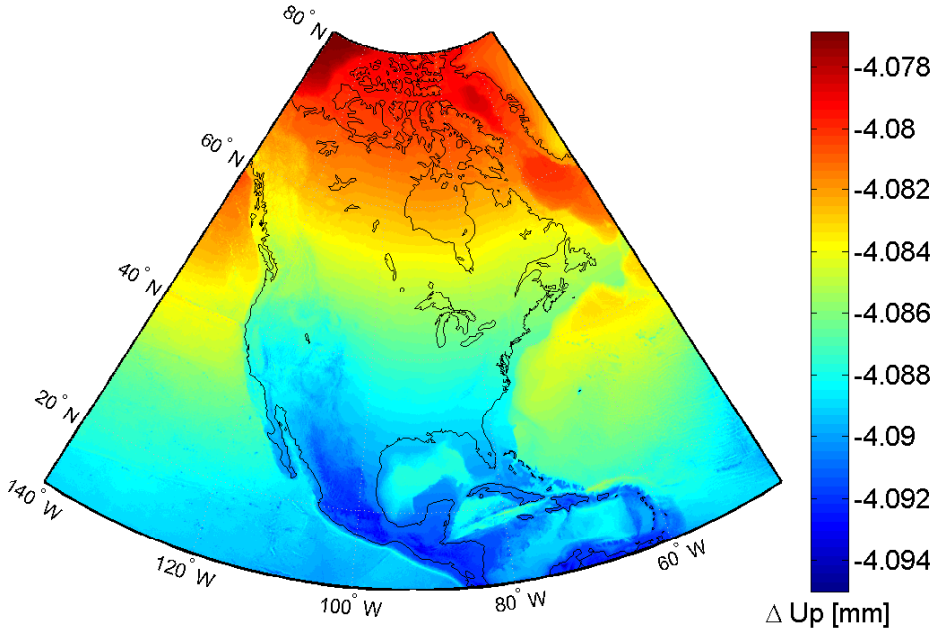
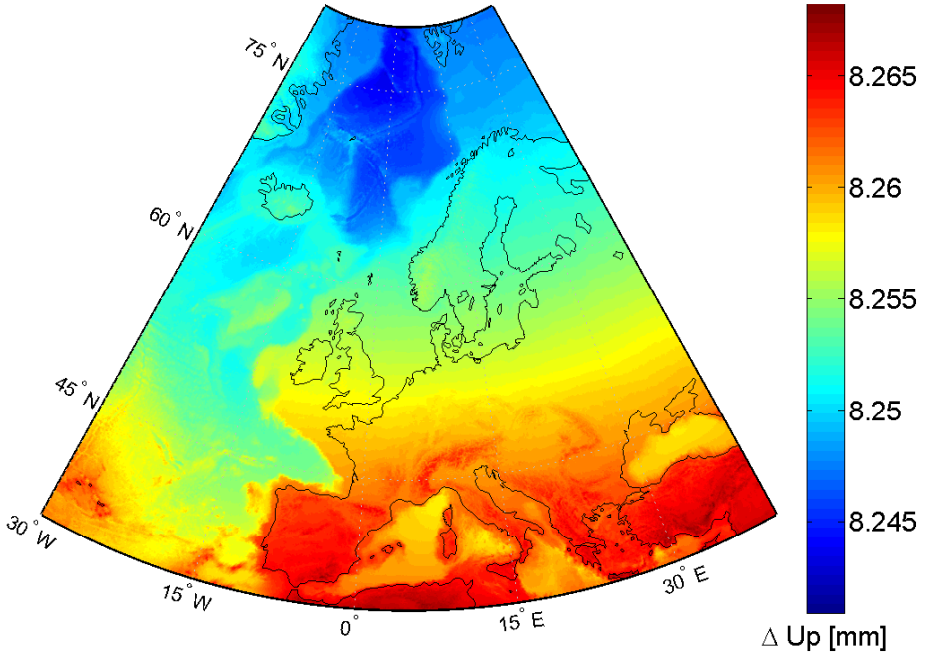
Unscaled RBC

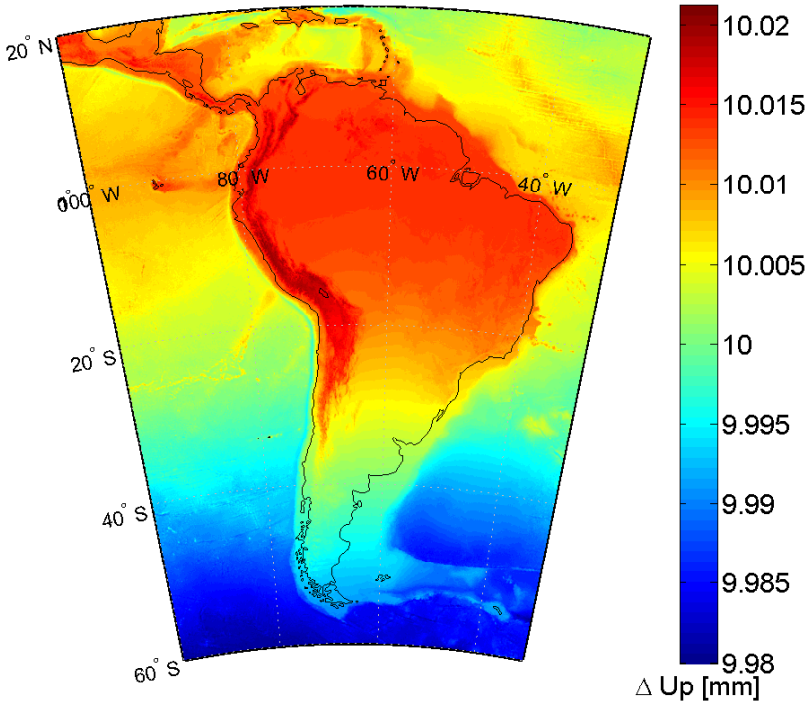
- Results

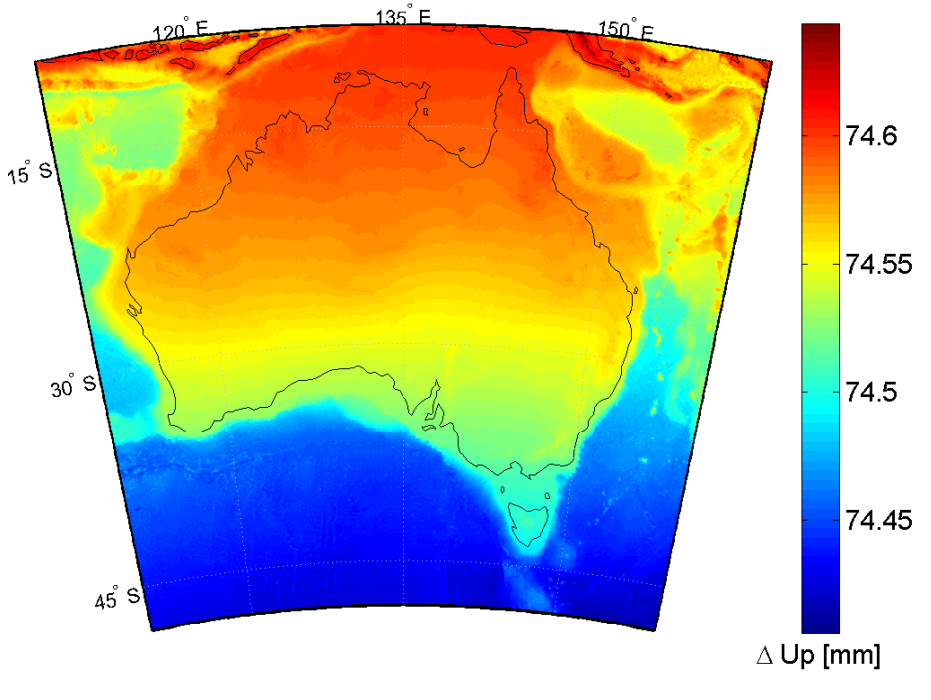





80° N
60° N
40° N
20° N
140° W
120° W
100° W
80° W
60° W
-4.078
-4.08
-4.082
-4.084
-4.086
-4.088
-4.09
-4.092
-4.094
Δ Up [mm]


75° N
60° N
45° N
30° W
15° W
0°
15° E
30° E
8.265
8.26
8.255
8.25
8.245
Δ Up [mm]


20° N
0°
80° W
60° W
40° W
20° S
40° S
60° S
10.02
10.015
10.01
10.005
10
9.995
9.99
9.985
9.98
Δ Up [mm]


120° E
135° E
150° E
15° S
30° S
45° S
74.6
74.55
74.5
74.45
Δ Up [mm]

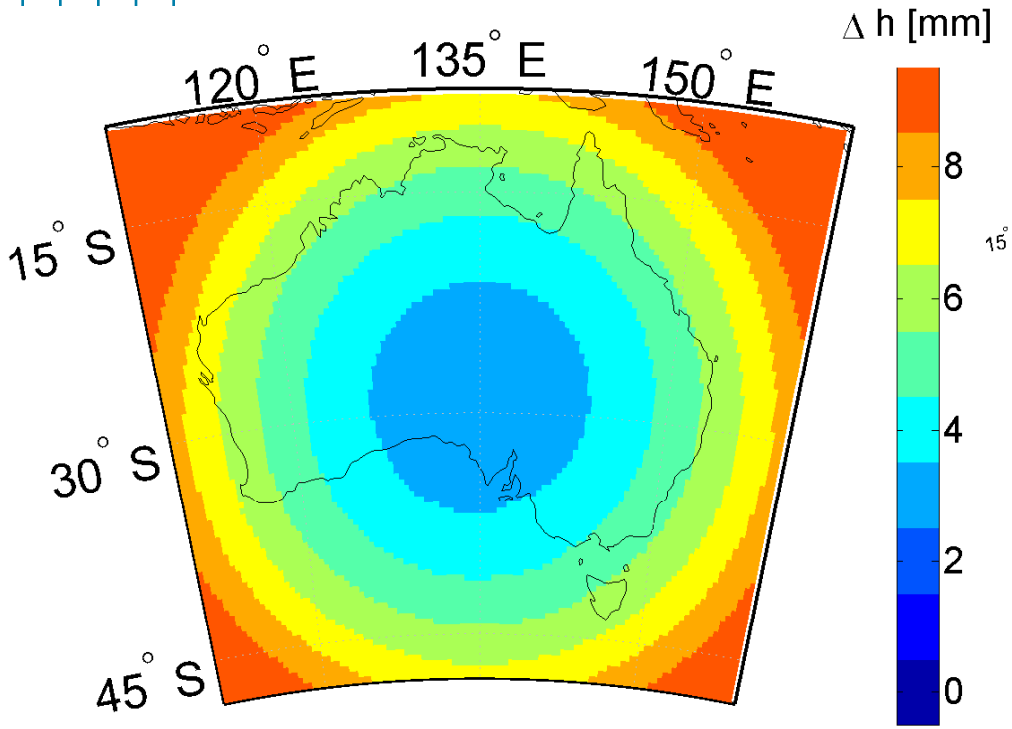
‘Scale-absorbed’ transformation parameters

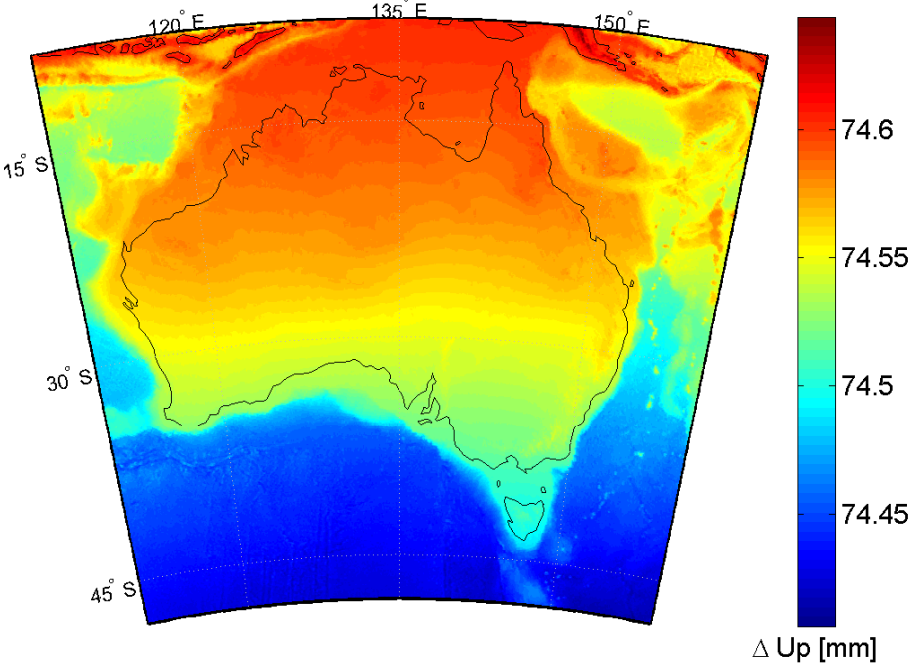
- Can we come-up with a transformation that minimizes the scale-induced bias on the server side?

- Approach:
  - Grid of points covering the region to which the RRF applies
  - Estimate a 6-parameter (3x translation, 3x rotation, NO scale) transformation between the GRF and the RRF

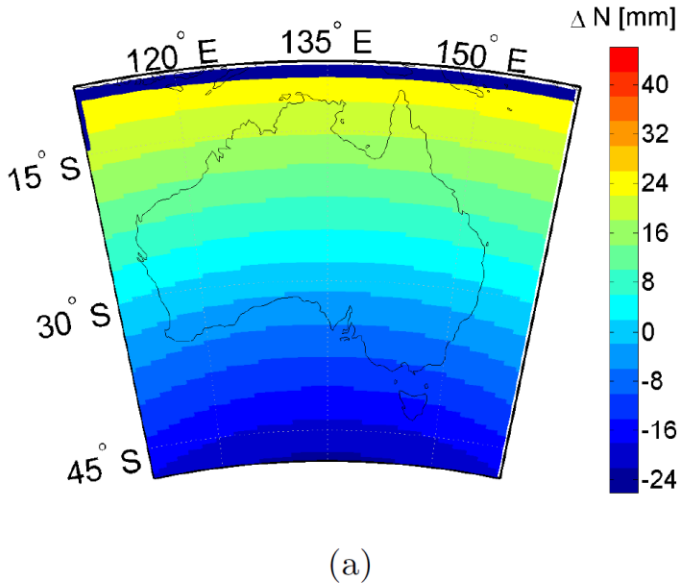
‘Scale-absorbed’ transformation parameters

- Results

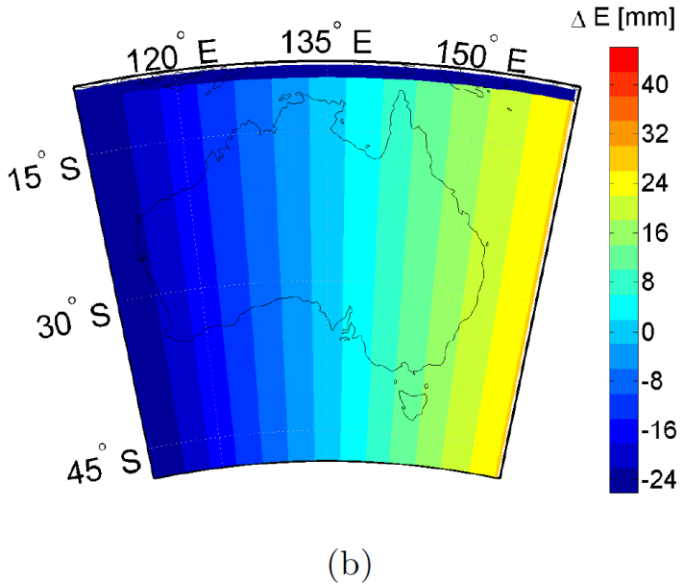




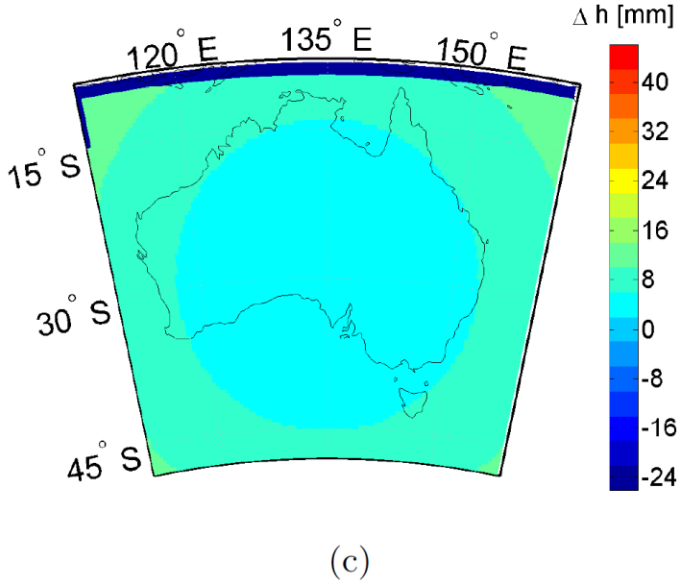
Scale-induced biases



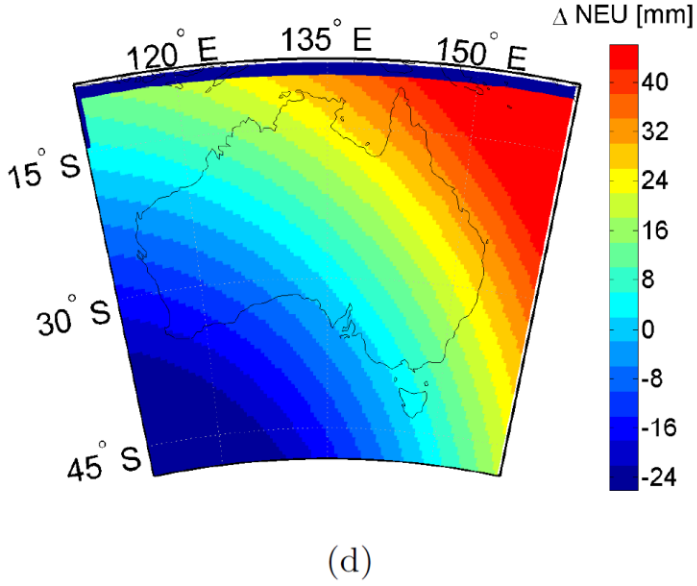
(a)



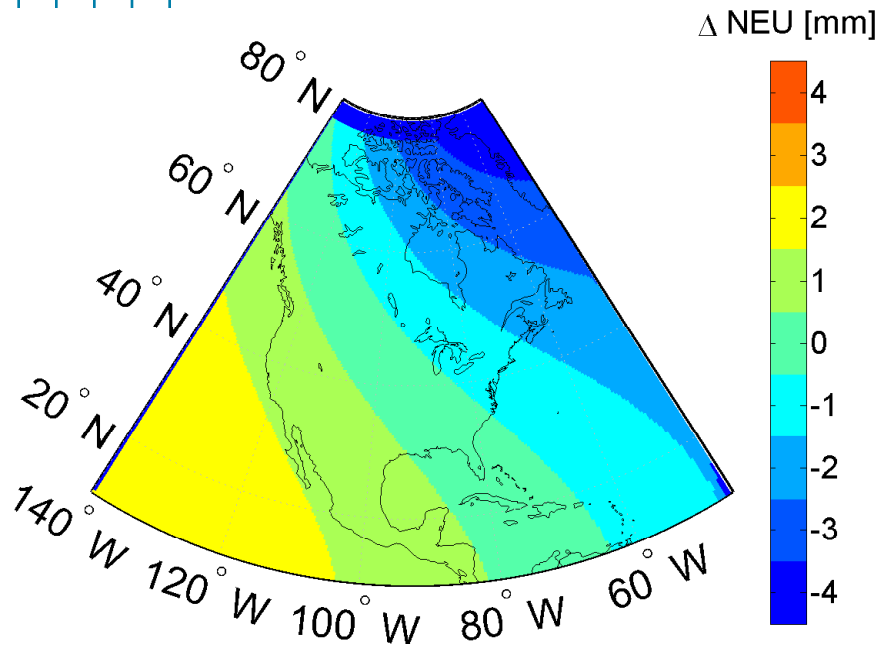
(b)

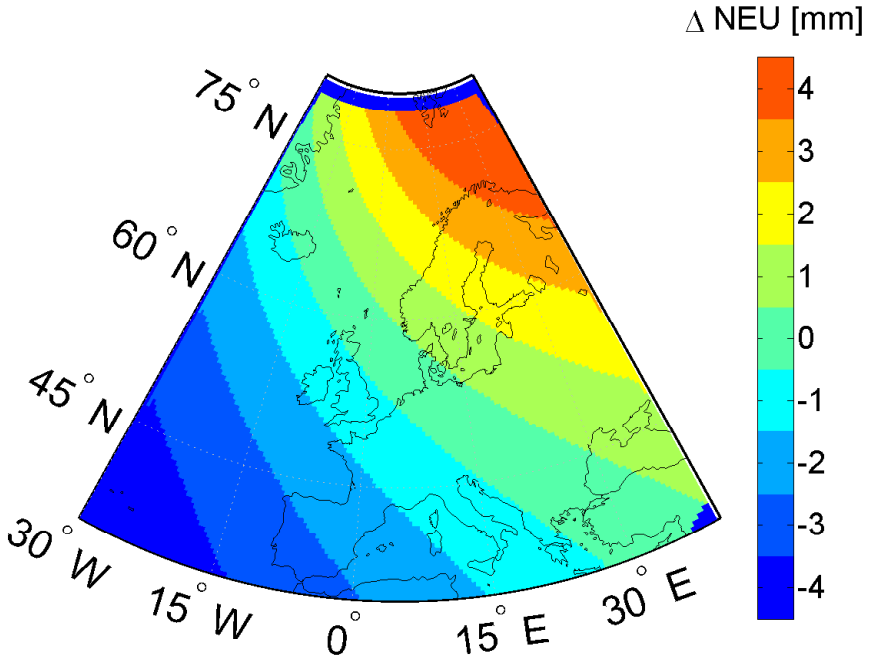


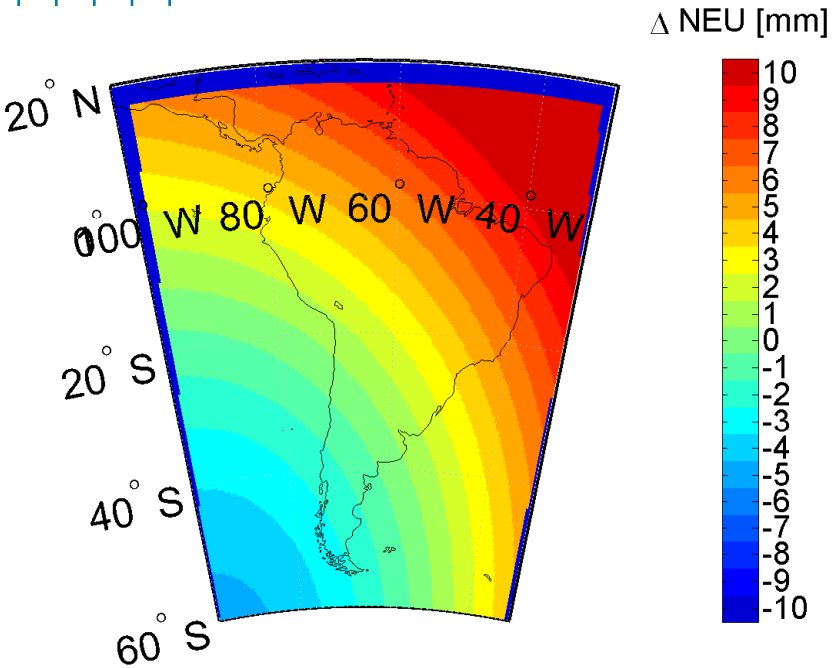
(c)

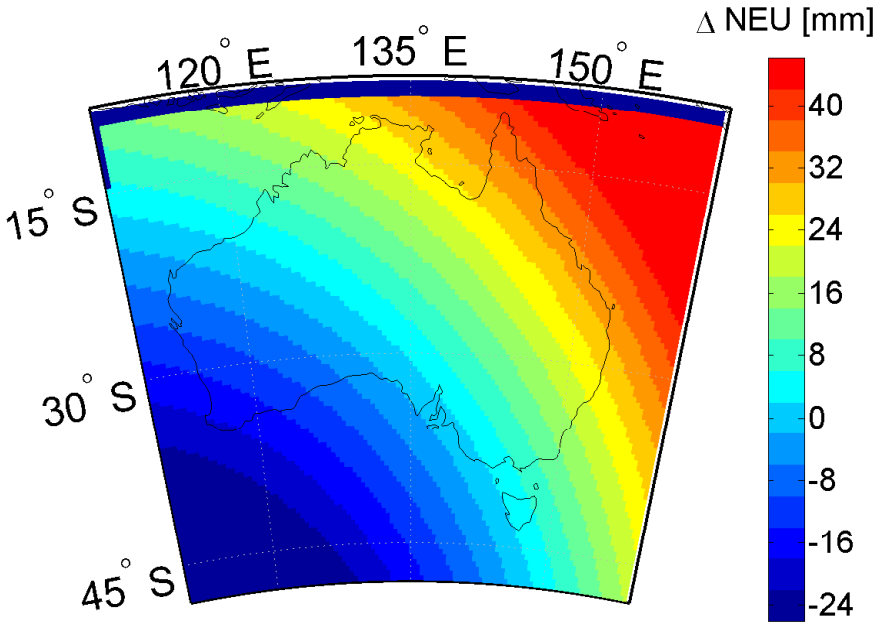


(d)


Δ NEU [mm]
80 ° N
60 ° N
40 ° N
20 ° N
140 ° W
120 ° W
100 ° W
80 ° W
60 ° W
4
3
2
1
0
-1
-2
-3
-4

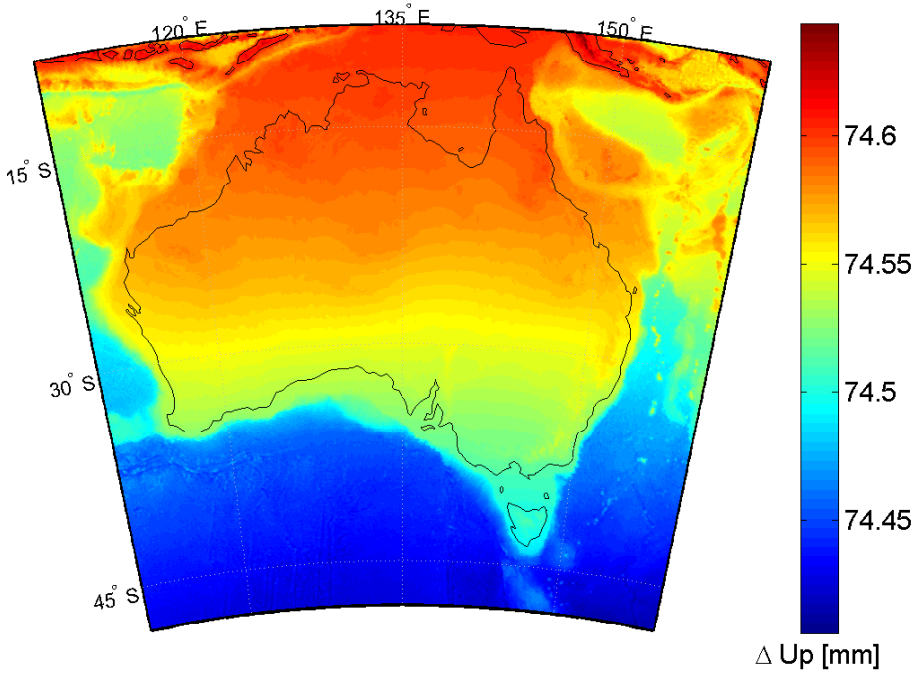

Δ NEU [mm]
75 ° N
60 ° N
45 ° N
30 ° W
15 ° W
0 °
15 ° E
30 ° E
4
3
2
1
0
-1
-2
-3
-4

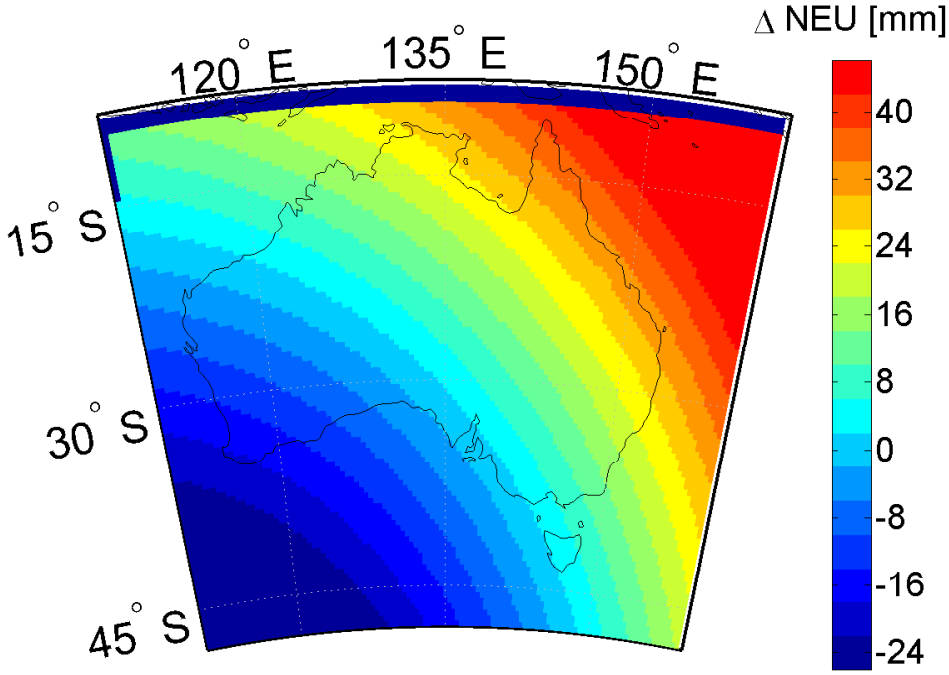

Δ NEU [mm]
20 ° N
0 °
100 ° W
80 ° W
60 ° W
40 ° W
20 ° S
40 ° S
60 ° S
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10


Δ NEU [mm]
120 ° E
135 ° E
150 ° E
15 ° S
30 ° S
45 ° S
40
32
24
16
8
0
-8
-16
-24

Scale-induced biases of both approaches

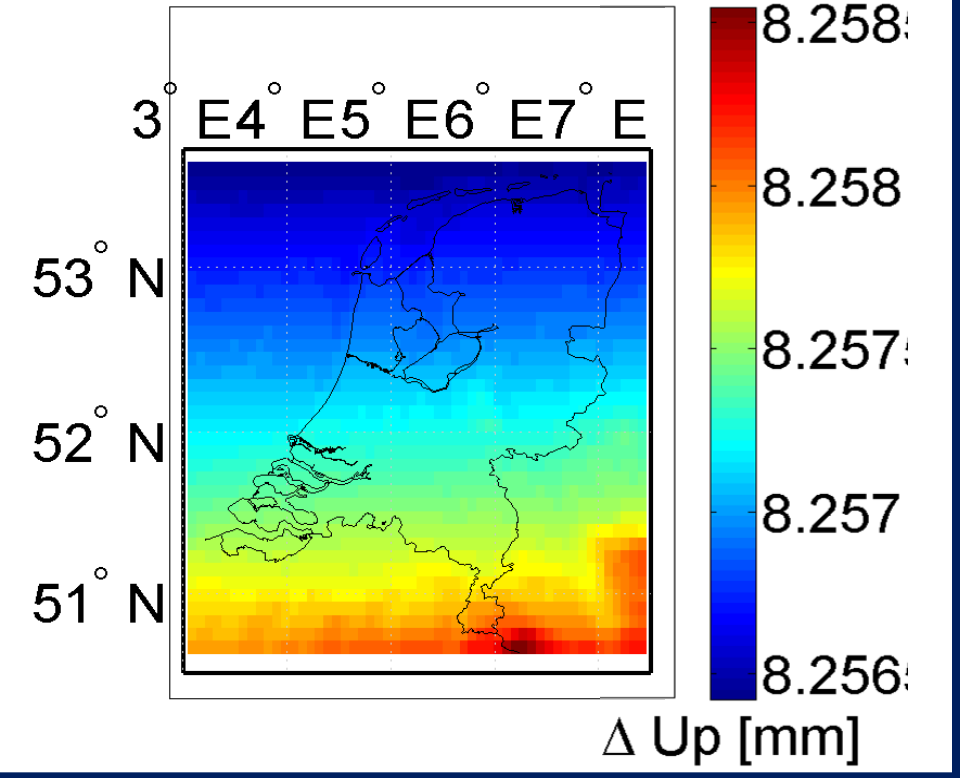
System	Unscaled RBC bias [mm]	Scale absorbed bias range [mm]
ETRF2000(R05)	8.3	-3.5 - 3.5
GDA94	74.6	-20 - 40
NAD83	-4.1	-1.5 - 3.0
SIRGAS95	10.0	-3.5 - 9.0

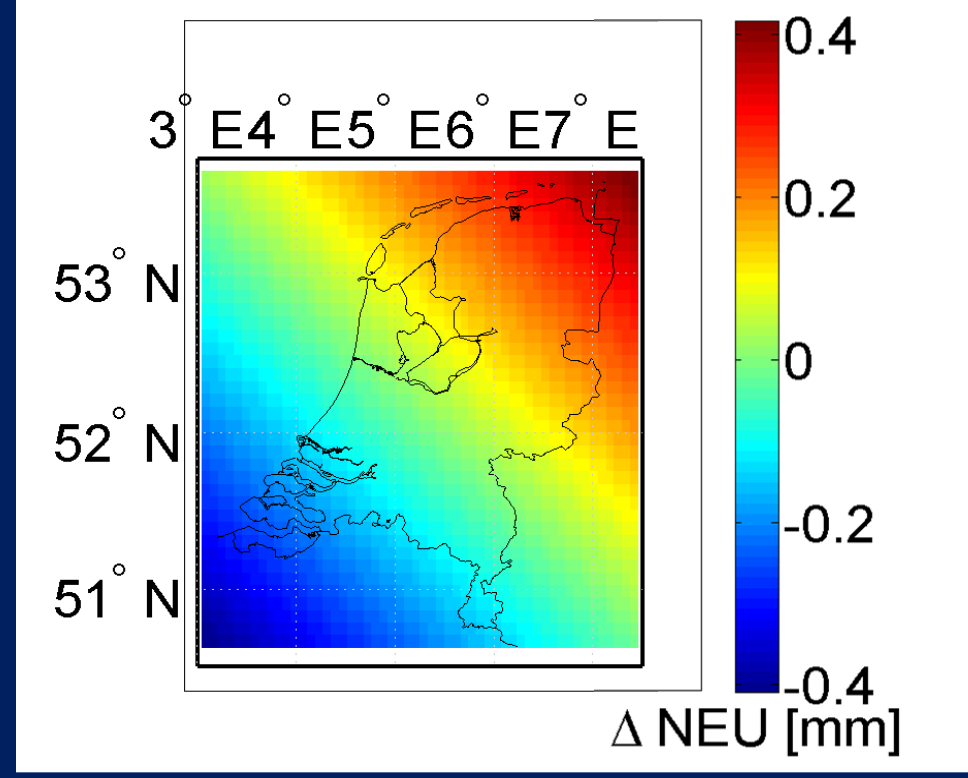


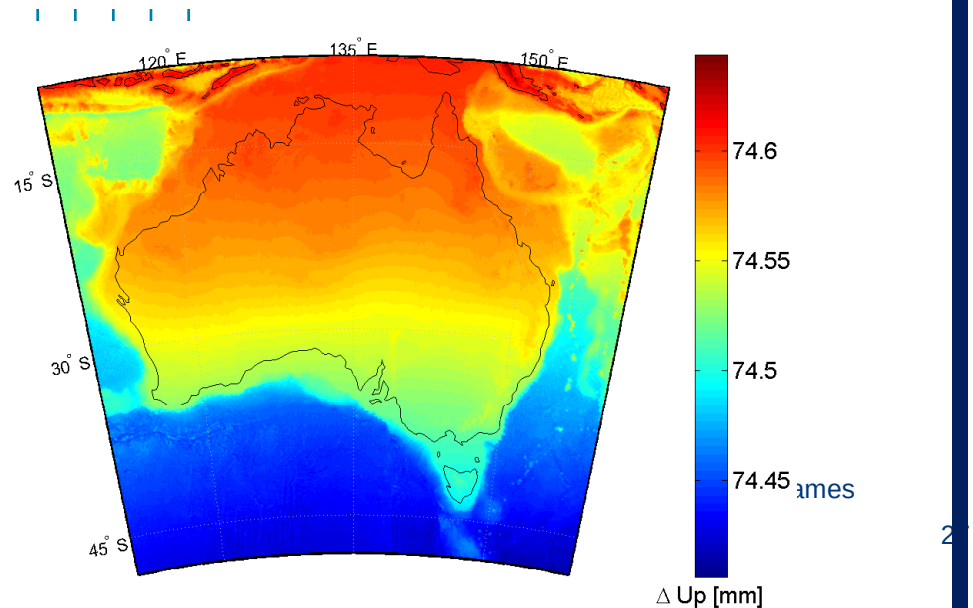


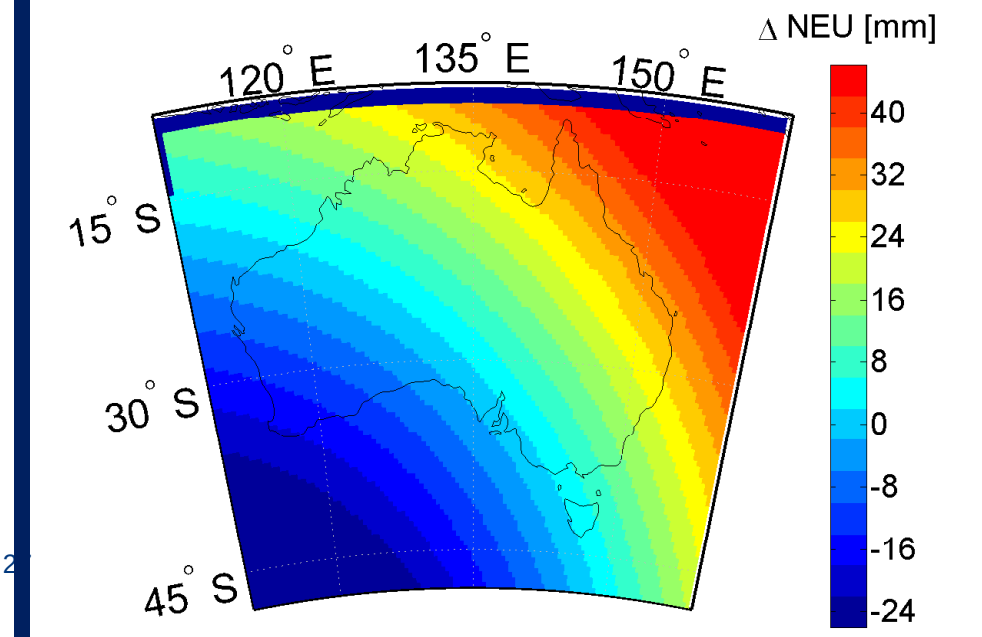
Conclusions

- Existing approach causes satellite-receiver geometry dependent biases
- Proposed approaches cause regional dependent bias(es) that can be a-priori computed
  - RTCM message?
  - Include in NTRIP sourcetable?
- Needs to be addressed for PPP-RTK, is it a problem?


3° E4° E5° E6° E7° E
53° N
52° N
51° N
8.258
8.258
8.257
8.257
8.256
Δ Up [mm]


3° E4° E5° E6° E7° E
53° N
52° N
51° N
0.4
0.2
0
-0.2
-0.4
Δ NEU [mm]


120° E
135° E
150° E
15° S
30° S
45° S
74.6
74.55
74.5
74.45
Δ Up [mm]


Δ NEU [mm]
120° E
135° E
150° E
15° S
30° S
45° S
40
32
24
16
8
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