The role of VLBI in the weekly inter-technique combination

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DGFI

Outline

- Inter-technique computation algorithm
- Relative weighting
- Inter-technique solution (EOP)
- Conclusions

VLBI in the weekly inter-technique combination

Input data from TUM, DGFI, IGG (common a-priori models for all techniques) →

Reconstruction of constraint-free Normal equations (NEQs)

GPS-NEQ (weekly)

SLR-NEQ (weekly)

VLBI-NEQ (session-wise)

Time series of NEQs (1994 until 2007)

Pre-processing and analysis of time series:
- Introduction of discontinuities / Elimination of outliers
- Trafo of VLBI-EOP representation (offset/drift → 2 offsets,pwl)
- Rescale of GPS-NEQs (due to wrong stochastic model)
- Introduction of a-priori variance factors
- Selection and introduction of local ties (LTs)
- Realization of the geodetic datum

Epoch reference frames (ERFs)

Computation of a-posteriori variance factors

Iterative update

Two different solutions are computed:
- constant weighting of the techniques
- weighting of the techniques with VCE

VLBI in the weekly inter-technique combination

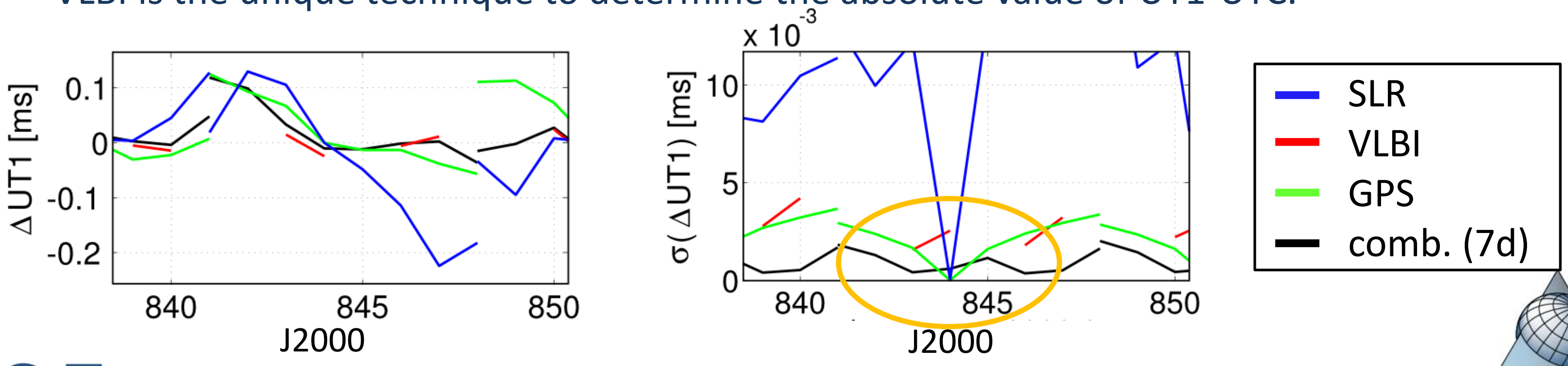
In the combination with the geodetic satellite techniques GPS and SLR, VLBI is essential for …

… the realization of the geodetic datum of the estimated station network

- Origin: information from SLR, conveyed to GPS and VLBI via the local ties (LTs)
- Orientation: NNR-condition over a subnetwork of GPS stations, conveyed to SLR and VLBI via LTs
- Scale: combination of VLBI and SLR, conveyed to GPS via LTs

… the determination of the absolute value of UT1-UTC

- GPS and SLR are only sensitive to the rate of change of UT1-UTC (but high correlations with the orbit falsify this rate)
- VLBI is the unique technique to determine the absolute value of UT1-UTC.



Relative weighting

The relative weighting of the techniques can be done in two different ways:

Equal weighting or weighting with VCE (Böckmann,2010):

$$\sigma_i^{2^{(k+1)}} = \frac{\Omega_{c,i}^{(k)}}{r_{c,i}^{(k)}} \quad \text{with} \quad \begin{aligned} \Omega_{c,i}^{(k)} &= \hat{x}_c^{(k)^T} N_i \hat{x}_c^{(k)} - 2 n_i^T \hat{x}_c^{(k)} + l_i^T P_i l_i \\ r_{c,i}^{(k)} &= m_i - \frac{1}{\sigma_i^{2^{(k)}}} tr\left(N_i N_c^{(k)^{-1}}\right) \end{aligned}$$

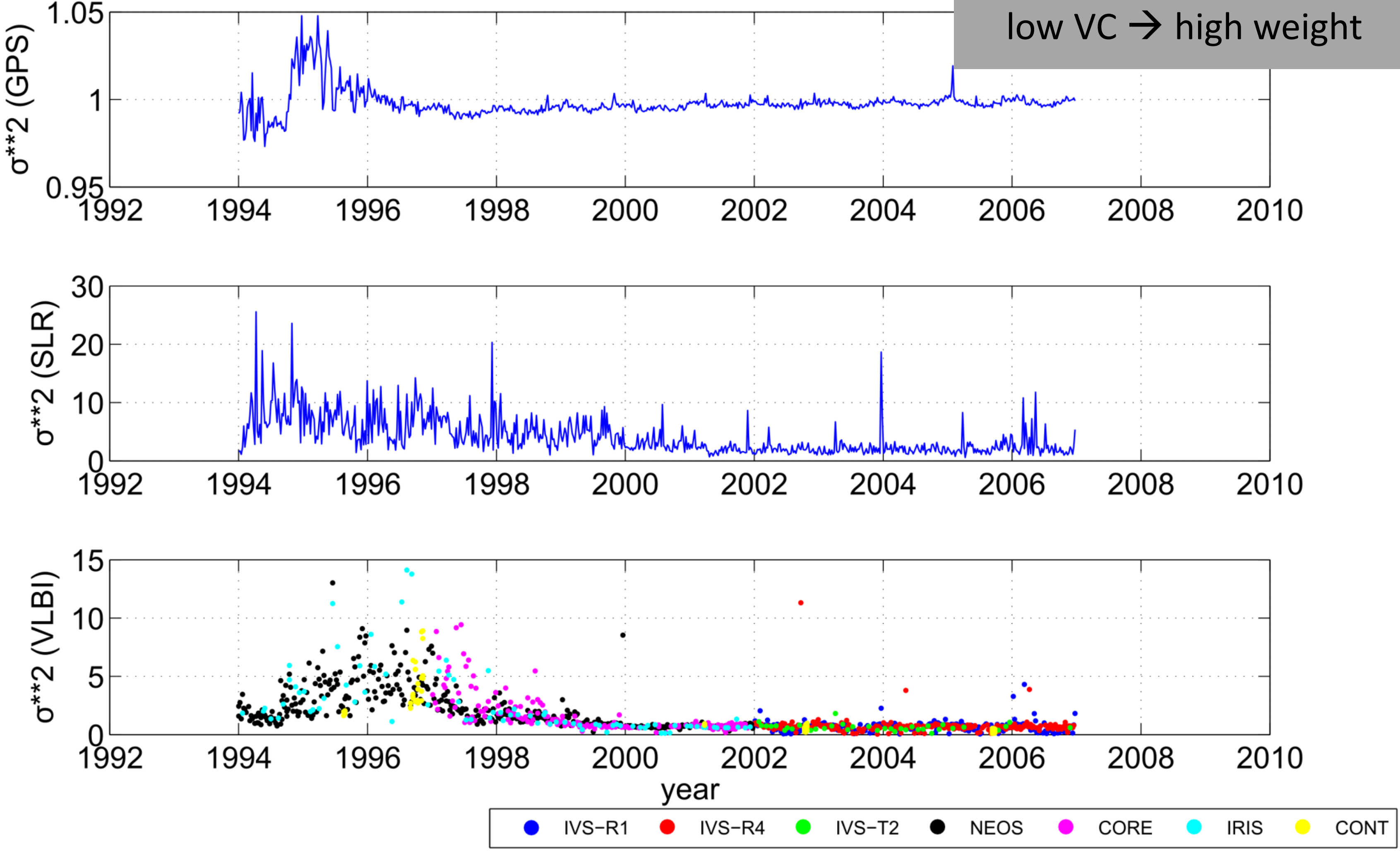
i … single-techn. solution, c … combined solution, k … iteration step

- 1 VC for each weekly GPS- and SLR-NEQ,
  1 VC for each VLBI session
  → time series of VCs for GPS, SLR and VLBI
- Statistics: iterations/week: 3-4, sessions/week: 1-3, except CONT periods

Relative weighting

Variance components for GPS, SLR and VLBI between 1994.0 and 2007.0

low VC → high weight



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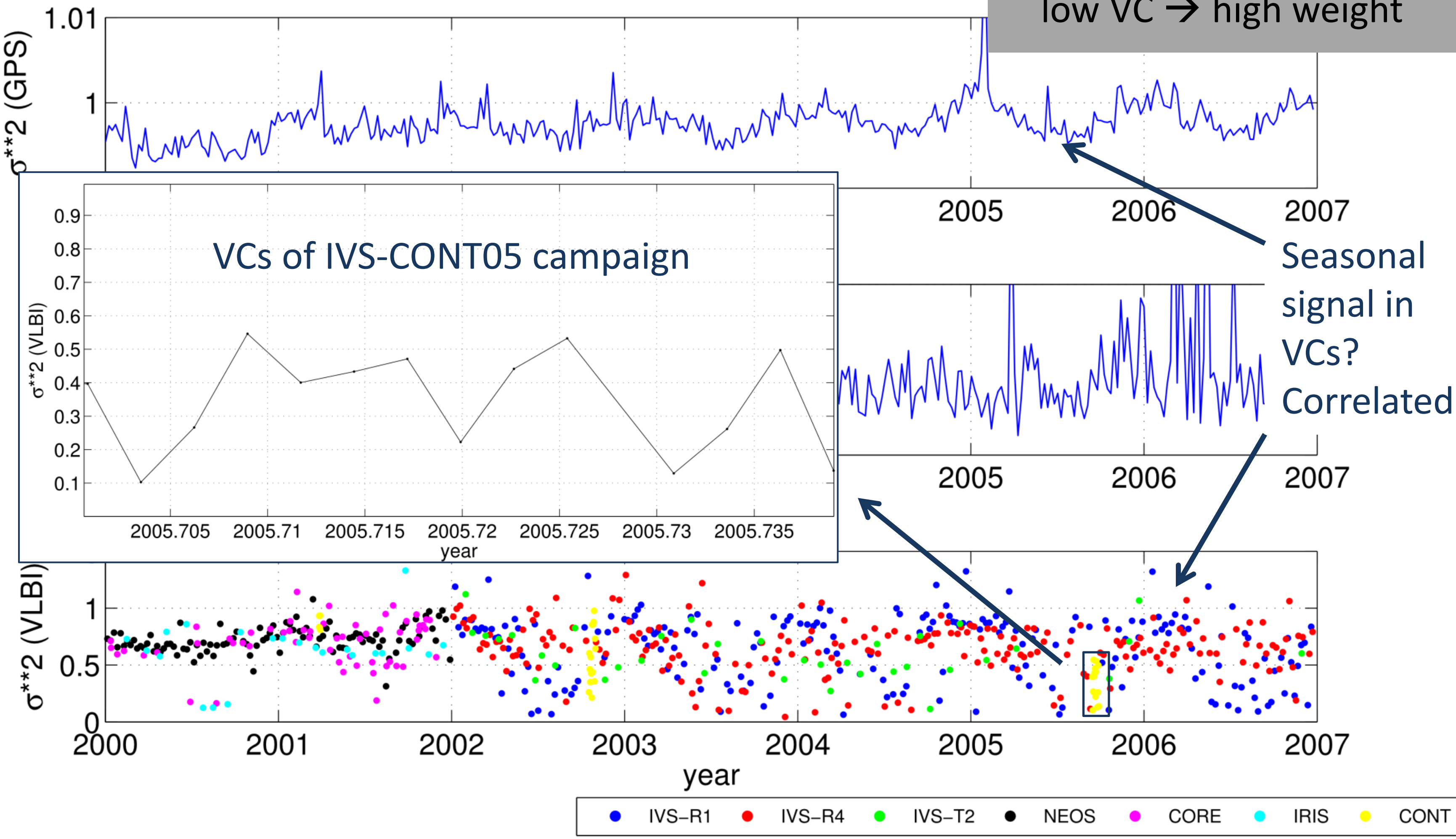
Relative weighting

Variance components for GPS, SLR and VLBI between 2000.0 and 2007.0

low VC → high weight

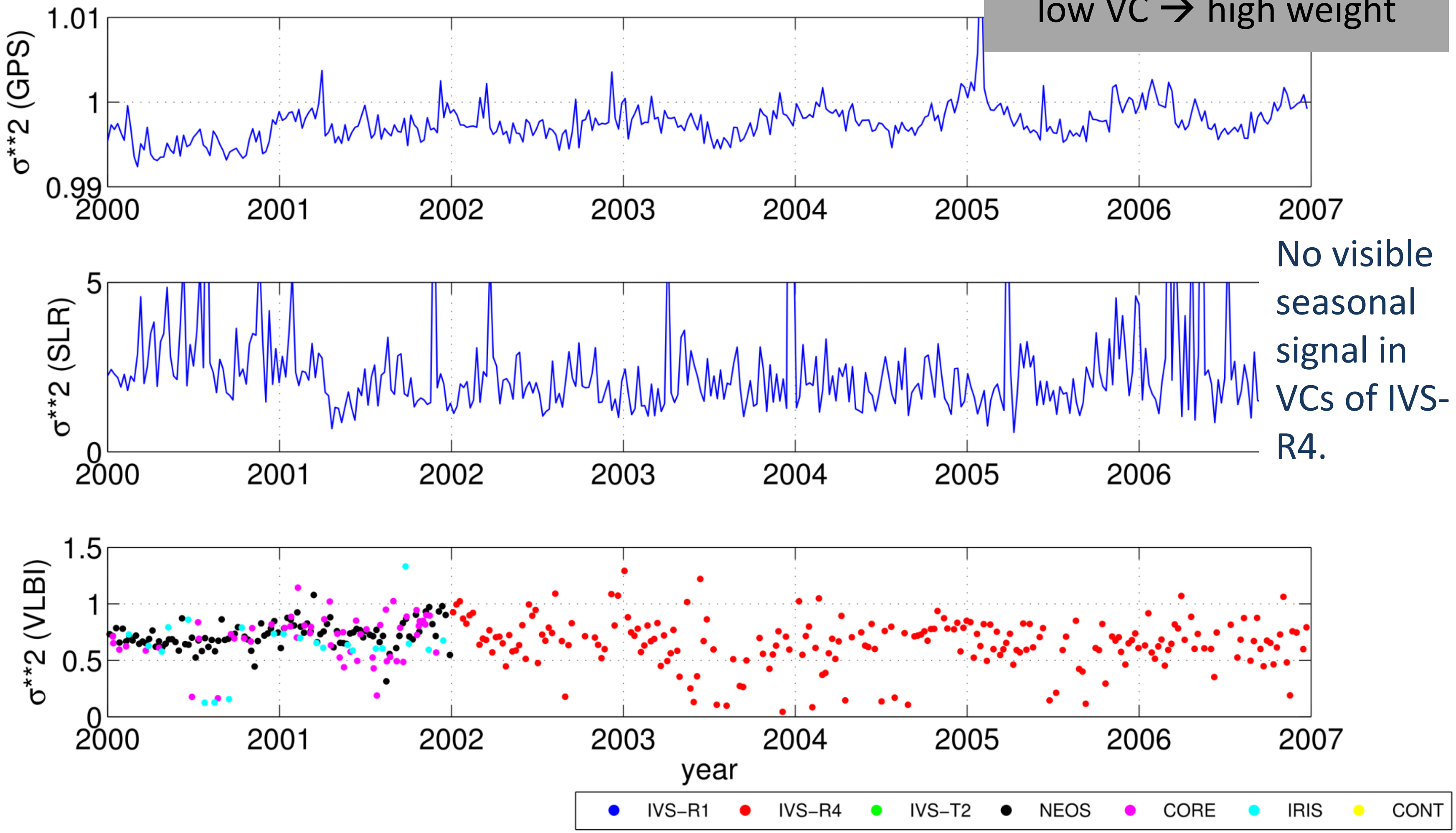


Seasonal signal in VCs? Correlated?

Relative weighting

Variance components for GPS, SLR and VLBI (IVS-R4) between 2000.0 and 2007.0

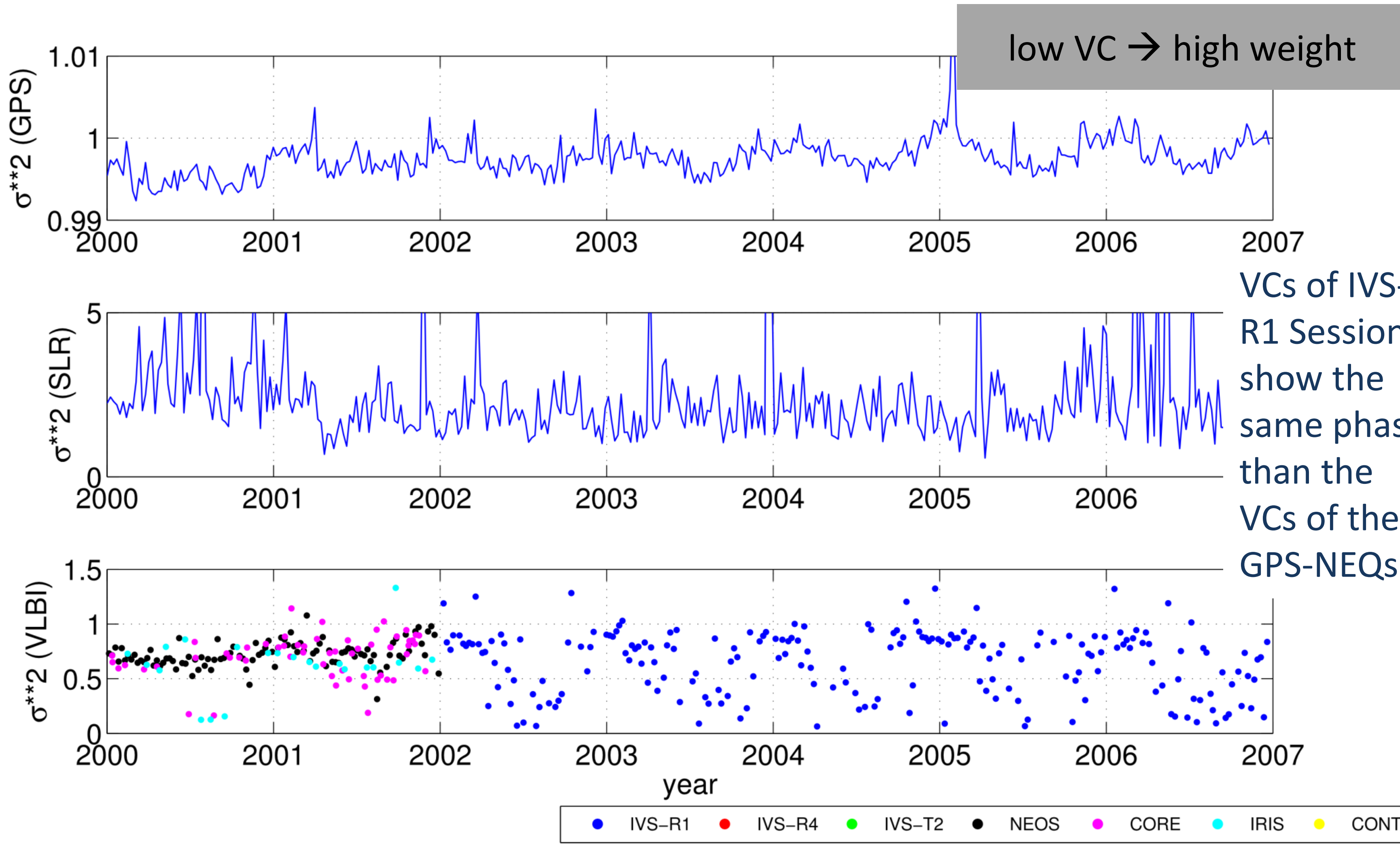
low VC → high weight



No visible seasonal signal in VCs of IVS-R4.

Relative weighting

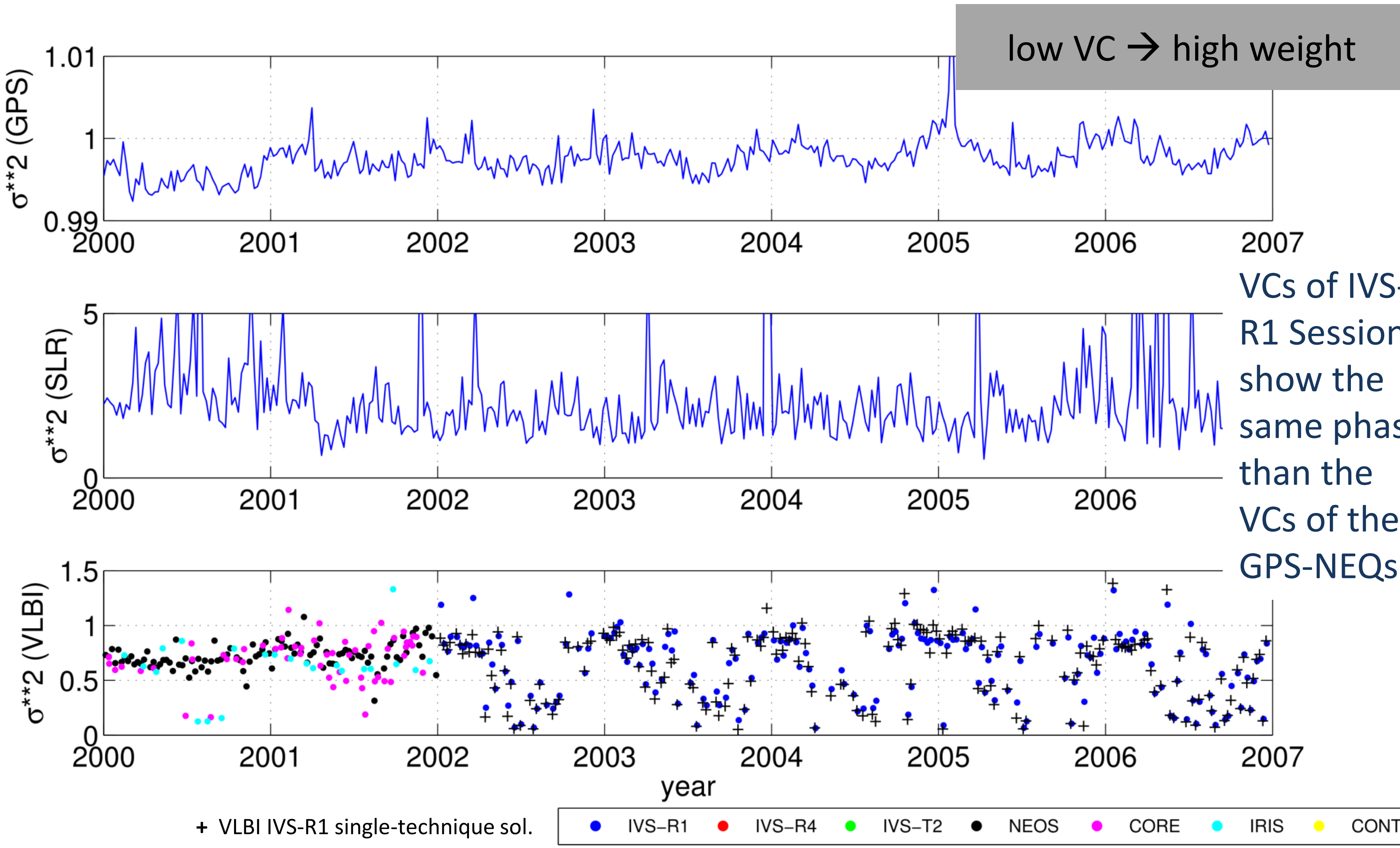
Variance components for GPS, SLR and VLBI (IVS-R1) between 2000.0 and 2007.0



VCs of IVS-R1 Sessions show the same phase than the VCs of the GPS-NEQs.

Relative weighting

Variance components for GPS, SLR and VLBI (IVS-R1) between 2000.0 and 2007.0



VCs of IVS-R1 Sessions show the same phase than the VCs of the GPS-NEQs.

Relative weighting

Variance components for GPS, SLR and VLBI between 1994.0 and 2007.0

Mean values	t < 2000.0	t ≥ 2000.0
GPS	0.998	0.998
SLR	6.122	2.343
VLBI	2.628	0.907

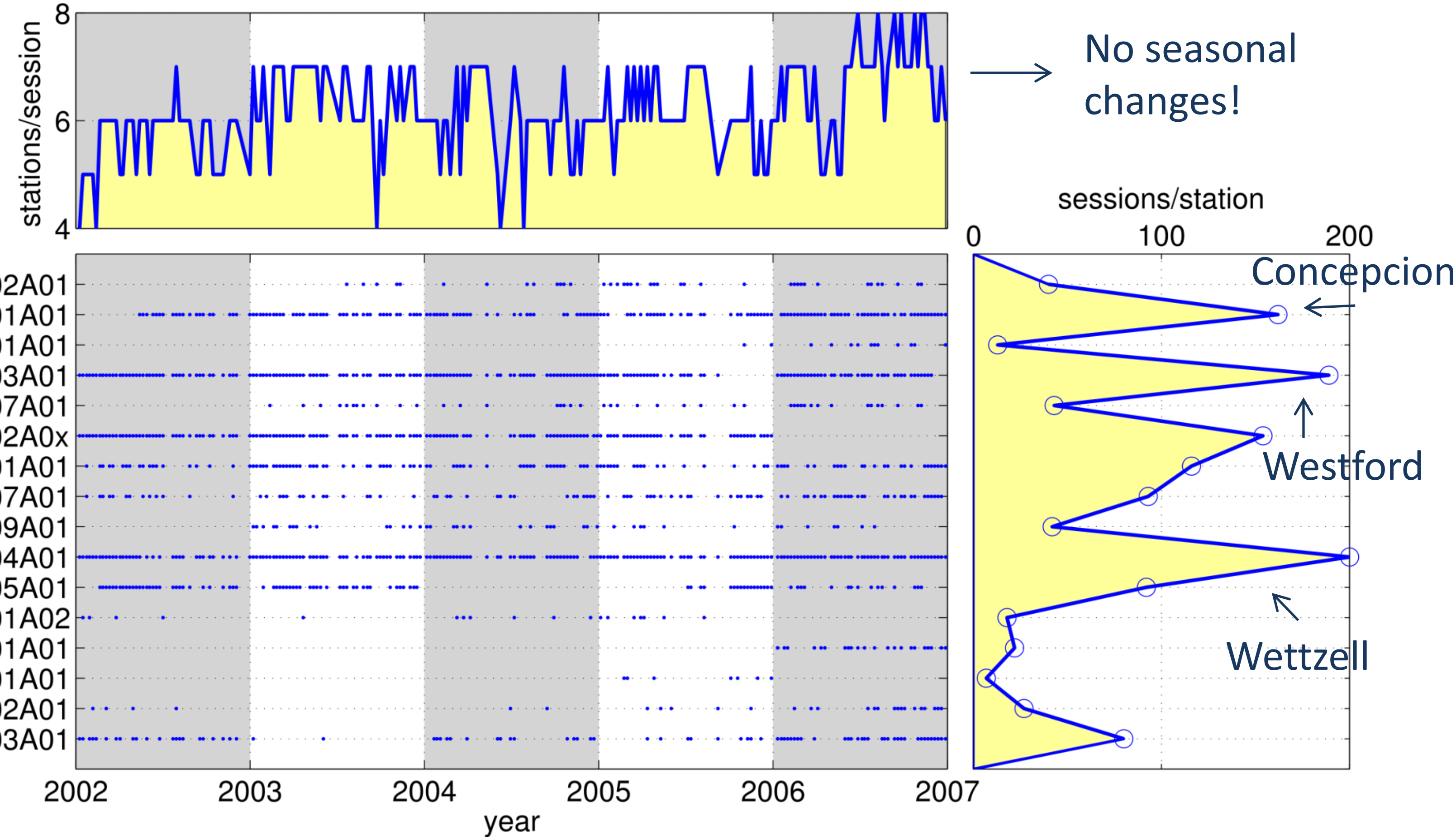
Mean values	t < 2002.0	t ≥ 2002.0
IVS-R1	---	0.703
IVS-R4	---	0.734
IVS-T2	---	0.635
NEOS	2.199	---
CORE	1.633	---
IRIS	3.547	---
CONT	2.123	0.926

- GPS VCs are nearly 1.0 within the whole time period
- The improvement of the SLR observation network since 1994 reflects in the decrease of the SLR VCs
- Since 2000, all VLBI session VCs are below 1.0
- VCs of IVS-R1 campaign show clear seasonal signal; higher impact on combined NEQ in summer

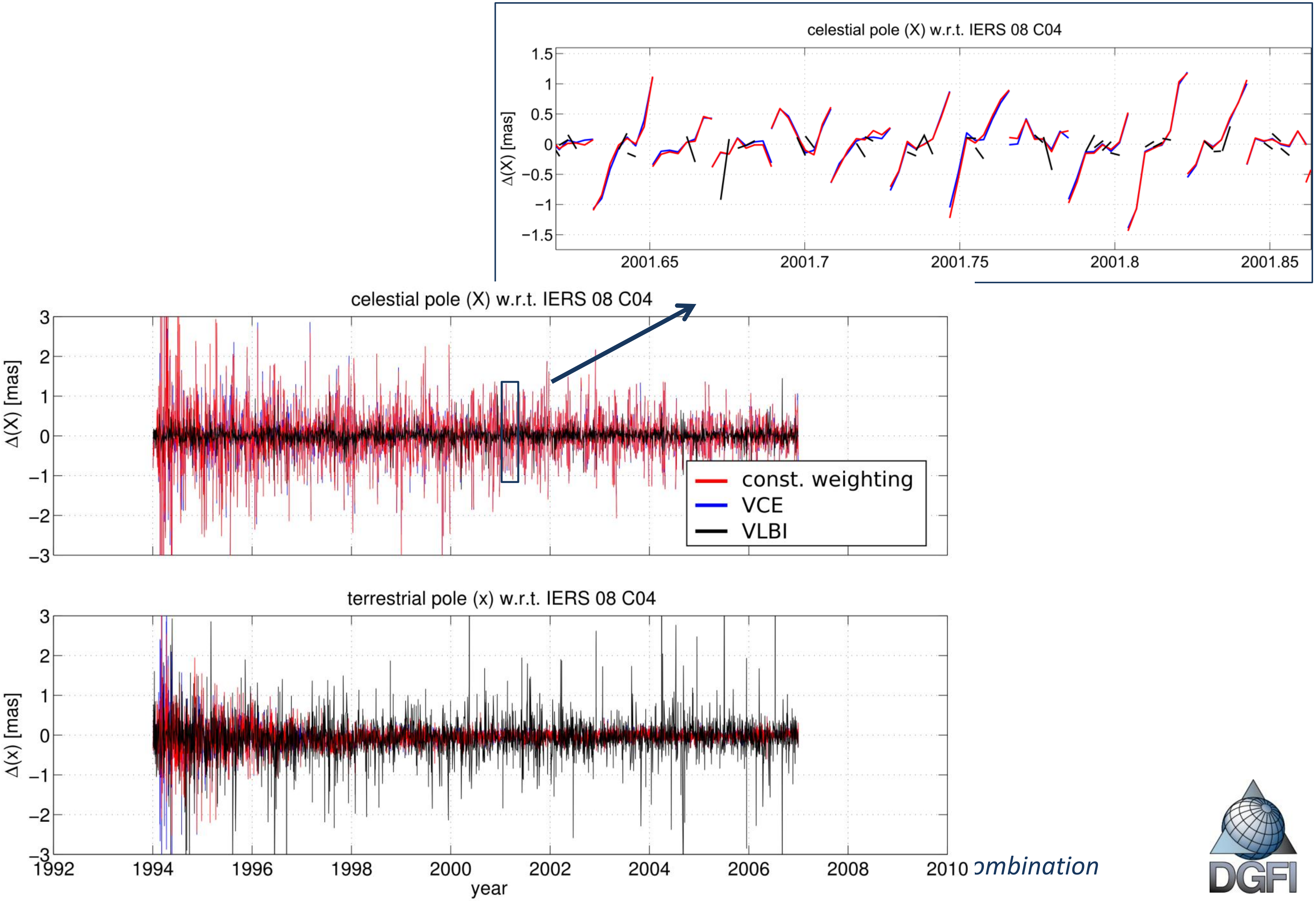
→ What cause this seasonal behaviour?

Relative weighting – network geometry

Network geometry for IVS-R1 sessions



Weekly inter-technique solutions - EOP



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Weekly inter-technique solutions - EOP

WRMS	GPS	VLBI	const. weighting	VCE	VCE (at VLBI epochs)
cel. pole (X) [µas]		88.7	240.9	239.8	94.8
cel. pole (Y) [µas]		95.3	112.5	112.4	100.0
UT1-UTC [µs]		12.1	39.9	39.5	17.5
terr. pole (x) [µas]	123.0	213.7	142.3	122.7	
terr. pole (y) [µas]	114.2	248.2	136.6	117.9	

celestial pole offsets (X,Y), UT1-UTC:

- Scattering of the combined solution is much higher, but the time series is continuous!
- If only VLBI epochs are considered, WRMS is comparable to the VLBI solutions

terrestrial pole offset (x,y):

- Scattering of the VCE solution is comparable to the scattering of the GPS solution

Conclusions

- VLBI plays a central role in the inter-technique combination
  - Determination of the scale (with SLR)
  - Determination of the absolute value of UT1-UTC and celestial pole (X,Y)
- VLBI in the VCE of the weekly inter-technique combination
  - After 2000, VC < 1.0 for all VLBI sessions → high impact of VLBI on the combined NEQs
  - Seasonal behavior of the VCs of the IVS-R1 campaigns (small VCs during summer, high VCs during winter)

    → reason not yet found!
- Weekly inter-technique solutions
  - No a-priori fixing necessary for UT1-UTC/cel. pole (X,Y) determination (VLBI delivers info to GPS/SLR!)
  - GPS/SLR rates for UT1-UTC are falsified → values between VLBI sessions are falsified
  - Scattering of terrestrial pole (x,y) in the VCE sol. decreases compared to the GPS single-technique sol.

Not shown, but:

- Scattering of VLBI station coordinates decreases in the combination!

Thank you very much for your attention.

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Additional

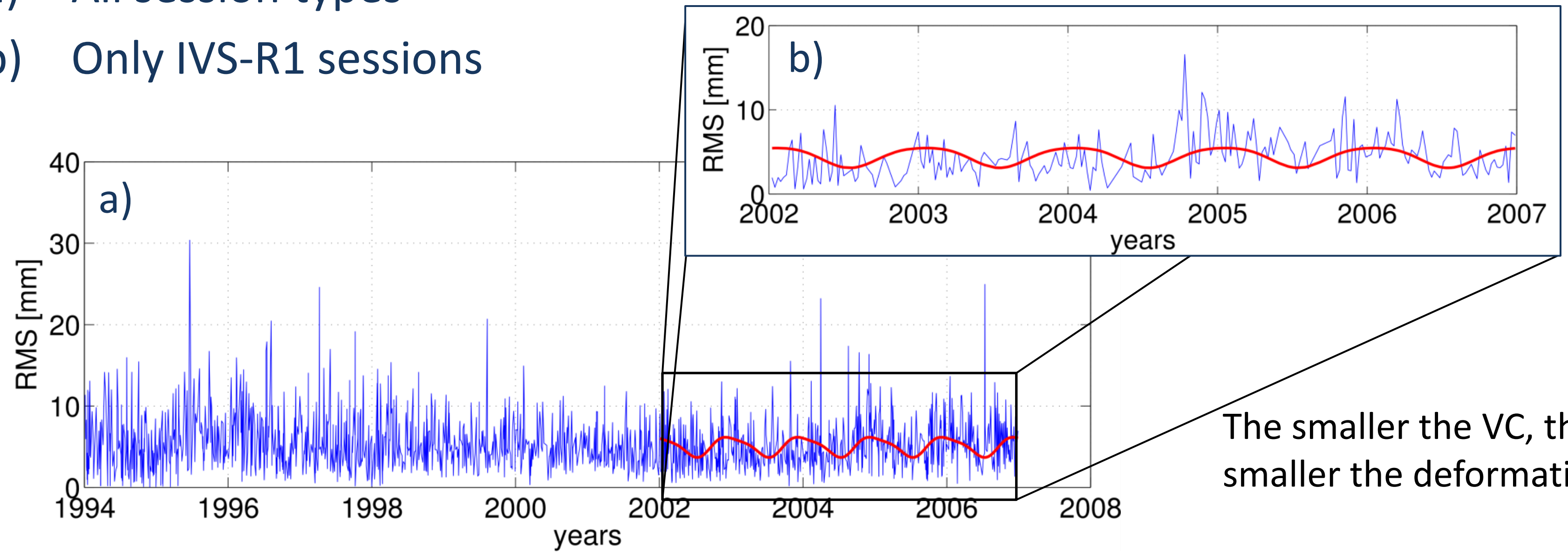
slides

Relative weighting

Network deformation of VCE sol. w.r.t. epoch single-technique sol. for

a) All session types

b) Only IVS-R1 sessions



The smaller the VC, the smaller the deformation!

The deformation of the combined NEQs (VLBI network) w.r.t. the IVS-R1 sessions is smaller during the summer than during the winter.

→ Seasonal changes in network geometry of IVS-R1 sessions?

Rescale of GPS-NEQs

Due to the wrong stochastic model of the GPS-NEQs (correlatios between observations are neglected), they have to be rescaled.

The algorithm for computing the scaling factors is based on the station repeatability.

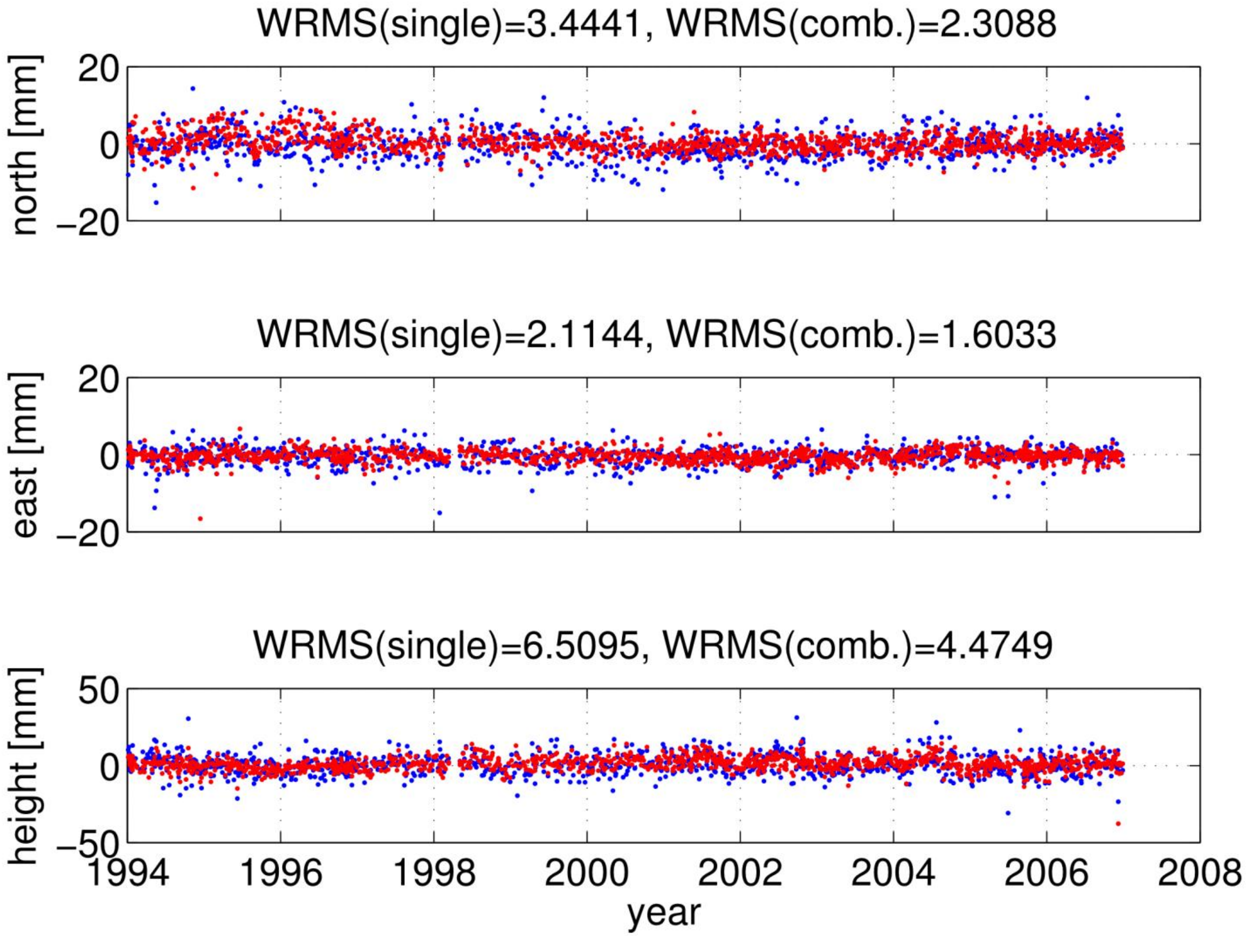
$$\sigma_2^2 = \left(\frac{b}{a}\right)^2 \quad \text{with} \quad a = \frac{\overline{RMS}_1}{\overline{RMS}_2} \quad \text{and} \quad b = \frac{\bar{\sigma}_1}{\bar{\sigma}_2}$$

1,2 … techniques, $\sigma_1 = 1$

technique	variance factor	relative weight
GPS	9.09	0.12
SLR	1.0	1.0
VLBI	1.0	1.0

→ GPS is downweighted w.r.t. the other techniques (due to its wrong stochastic model)

Weekly inter-technique solutions - stations



Weekly inter-technique solutions – 3D fit of LTs

Mean 3D fit of LTs per session:

$$\bar{d} = \frac{1}{N}\sum_{i=1}^{N}\sqrt{\left(\Delta x_i - LT_{x,i}\right)^2 + \left(\Delta y - LT_{y,i}\right)^2 + \left(\Delta z_i - LT_{z,i}\right)^2}$$

with

N … number of stations,

$(\Delta x, \Delta y, \Delta z)$ … difference between single-technique solutions

LT … local tie