ITRF and seasonal station motions

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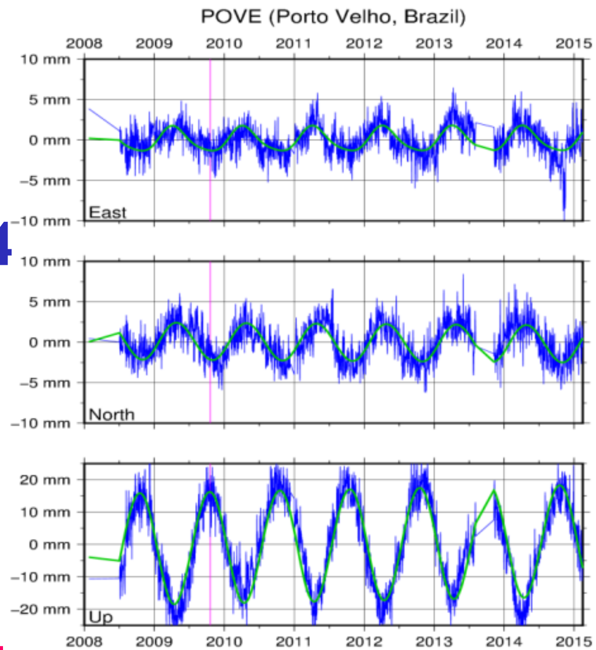
Motivations

- **Seasonal signals :**
  - Evaluate and understand technique differences at co-location sites
  - Concentrate on annual & semi-annual signals
  - Combine them at co-location sites
  - Provide them in a coherent Reference Frame (CM or CF/CN)
  - Provide a coherent annual geocenter motion model compatible with ITRF2014



Periodic signals: reference frame definition

- **CM : Center of Mass Frame**
- **CF : Center of Figure Frame**
- **CN : Center of Network Frame**

IERS Conventions: $$\boxed{\vec{X} = \vec{X}_{ITRF} - \vec{O}_G}$$

$\vec{O}_G$ **is the vector from the ITRF origin to the instantaneous CM**

Input data frame origin

Service/ Technique	Number of Solutions	Time span	# of sites	Theor. Origin
IGS/GNSS/GPS (Rebischung et al., 2016)	7714 daily	1994.0 – 2015.1 (21 yrs) **Aligned (NNT, NNR) to IGS08**	884	**GPS** **CN**
IVS/VLBI (Bachmann et al., 2016)	5328 daily	1980.0 – 2015.0 (35 yrs) **Aligned (NNT, NNR) to a priori coord. frame (ITRF2008)**	124	**VLBI** **CN**
ILRS/SLR (Luceri et al., 2015)	244 fortnightly 1147 weekly	1980.0 – 1993.0 1993.0 – 2015.0 (35 yrs)	96	**CM**
IDS/DORIS (Moreaux et al., 2016)	1140 weekly	1993.0 – 2015.0 (22 yrs)	71	**CM**

Using data from 2000.0 on

Periodic Signals : General Equations

Sine & Cosine Function $$\Delta X_f = \sum_{i=1}^{n_f} a^i \cos(\omega_i t) + b^i \sin(\omega_i t)$$

→ 6 parameters per station & per frequency: (*a* , *b*) following the three axis X, Y, Z.
→ With respect to a secular (ITRF) frame we can write:

$$\boldsymbol{X(t)_s - \delta X(t)_{PSD} = X(t_0)_{itrf} + \dot{X}_{itrf} \,.(t - t_0) + T(t) + \Delta X_f(t)}$$

If:

- $\boldsymbol{X(t)_s}$ is SLR time series, then $\boldsymbol{T(t)}$ reflects the geocenter motion as seen by SLR. Same for any satellite technique **in theory**

- $\boldsymbol{X(t)_s}$ is any time series pre-aligned to ITRF, then $\boldsymbol{T(t)}$ is zero.

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Combination of Seasonal Signals?

Approach 1: Stacking of all 4 technique time series

- Adding local ties at co-location sites
- Imposing co-motions at co-location sites
- Seasonal Signals can be expressed in CM or CF(CN)

Approach 2: Combine individual seasonal signals from the 4 techniques:

- Adding similarity transformation between techniques
- Imposing co-motions at co-location sites
- Seasonal Signals can be expressed in CM or CF(CN)
- More flexible to investigate technique agreement
- Variance factor estimation based only on seasonal signals agreement at co-location sites

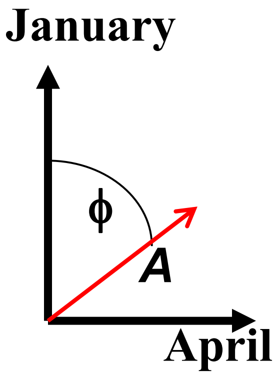
Stacking of time series & rank deficiency

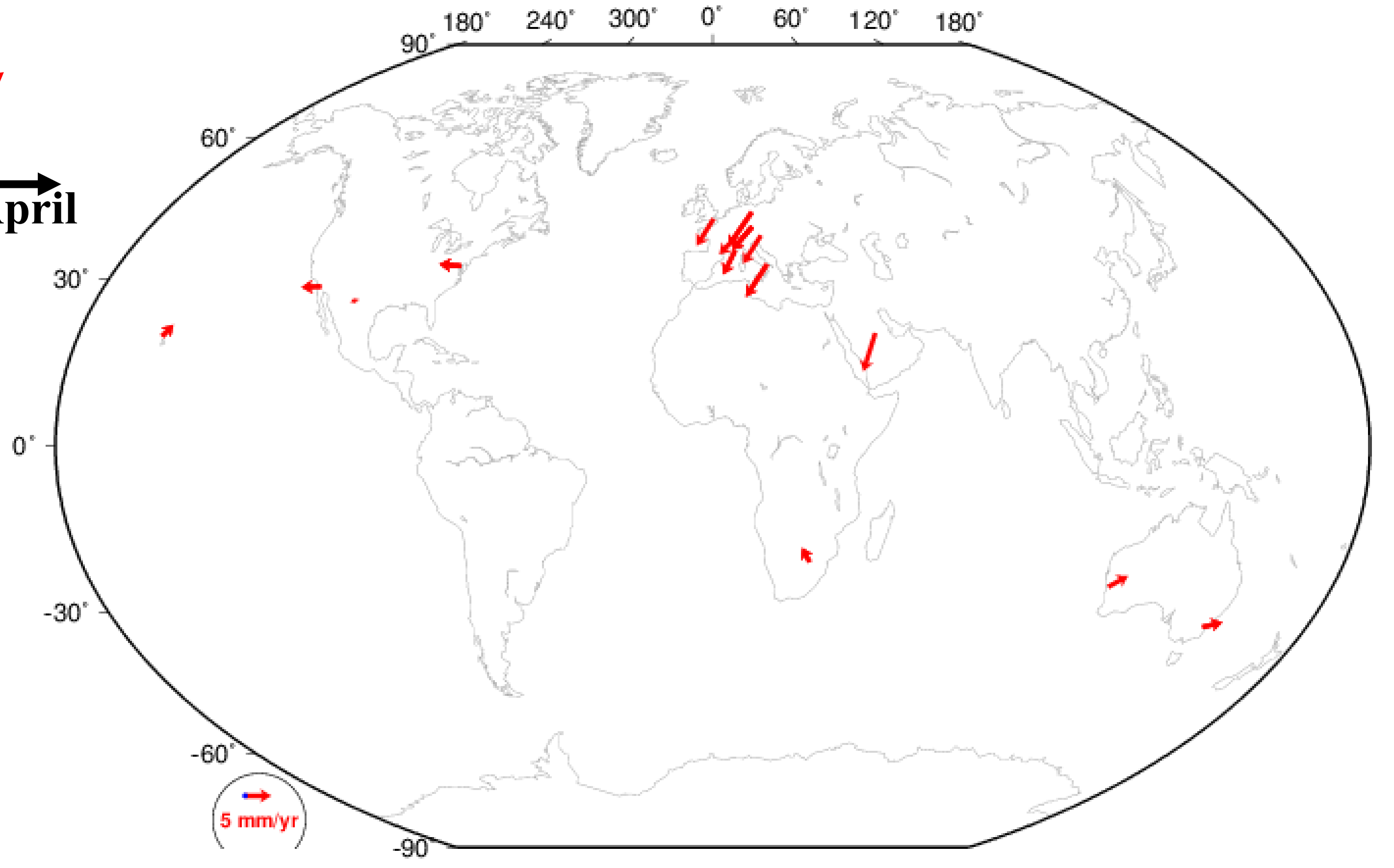
Need to specify the reference frames for both station positions & velocities and the periodic signals: CM or CN

- **14 DoF to define the secular frame**
- **14 DoF for each frequency, handled by:**
  - **Minimum Constraints (MC) : No net periodic Translation, Rotation, or/and Scale of a reference set of stations**
  - **Internal Constraints (IC): Zero periodic signals in Translation, Scale & eventually Rotation time series**

- **Note:**
  - **MC applied wrt a network of stations ==> CN Frame**
  - **IC wrt time series of transformation parameters ==> CM Frame (True for SLR and DORIS CM)**

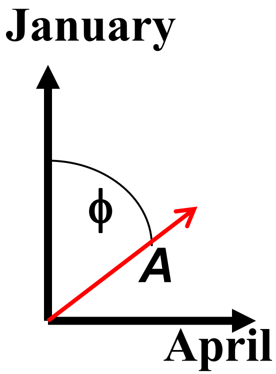
SLR Up annual signals : CM Frame

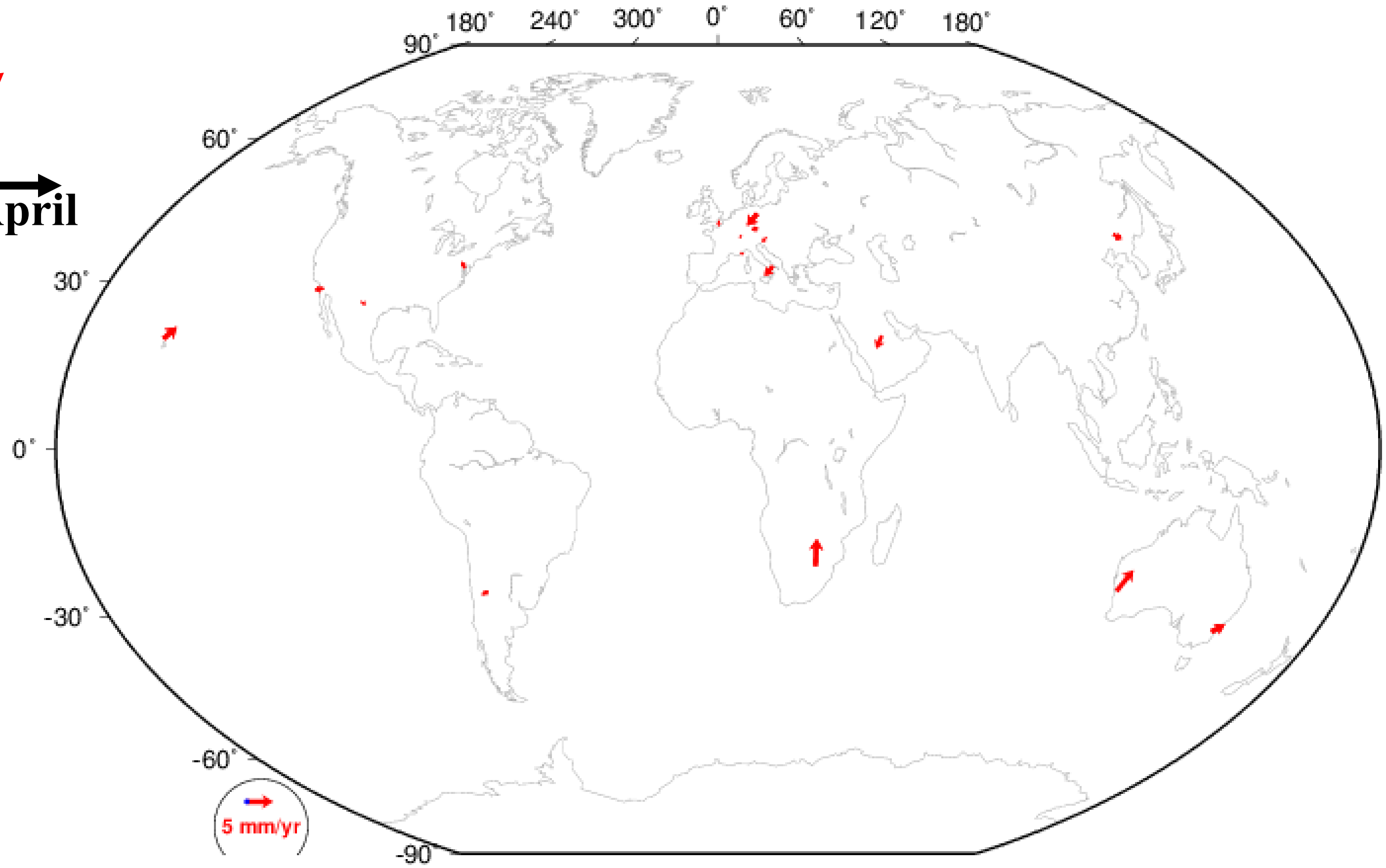




$$Dh = A.cos(\, 2\pi f\,(t - t_0) + \phi\,)$$

SLR Up annual signals : in CN Frame

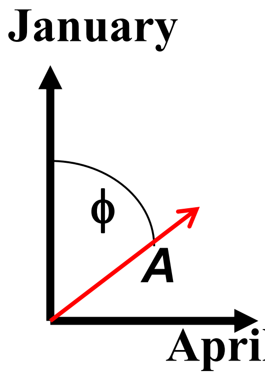




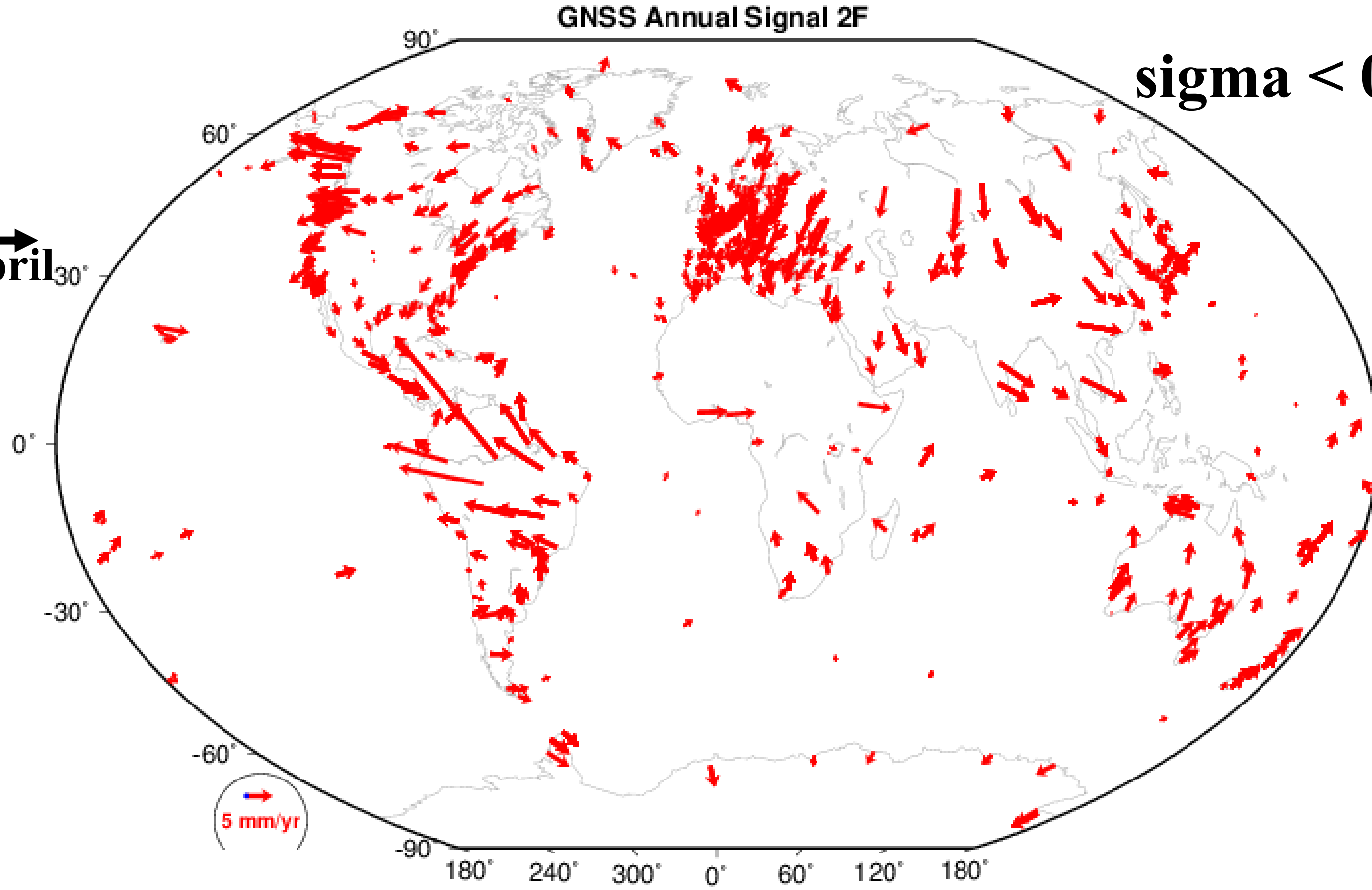
$$Dh = A.cos(2\pi f\,(t - t_0) + \phi\,)$$

Up annual signals : GNSS CN

2 Frequencies estimated (Ann + Semi-Ann)



sigma < 0.1 mm



$$Dh = A.cos(\, 2\pi f\, (t - t_0) + \phi\,)$$

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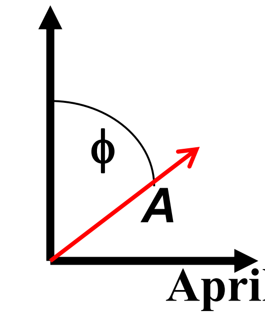
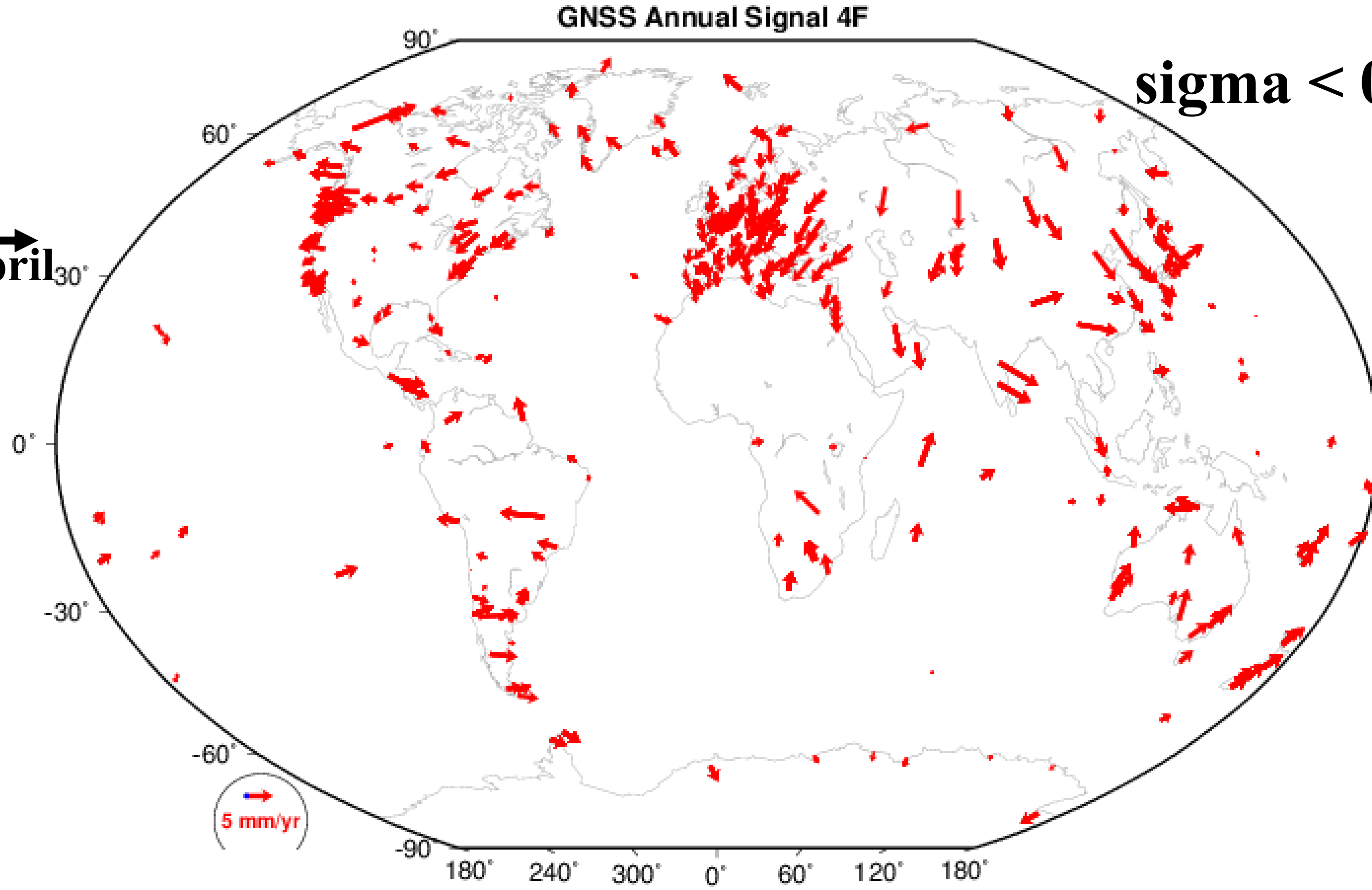
Up annual signals : GNSS CN

4 frequencies estimated (Ann, Semi-Ann + 2 draconitics)



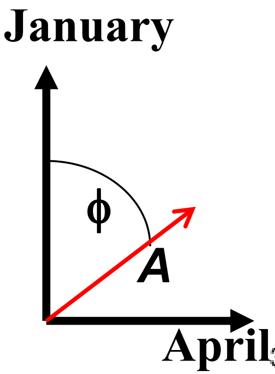


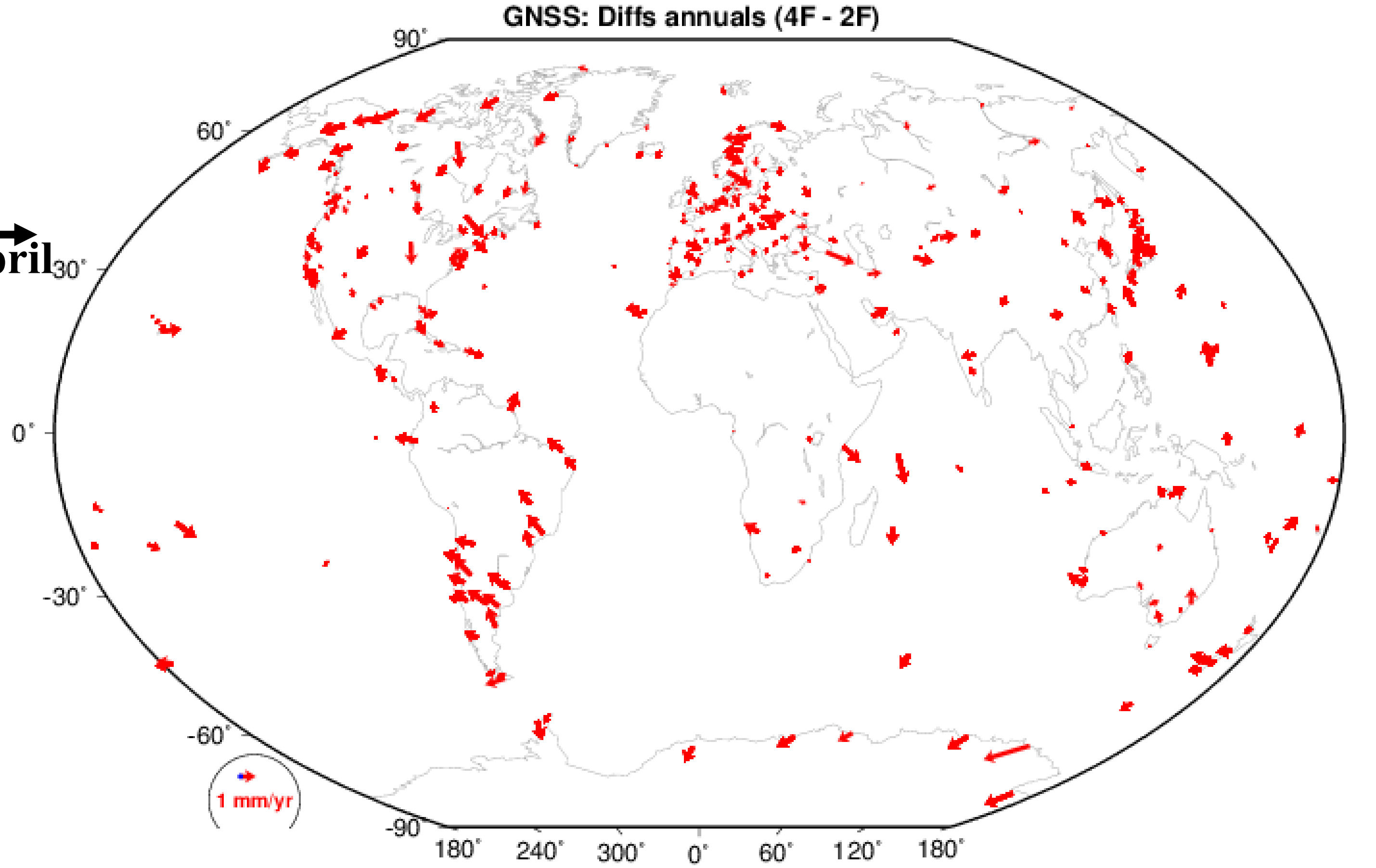
sigma < 0.1 mm

$$Dh = A.cos(\, 2\pi f\,(t - t_0) + \phi\,)$$

Diffs Up annual signals : GNSS CN

4 frequencies - 2 frequencies





$$Dh = A.cos(\ 2\pi f\ (t - t_0) + \phi\ )$$

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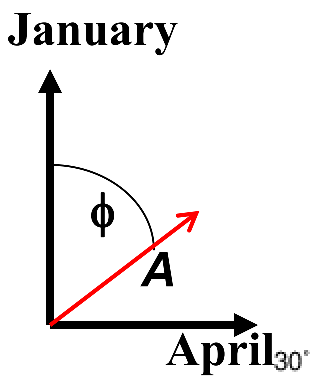
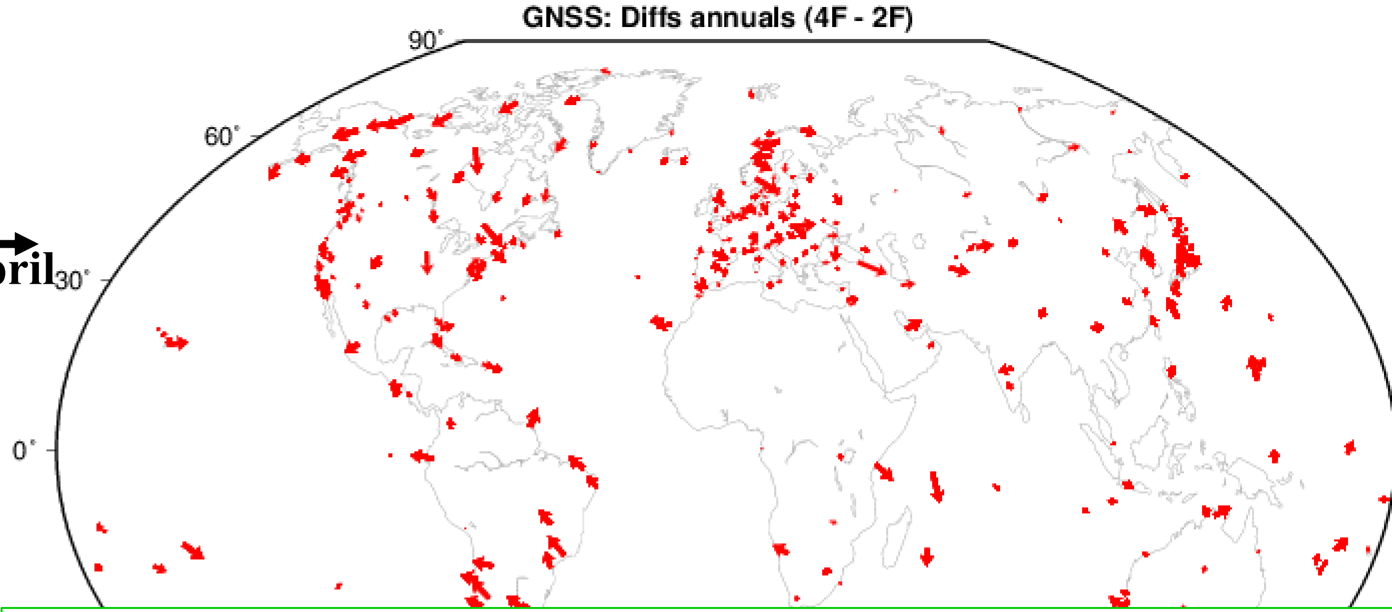
Diffs Up annual signals : GNSS CN

4 frequencies - 2 frequencies

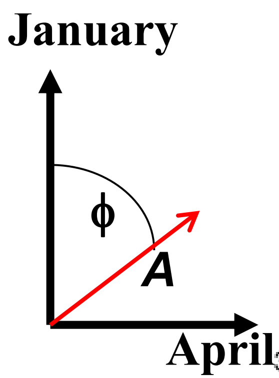


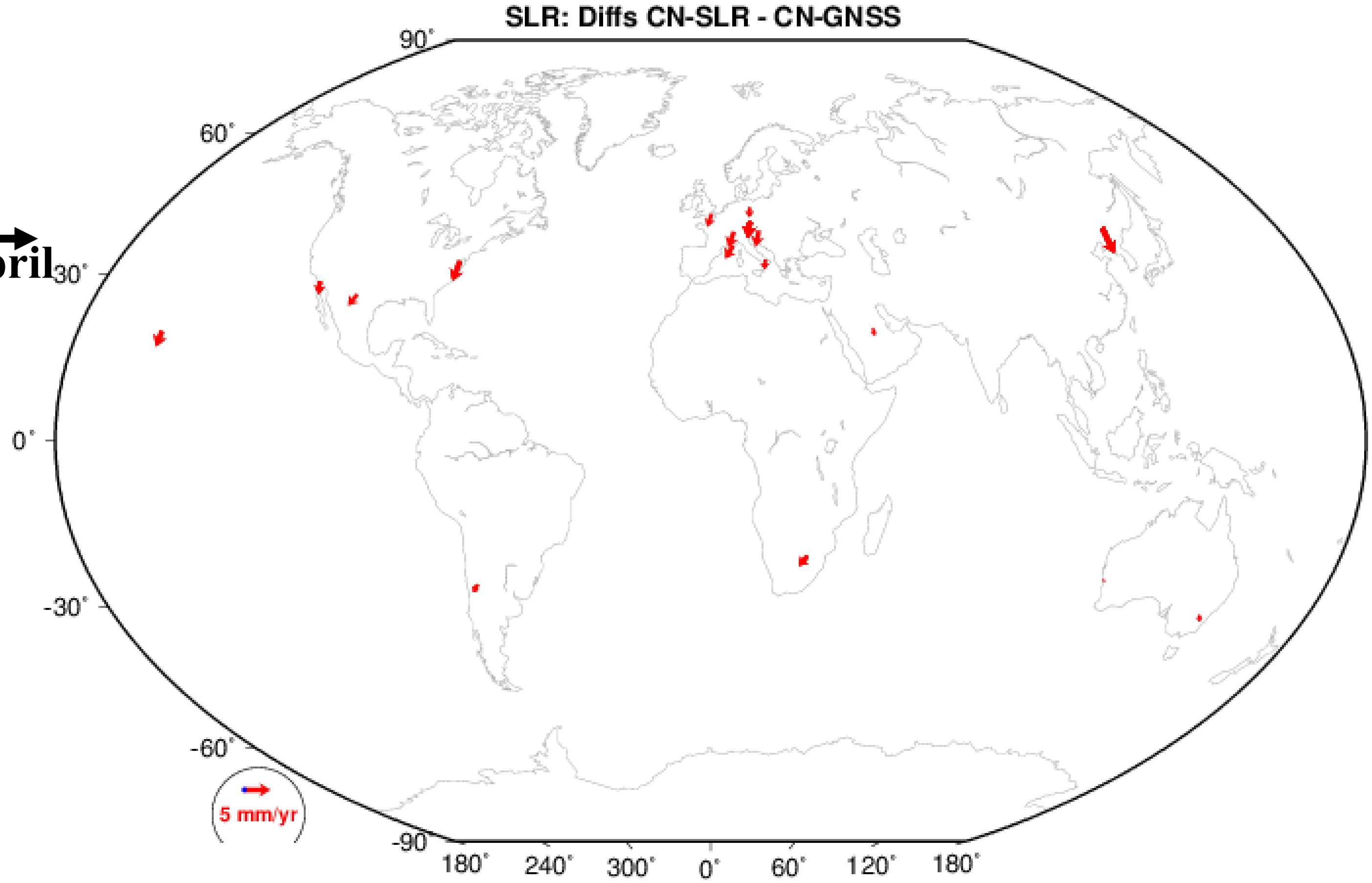


Std scaling factor of the multi-technique seasonal signal combination:

- with GNSS 2 frequencies: $\sigma_0 = 10.22$
- with GNSS 4 frequencies: $\sigma_0 = 10.11$

SLR: Diffs Up annual signals between CN SLR and CN GNSS





$$Dh = A.cos(\, 2\pi f\,(t - t_0) + \phi\,)$$

Estimated annual translations
Approach 1: Multi technique stacking : in CM SLR

Component	Amp X (mm)	Phase X (deg)	Amp Y (mm)	Phase Y (deg)	Amp Z (mm)	Phase Z (deg)
SLR	* ~0	~0	~0	~0	~0	~0
GPS	1.29	135.6	3.29	-152.1	2.64	130.9
VLBI	2.15	125.7	3.24	-162.7	2.76	130.5
DORIS	** 3.37	-179.9	2.28	129.3	2.50	82.5

* Expected

** Not expected: should be ~zero

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Annual Geocenter motion : different estimates

	Amp X (mm)	Phase X (deg)	Amp Y (mm)	Phase Y (deg)	Amp Z (mm)	Phase Z (deg)
Approach 1: Stacking all 4 technique time series						
SLR CN: Uneven Network	2.2	119.8	3.0	-148.4	3.0	155.4
SLR CN: 8 stations	1.6	107.3	3.7	-148.7	2.3	163.4
SLR Via Multi-technique	1.2	114.6	3.8	-156.6	1.9	122.4
Approach 2: Independent combination of seasonal signals						
SLR (GPS draconitic estimated)	1.2	121.0	3.7	-156.2	1.6	127.6
SLR (Multitech Re-weighted)	0.9	118.8	3.5	-157.9	1.8	137.3
SLR (Multitech Re-weighted GPS draconitic estimated)	0.9	120.4	3.6	-157.9	1.8	139.8

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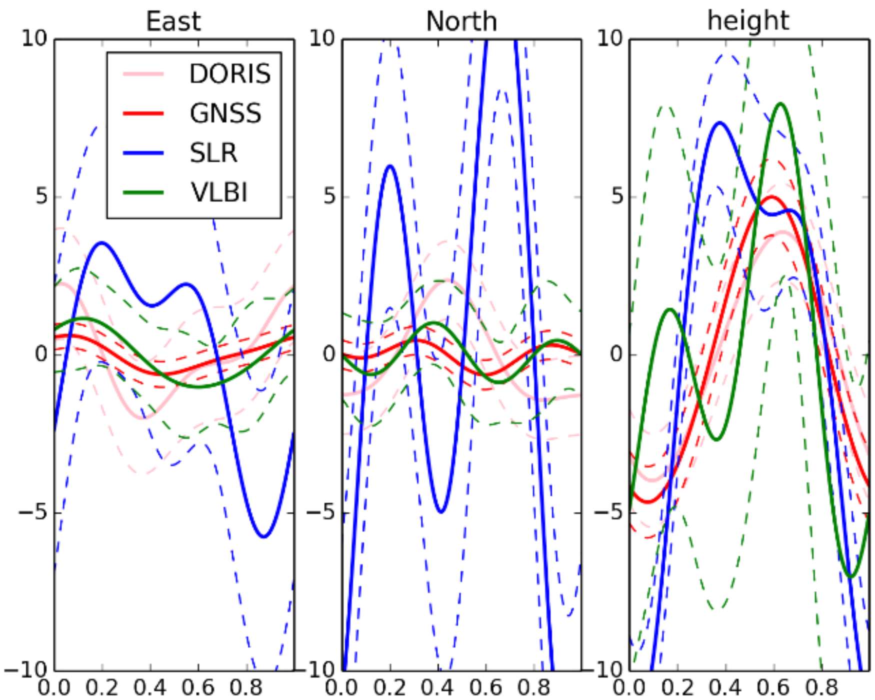
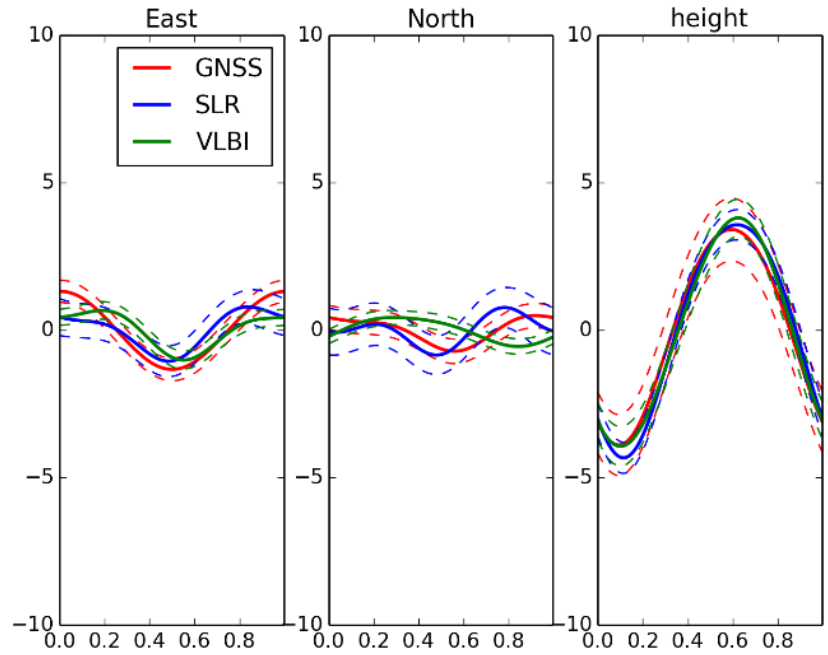
Approach 2: Combination of individual technique signals
Level of agreement at co-location sites

Wettzell



Metsahovi



Conclusion

- **GNSS draconitic signals must be estimated for better estimation of ann. & semi-ann. signals**
- **Amplitude variations of Annual Geocenter motion from SLR (in mm):**
  - **Gx 0.9 – 2.2 ($\delta = \pm 1.3$)**
  - **Gy 3.0 – 3.8 ($\delta = \pm 0.8$)**
  - **Gz 1.6 – 3.0 ($\delta = \pm 1.4$)**
- **Fair agreement between the two approaches**
- **Level of agreement at co-location sites still to be carefully investigated:**
  - **Good agreements for some sites**
  - **Bad for other sites**