ITRF: seasonal station motions and geocenter motion

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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
- **Focus on DORIS results**

Periodic signals: reference frame definition

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

IERS Conventions:

$$\vec{X} = \vec{X}_{ITRF} - \vec{O}_G$$

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

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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

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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:

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

If:

- $X(t)_s$ is SLR time series, then $T(t)$ reflects the geocenter motion as seen by SLR. Same for any satellite technique **in theory**
- $X(t)_s$ is any time series pre-aligned to ITRF, then $T(t)$ is zero.

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

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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)**

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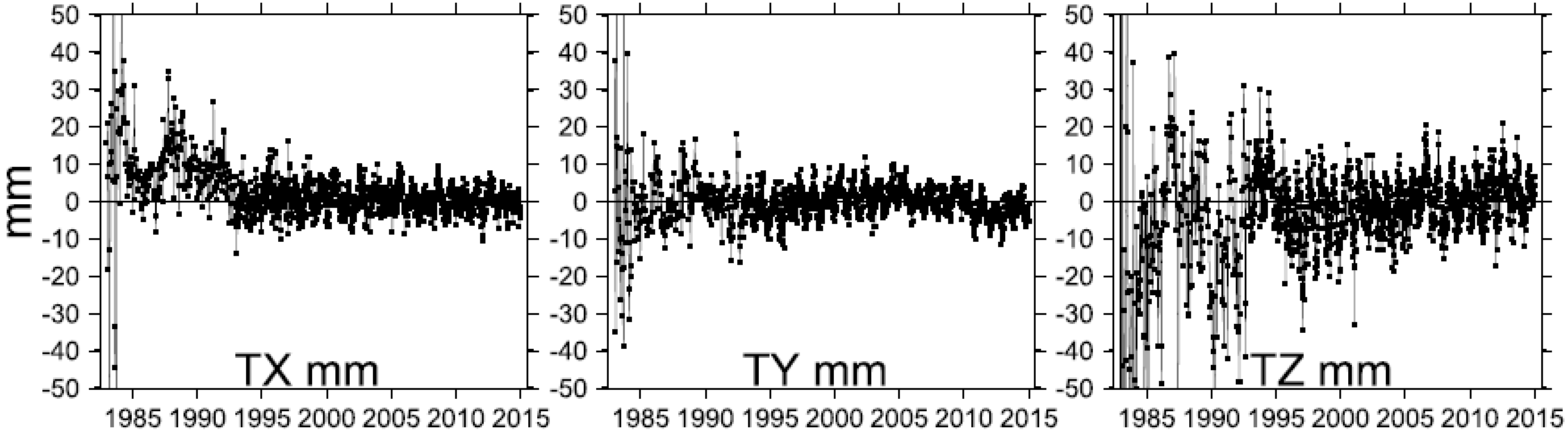
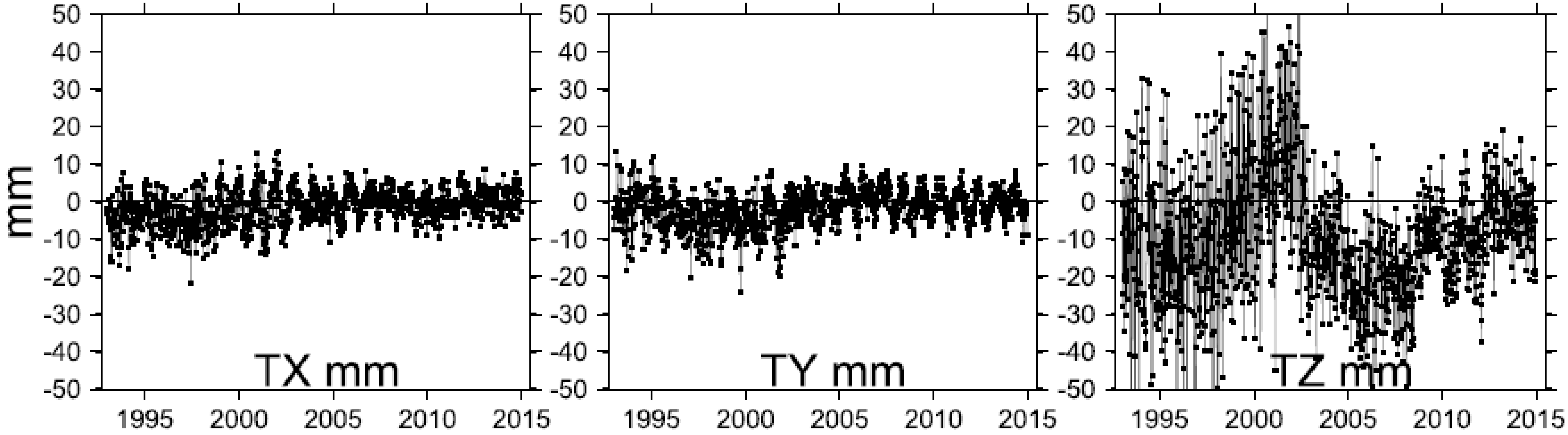
SLR & DORIS Geocenter Components

SLR



DORIS



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Frequencies Considered

- **Annual and semi-annual**

- **First and 2nd draconitics for GPS:**
  - **351.5 & 175.75 days**

- **Draconitics for DORIS:**
  - **117.3 days for Topex and Jason**

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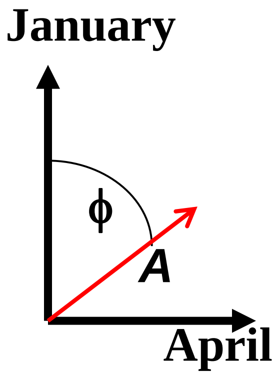
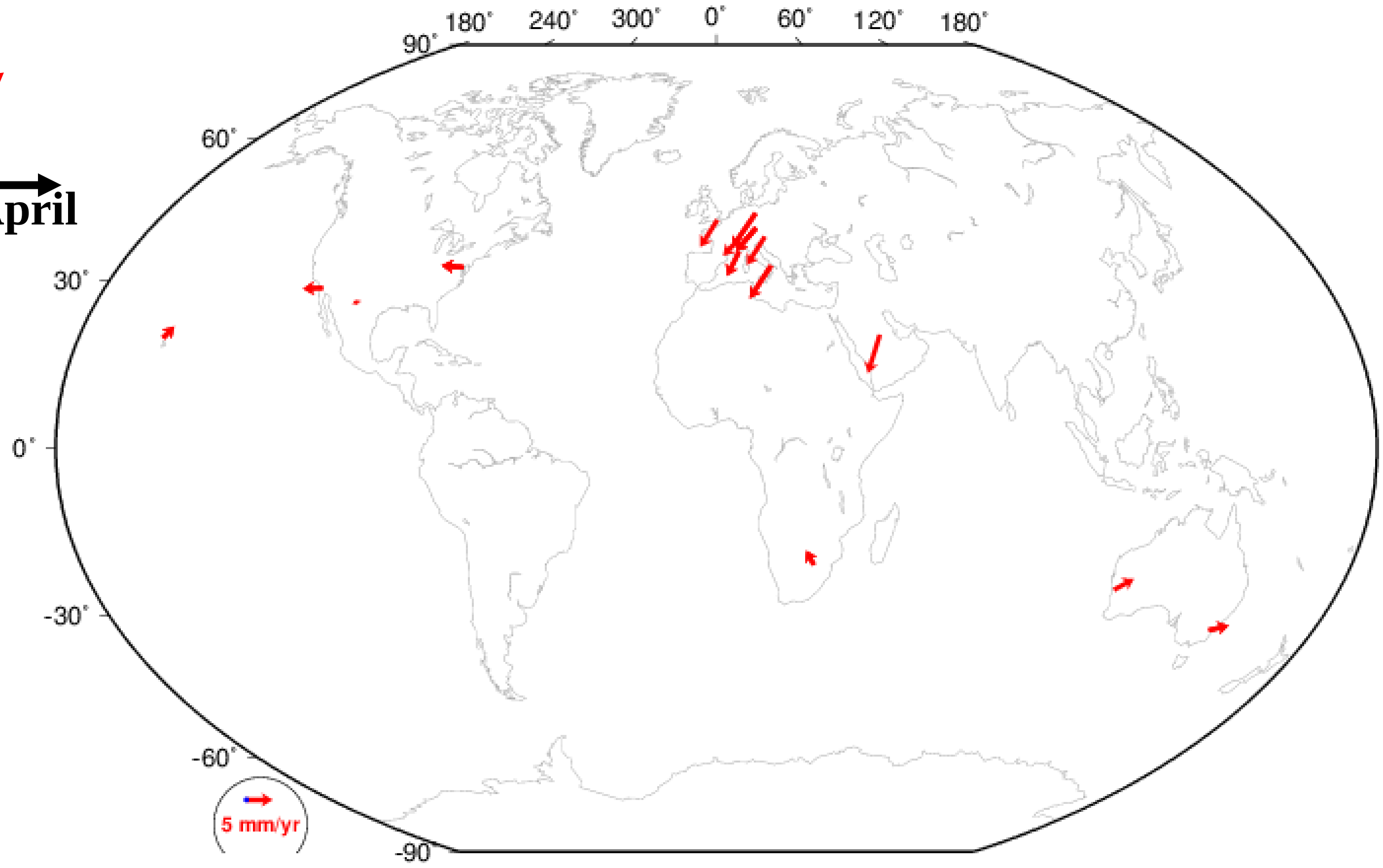
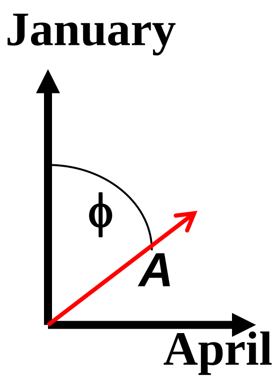
SLR Up annual signals : CM Frame

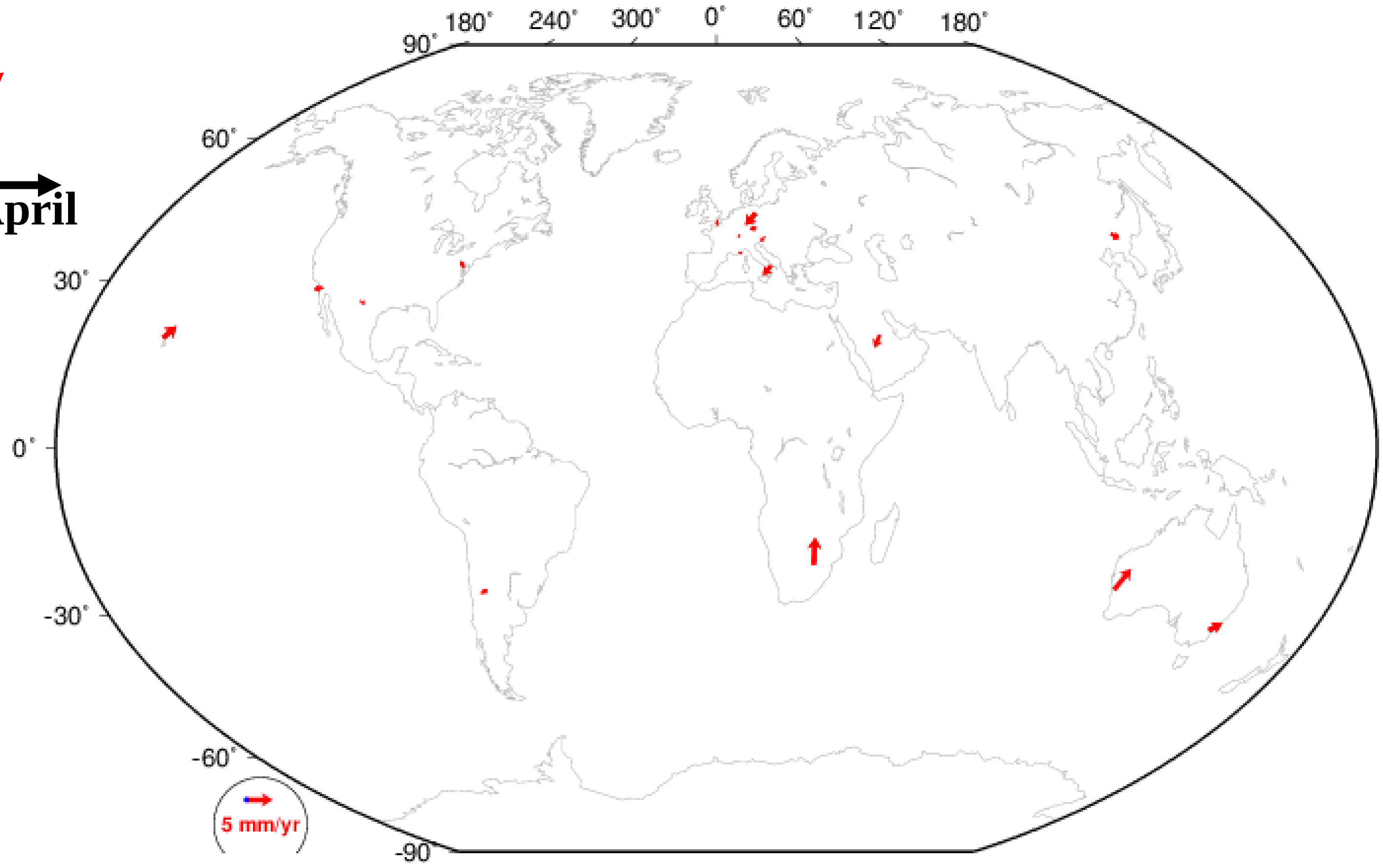




$$Dh = A.cos(\,2\pi f\,(t - t_0) + \phi\,)$$

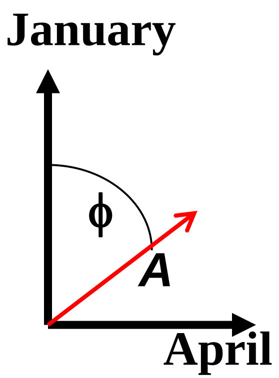
SLR Up annual signals : CN Frame

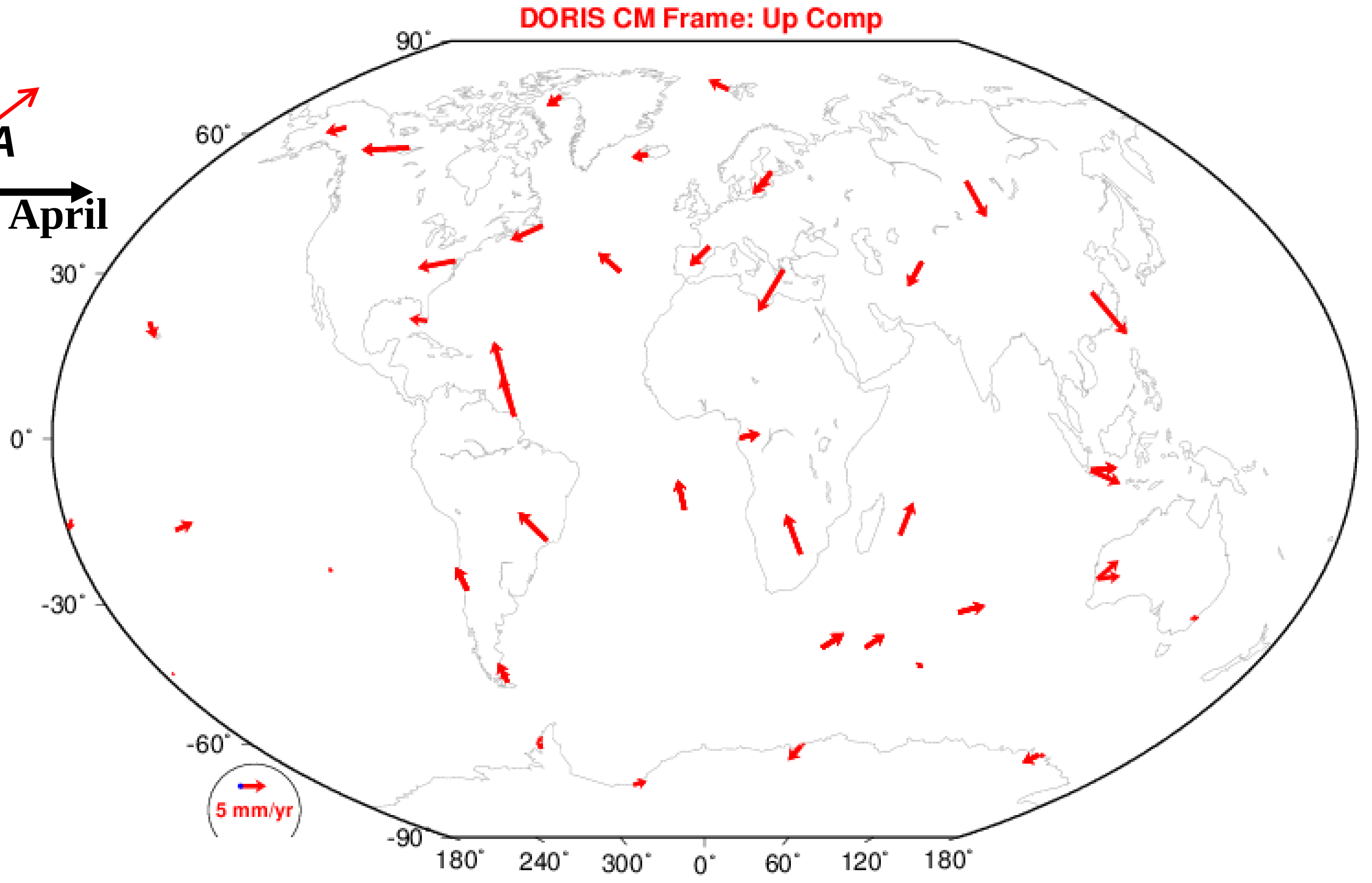




$$Dh = A.cos(2\pi f\,(t - t_0) + \phi)$$

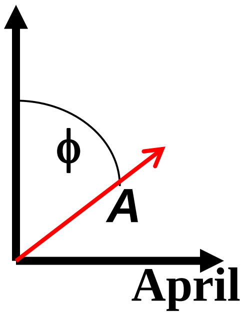
DORIS Up annual signals : CM Frame

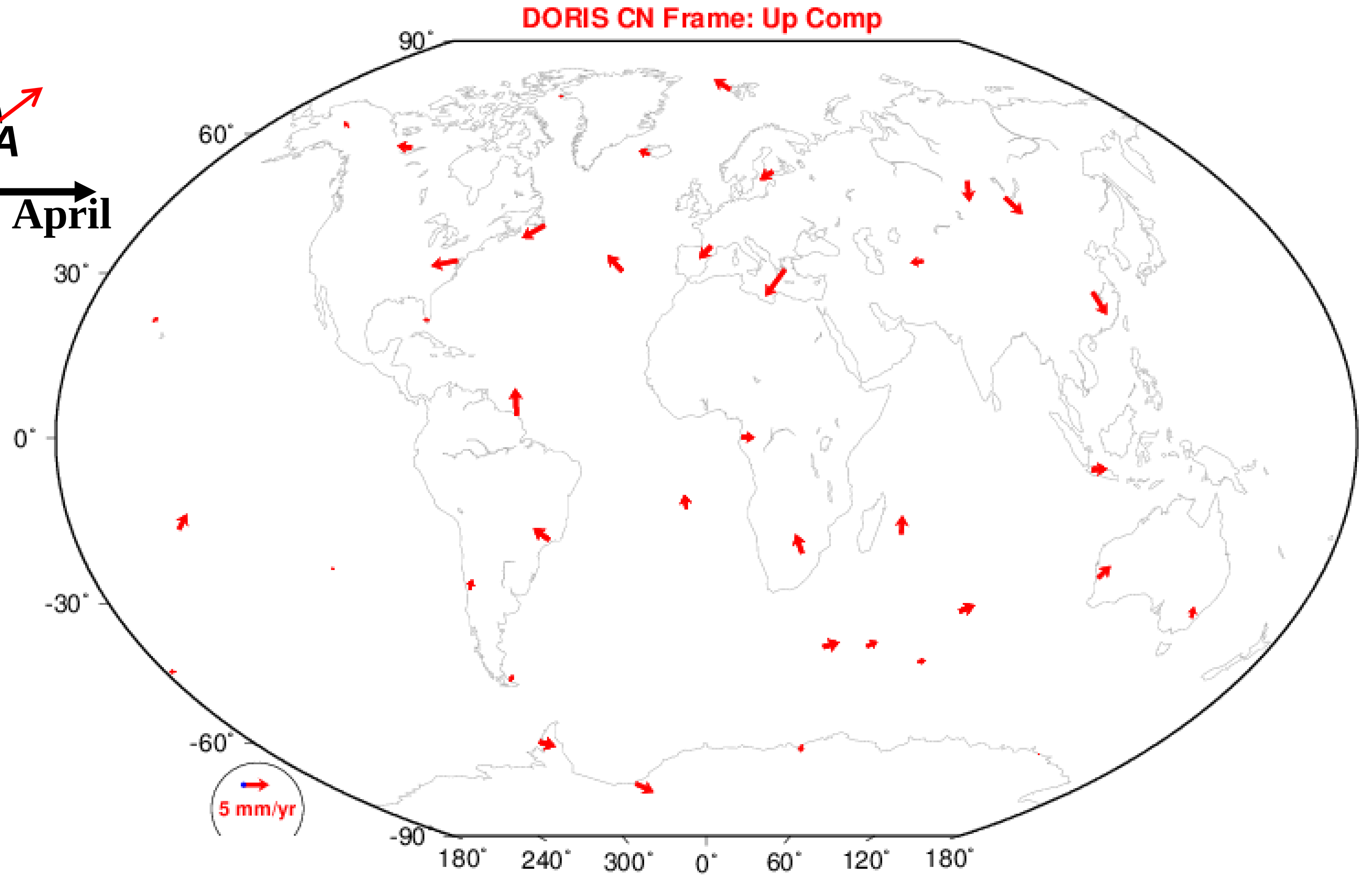




$$Dh = A.cos(2\pi f \, (t - t_0) + \phi)$$

DORIS Up annual signals : CN Frame





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

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DORIS Annual Geocenter Motion

	Amp X (mm)	Phase X (deg)	Amp Y (mm)	Phase Y (deg)	Amp Z (mm)	Phase Z (deg)
CM: 3F *	0.9	340.7	0.4	22.1	1.1	190.0
CM: 2F *	0.9	341.7	0.4	19.5	1.3	188.3

*** Should be ~zero**

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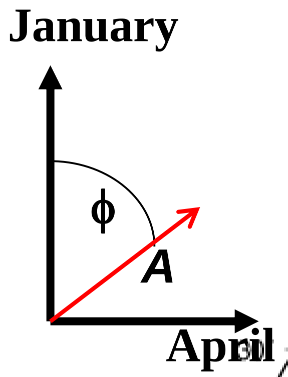
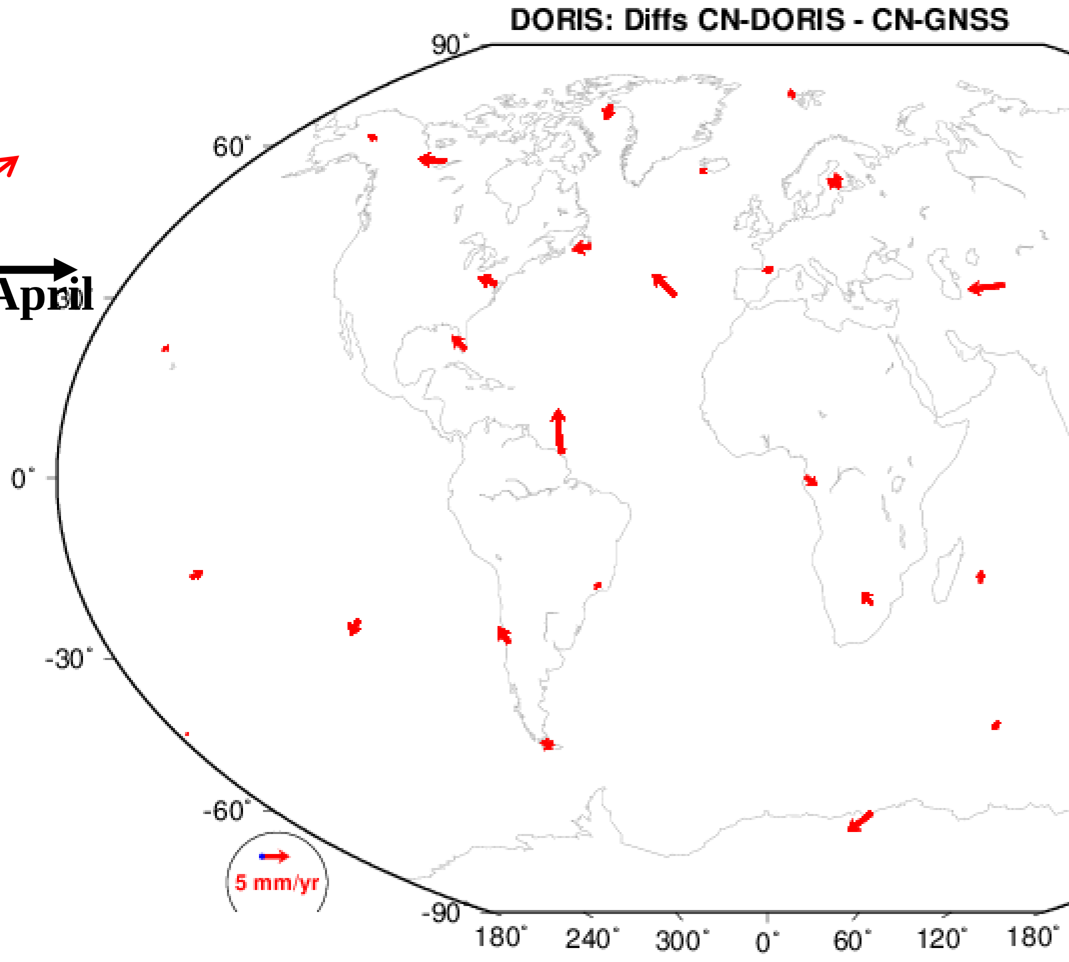
SLR vs DORIS Annual Geocenter

	Amp X (mm)	Phase X (deg)	Amp Y (mm)	Phase Y (deg)	Amp Z (mm)	Phase Z (deg)
SLR CN: Uneven Network	2.1	63.7	3.1	329.1	3.1	22.7
SLR CN: 8 stations	1.7	60.7	3.6	325.0	2.2	28.7
SLR Via Multi-technique	1.1	55.7	3.7	356.8	2.3	51.1(*)
DORIS CN: 3F	2.3	167.5	3.0	312.1	2.3	343.1
DORIS CN: 2F	2.3	167.7	3.0	309.3	2.3	344.8
DORIS Via Multi-technique	2.9	163.1	3.6	303.6	1.4	335.2(*)

(*) Using data from 1993.0 on

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

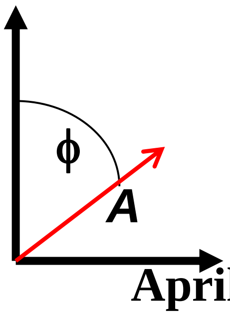


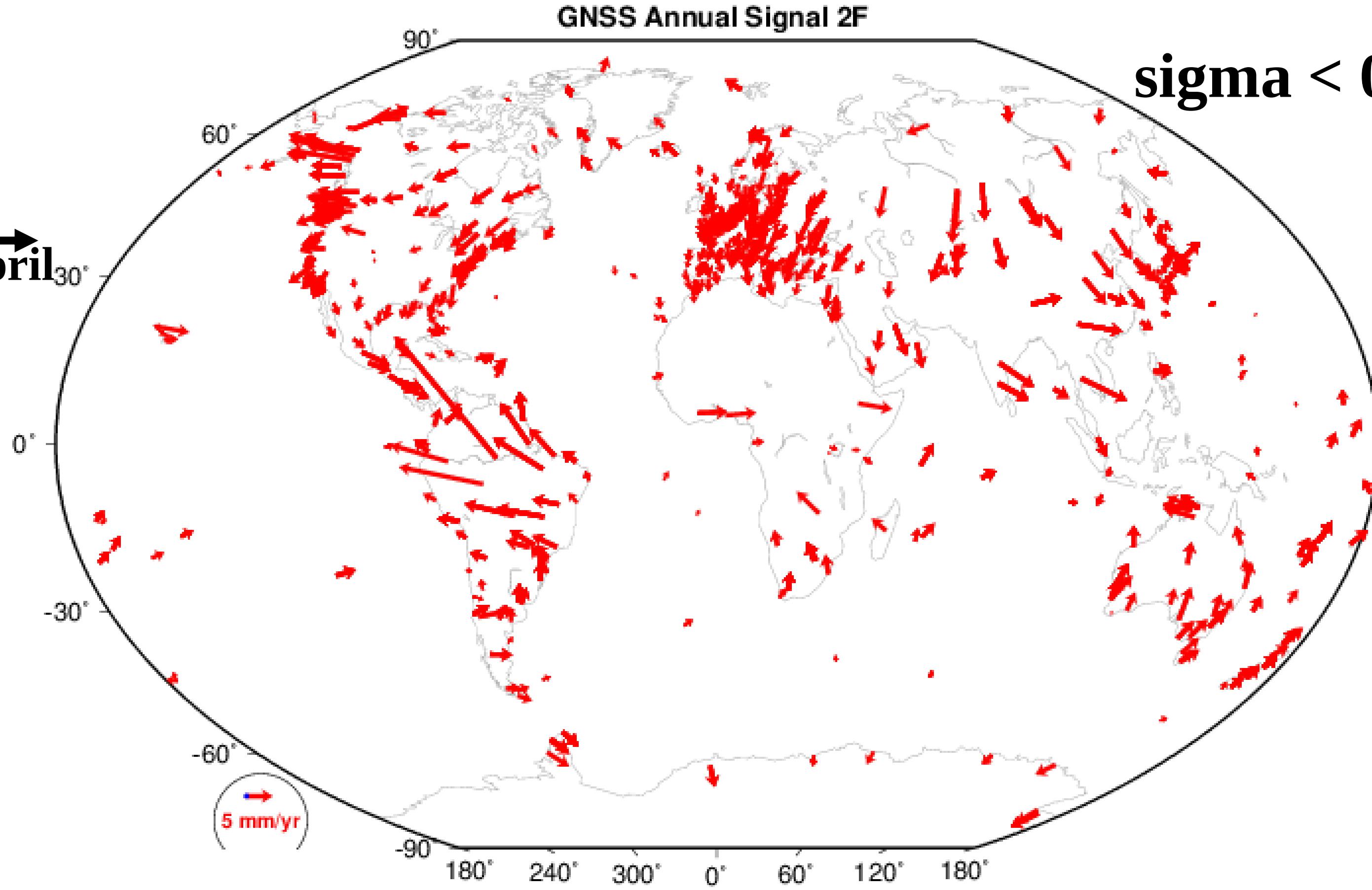


$$Dh = A.cos(2\pi f\ (t - t_0) + \phi)$$

Up annual signals : GNSS CN

2 Frequencies estimated (Ann + Semi-Ann)



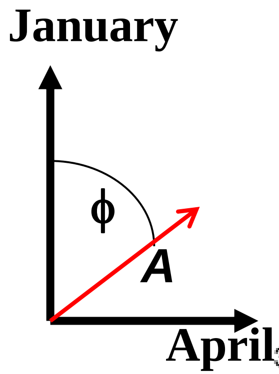


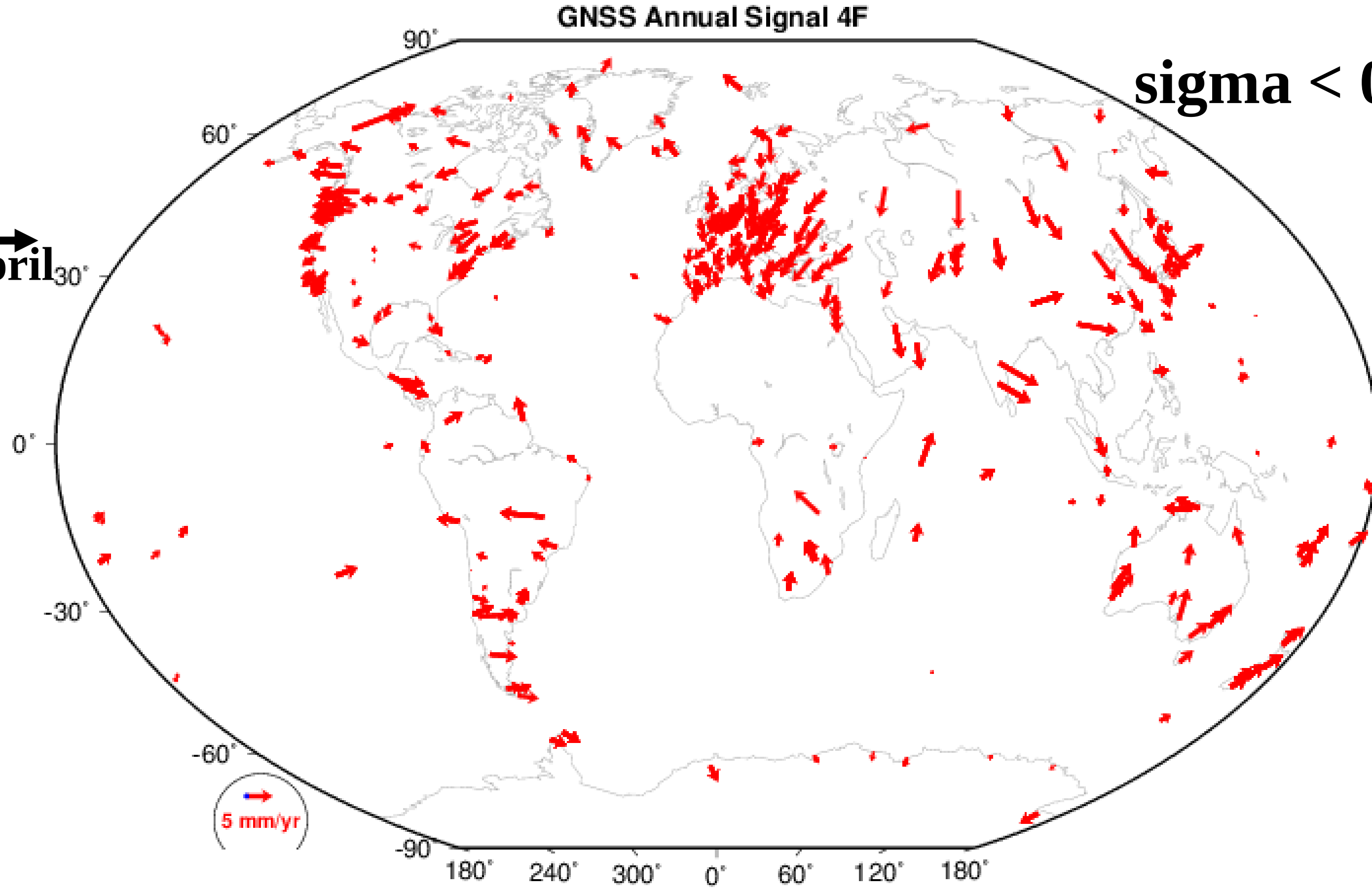
sigma < 0.1 mm

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

Up annual signals : GNSS CN

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





sigma < 0.1 mm

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

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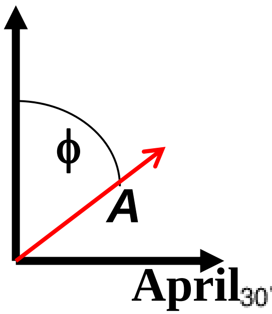
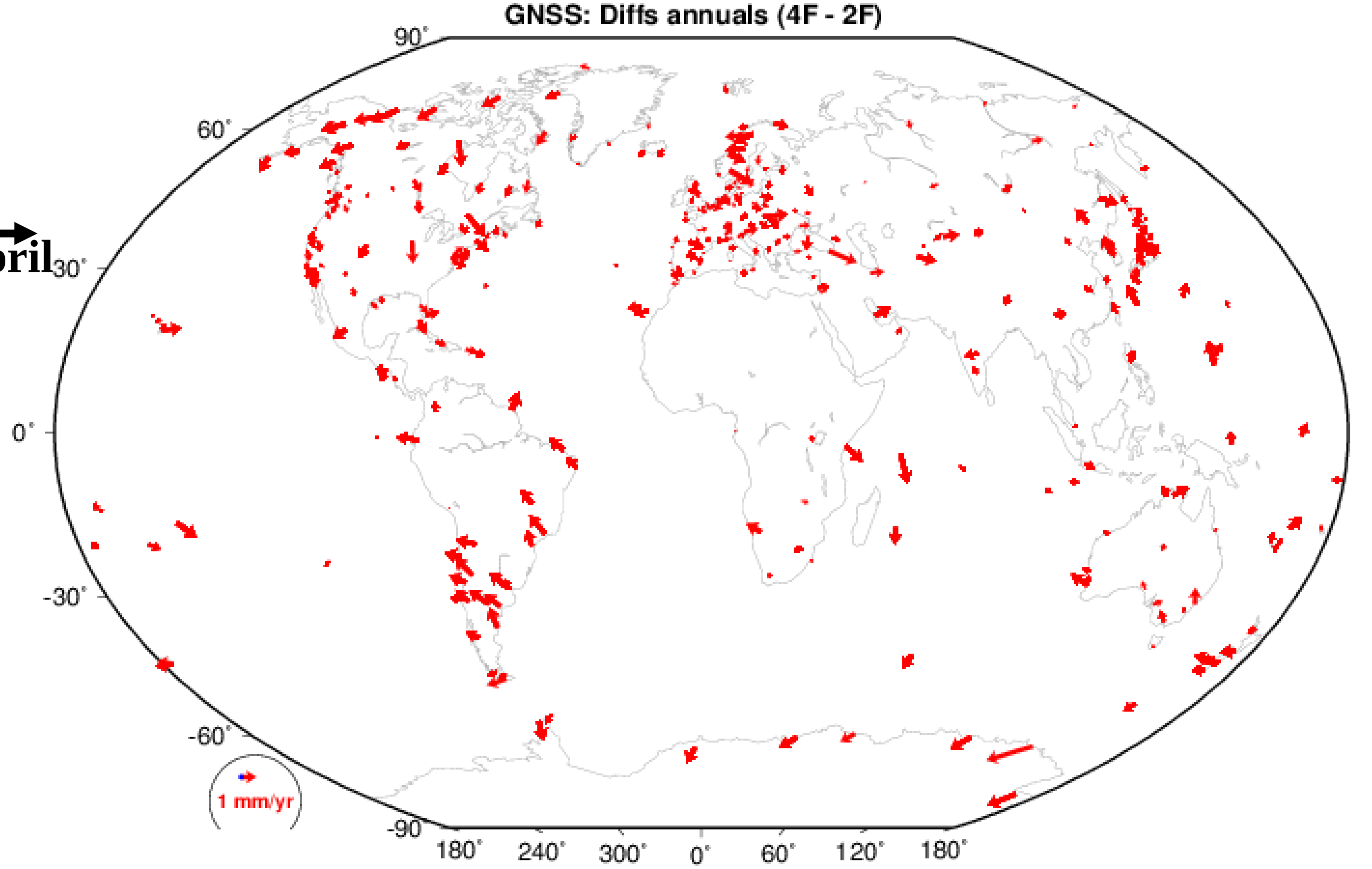
Diffs Up annual signals : GNSS CN

4 frequencies - 2 frequencies

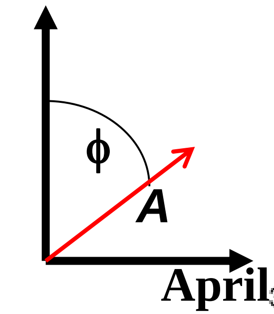


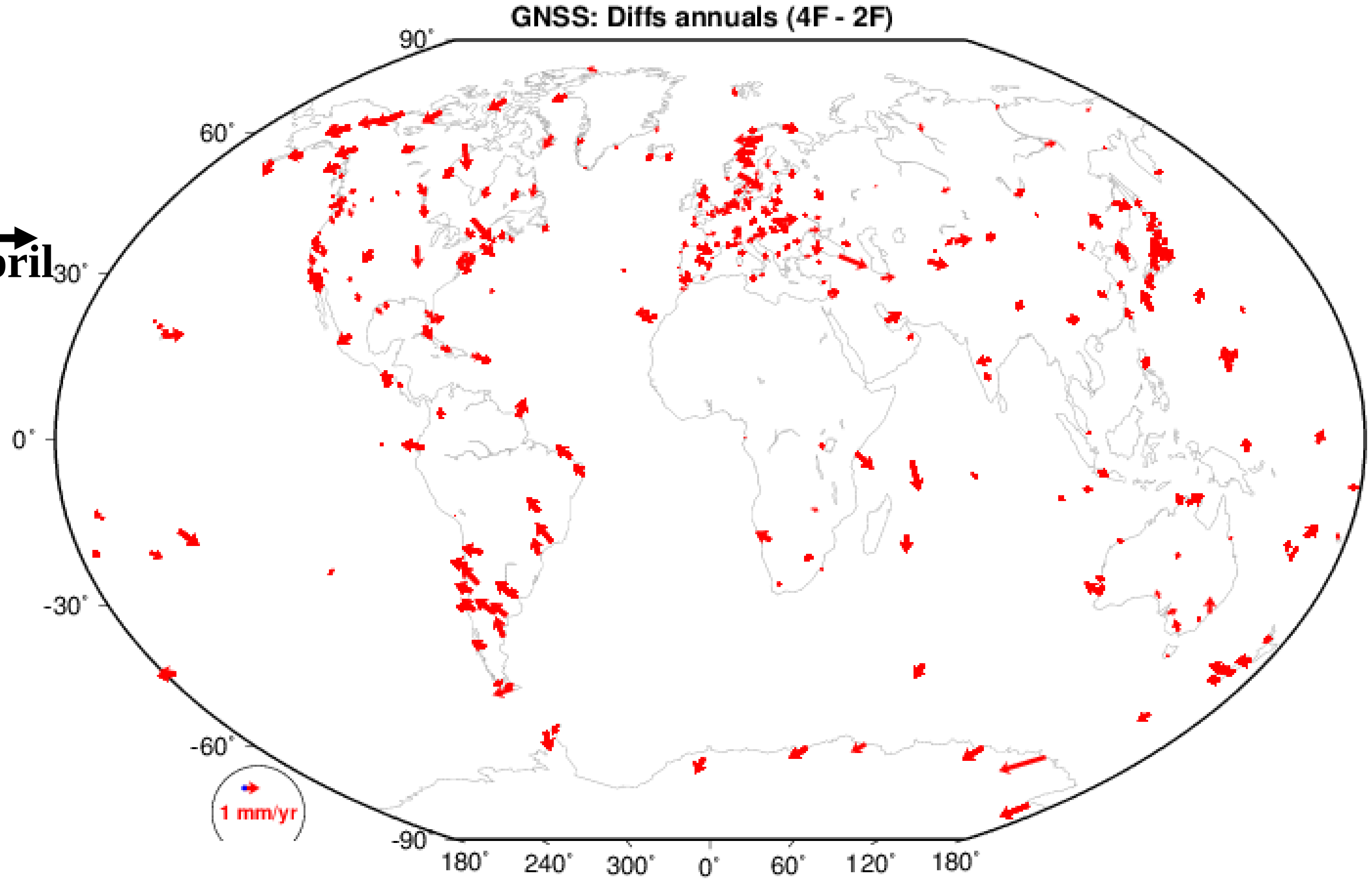


$$Dh = A.\cos(\, 2\pi f \,(t - t_0) + \phi\,)$$

Diffs Up annual signals : GNSS CN

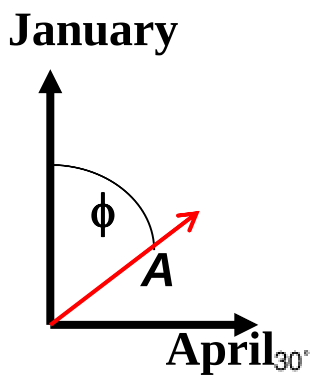
4 frequencies - 2 frequencies

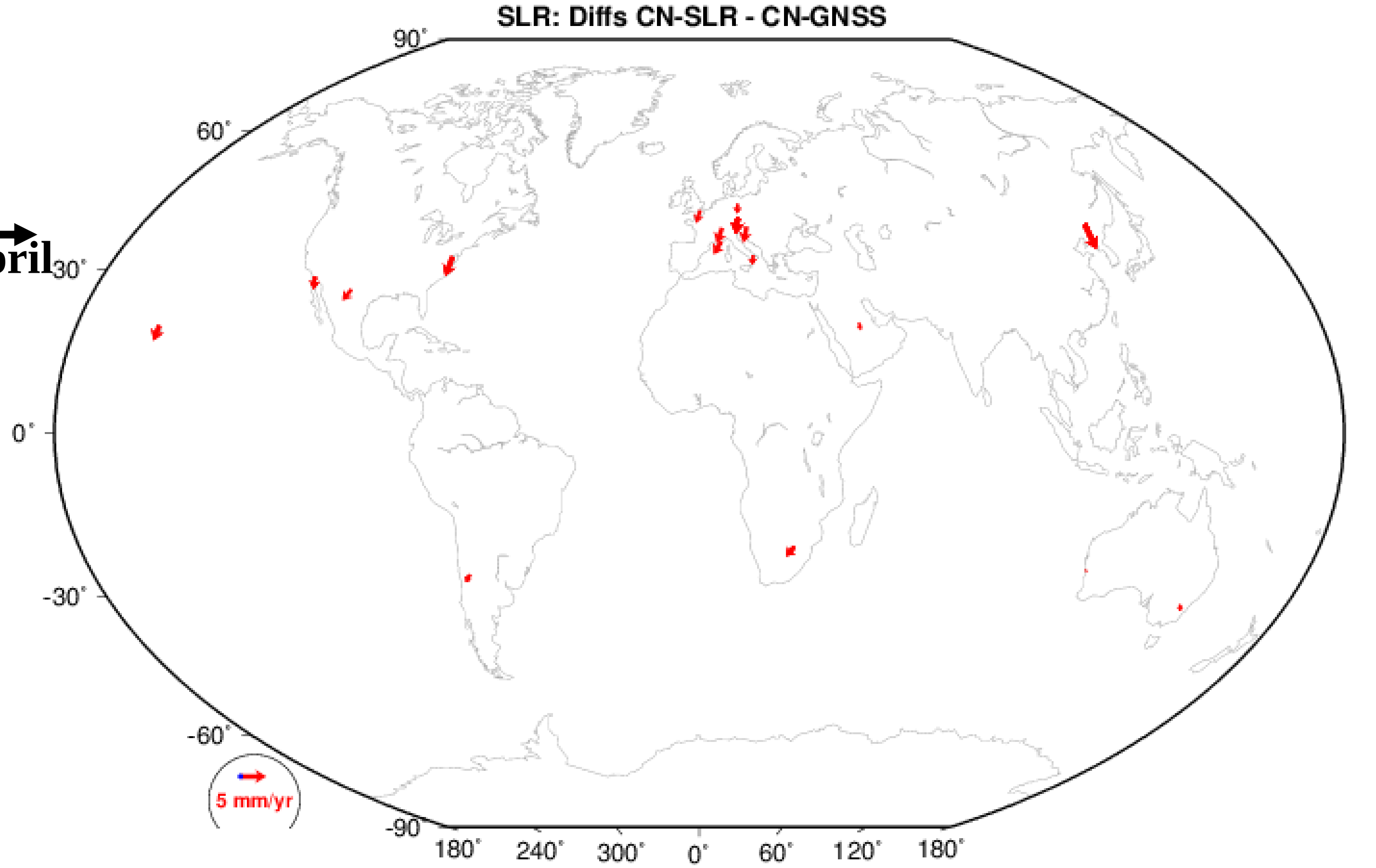




$$Dh = A.cos(\ 2\pi f\ (t - t_0) + \phi\ )$$

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	1.45	48.0	3.25	335.1	2.00	47.7
VLBI	1.65	53.7	3.07	327.1	2.87	55.8
DORIS	** 3.30	1.2	2.43	49.6	2.01	104.7

* Expected

** Not expected: should be ~zero

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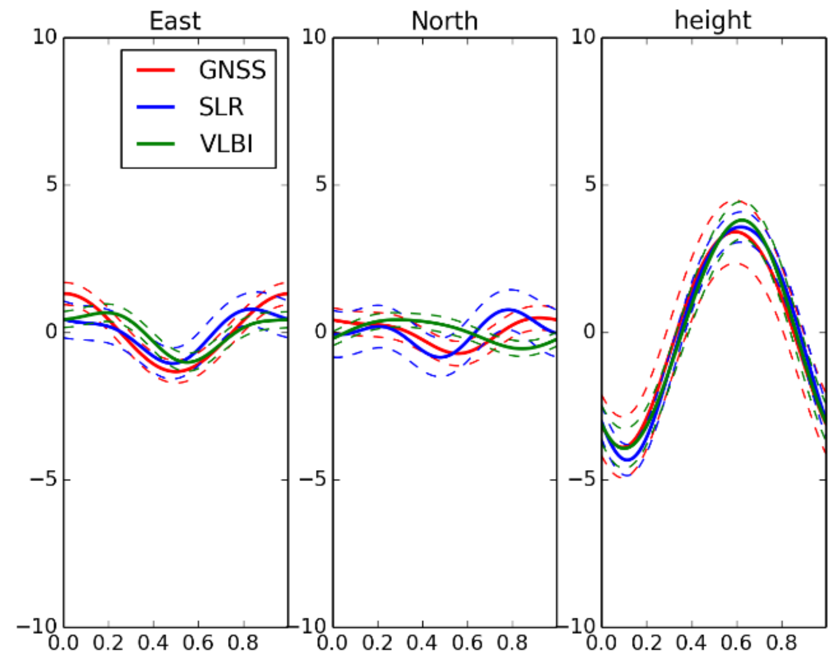
SLR Annual Geocenter motion : different estimates

	Amp X (mm)	Phase X (deg)	Amp Y (mm)	Phase Y (deg)	Amp Z (mm)	Phase Z (deg)
SLR CN: Uneven Network	2.1	63.7	3.1	329.1	3.1	22.7
SLR CN: 8 stations	1.7	60.7	3.6	325.0	2.2	28.7
SLR Via Multi-technique	1.1	55.7	3.7	356.8	2.3	51.1(*)

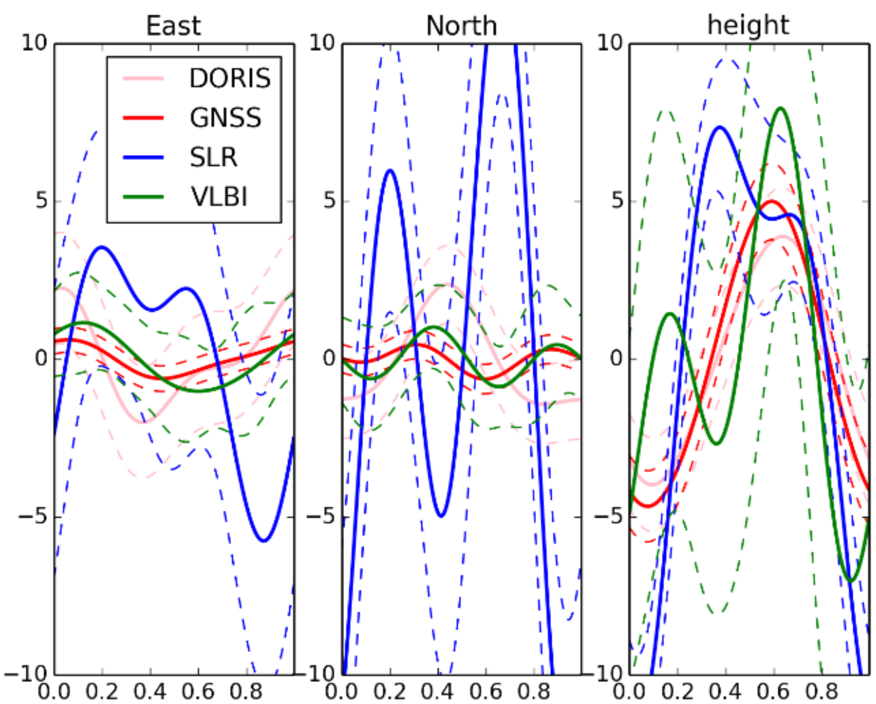
Approach 2: Independent combination of seasonal signals

SLR (GPS draconitic estimated)	1.2	59.0	3.7	336.2	1.6	52,4
SLR (Multitech Re-weighted)	0.9	61.2	3.5	337.9	1.8	42.7
SLR (Multitech Re-weighted GPS draconitic estimated)	0.9	59.6	3.6	337.9	1.8	40.2

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



Wettzell



Metsahovi

Conclusion

- **DORIS Geocenter Motion is not reliable, except maybe in the Y component**
- **GNSS draconitic signals must be estimated**
- **Amplitude variations of Annual Geocenter motion from SLR (in mm):**
  - **Gx 0.9 – 2.2 (δ = ±1.3)**
  - **Gy 3.0 – 3.8 (δ = ±0.8)**
  - **Gz 1.6 – 3.0 (δ = ±1.4)**
- **Level of agreement at co-location sites still to be carefully investigated**