DGFI Combination Methodology for Terrestrial Reference Frame Computations

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SIRGAS

GGOS-D
http://www.ggos-d.de

Outline

- Global terrestrial reference frame computations
  - Input data
  - Combination strategy
  - Analysis and accumulation of observation time series
  - Combination of different techniques
- Regional reference frame computations
  - Geodetic reference frame for the Americas (SIRGAS)
  - SIRGAS realizations
  - Latest multi-year solution: DGF08P01-SIR
  - Velocity field for SIRGAS and transformation between realizations
  - Future developments of SIRGAS
- Conclusions

Input data sets for global TRF computations (1/2)

ITRF2005: Time series of station positions and EOP

Techn.	Service / AC	Data	Time Period
GPS	IGS / NRCan	weekly solutions	1996 - 2005
VLBI	IVS / IGG	24 h session NEQ	1984 - 2005
SLR	ILRS / ASI	weekly solutions	1993 - 2005
DORIS	IGN - JPL/LCA	weekly solutions	1993 - 2005

ITRF2005 data sets are not fully consistent, the standards and models were not completely unified among analysis centers

Shortcomings concerning GPS:

- IGS solutions are not reprocessed (e.g., model and software changes)
- Relative antenna phase center corrections were applied

Input data sets for global TRF computations (2/2)

GGOS-D: Time series of station positions and EOP

Techn.	Institutions	Data	Time Period
GPS	GFZ	daily NEQ	1994 - 2007
VLBI	IGG / DGFI	24 h session NEQ	1984 - 2007
SLR	DGFI / GFZ	weekly NEQ	1993 - 2007

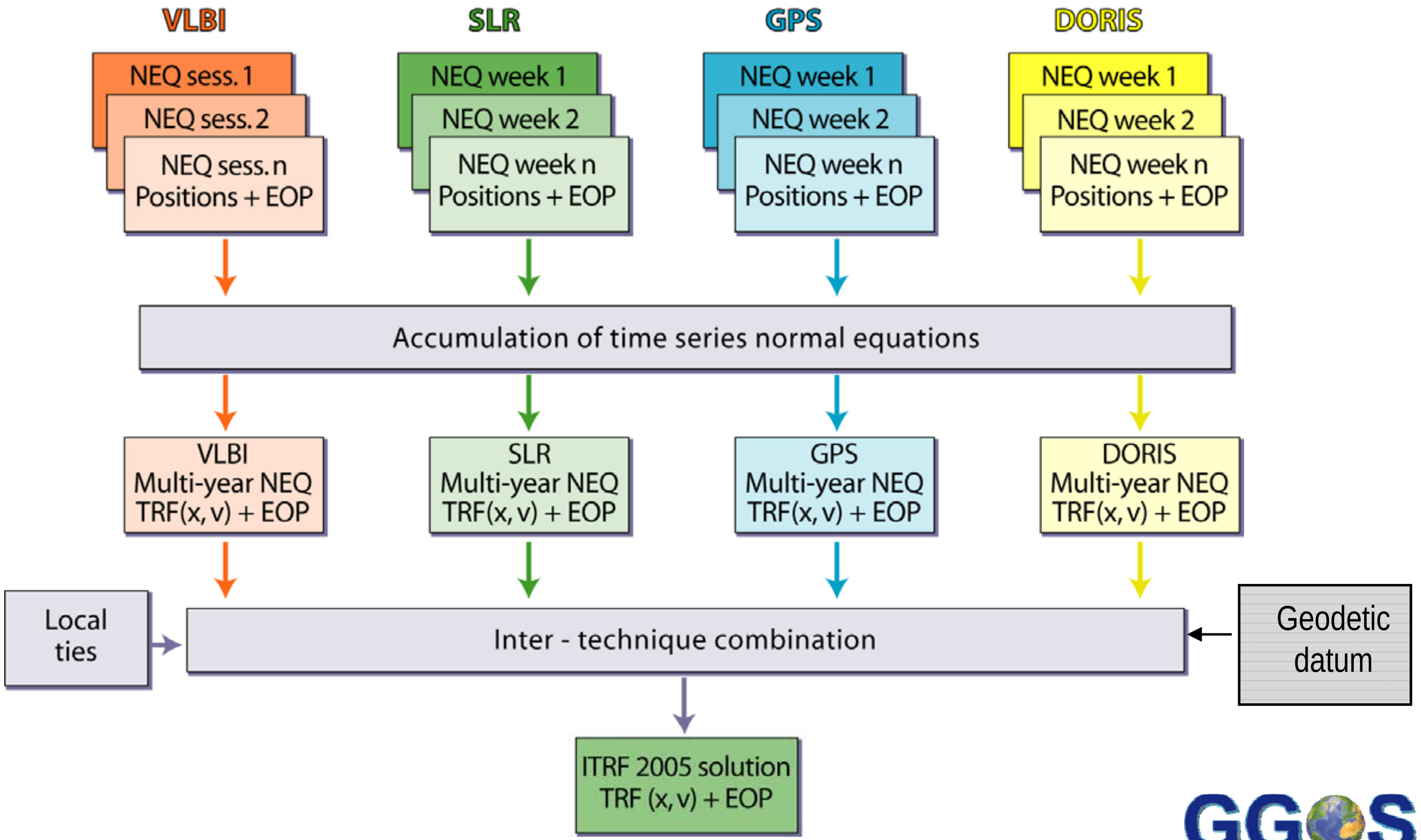
Improvements of GGOS-D data compared to ITRF2005:

- Homogeneously processed data sets
  - Identical standards, conventions, models, parameters
  - GPS: PDR (Steigenberger et al. 2006, Rülke et al. 2008)
- Improved modelling
  - for GPS: **absolute** instead of relative **phase centre** corr.
  - for VLBI: **pole tide model** was changed

GGOS-D: German project of BKG, DGFI, GFZ and IGG funded by BMBF

ITRS Combination Center at DGFI

- General concept: Combination on the normal equation level
- Software: DGFI Orbit and Geodetic Parameter Estimation Software (DOGS)



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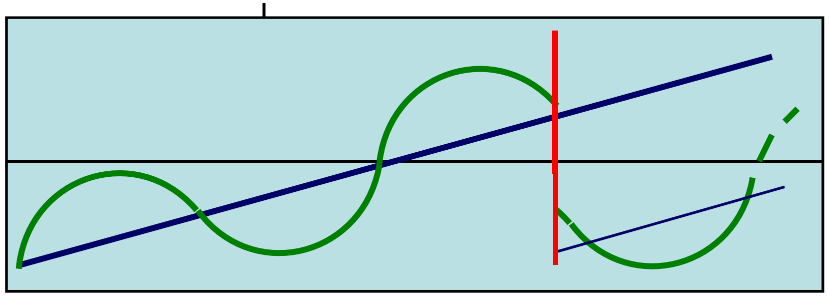
TRF computation per technique (1/6)

Analysis of station coordinate time series and computation of a reference frame per technique

Modelling time dependent station coordinates by

- epoch positions
- linear velocities
- seasonal signals
- discontinuities



Example: Number of discontinuities that were introduced for the accumulation of the GPS time series:

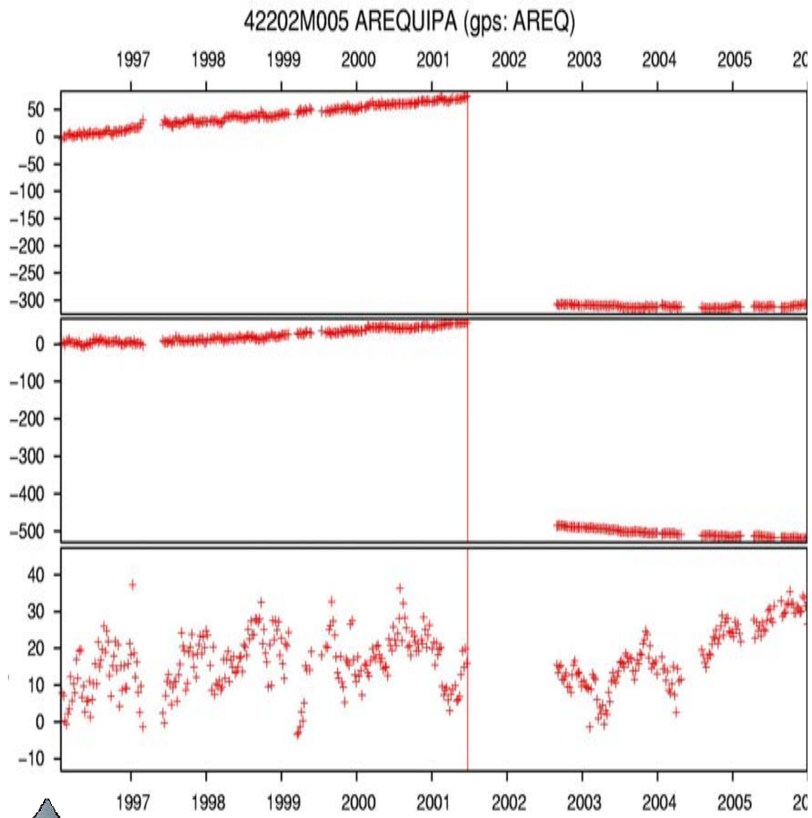
✓ ITRF2005: 221 discontinuities in 332 GPS stations (1996 - 2005)

✓ GGOS-D: 95 discontinuities in 240 GPS stations (1994 - 2007)

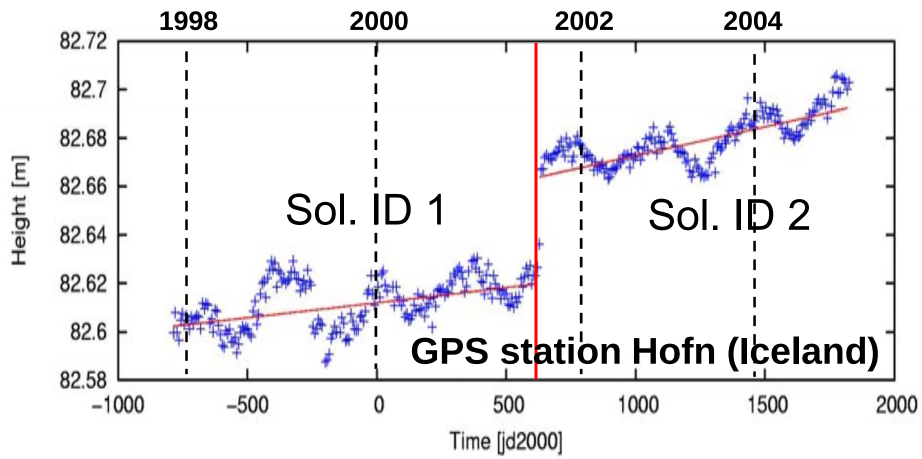
TRF computation per technique (2/6)

Discontinuities and the equating of station velocities ?

Earthquakes



Instrumentation changes



Solution ID	Velocities [mm/yr]
Sol. ID 1 Sol. ID 2	4.5 ± 0.9 8.7 ± 0.7
Δ (2 – 1)	4.2 ± 1.2

TRF computation per technique (3/6)

Effect of annual signals ?

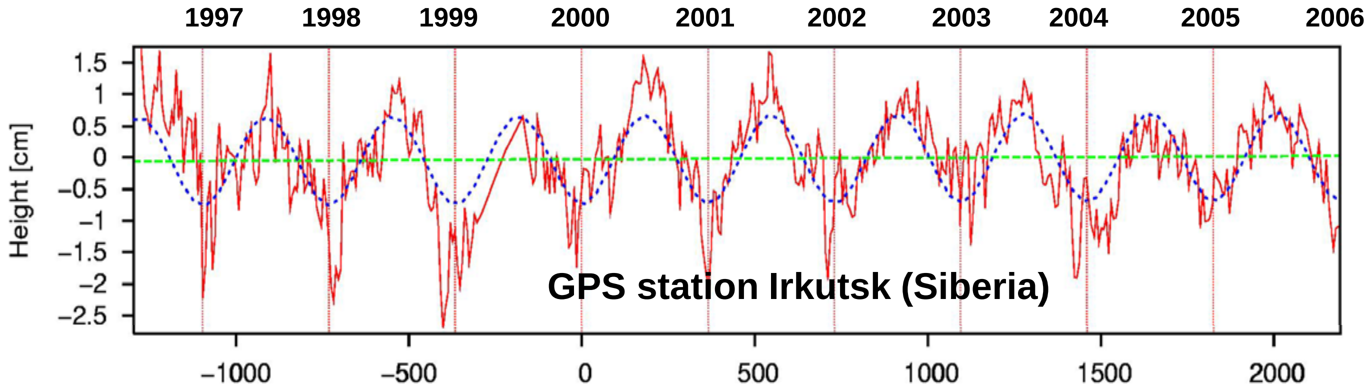


Table: Velocity differences w.r.t. the multi-year solution

obs time span [yrs]	0.5	1.0	2.0	3.0
Δ velocities [mm/yr]	-37.5 ± 3.2	-3.7 ± 2.3	2.7 ± 0.8	-0.3 ± 0.5

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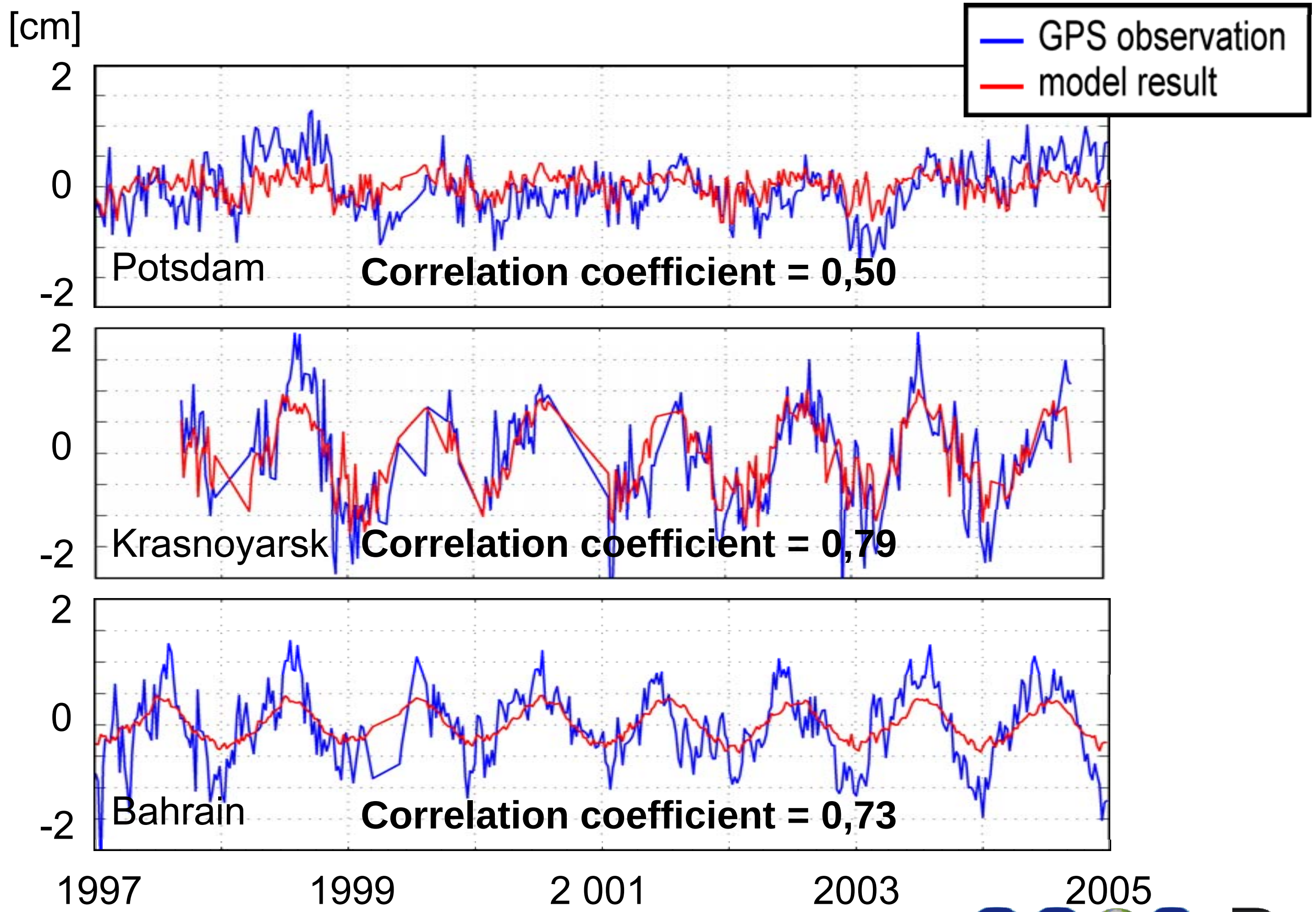
TRF computation per technique (4/6)

Seasonal signals - Comparison with geophysical data

Models consider **atmospheric, oceanic** and **hydrologic** mass loads:

NCEP, ECCO, GLDAS



TRF computation per technique (5/6)

Estimating annual signals in addition to linear velocities ?

Advantages of estimating annual signals:

- ✓ Better representation of „real“ station motions (e.g., loading effects)
- ✓ Improved estimation of velocities
- ✓ Better alignment of epoch solutions to the reference frame

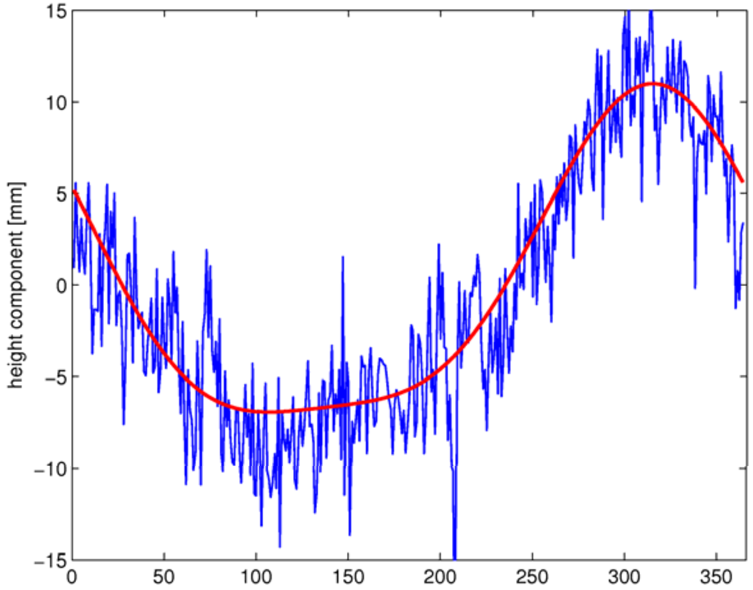
Disadvantages and open questions:

- ✓ More parameters are needed (stability) ?
- ✓ Are seasonal signals geophysically meaningful ?
- ✓ How to parameterize seasonal signals ?

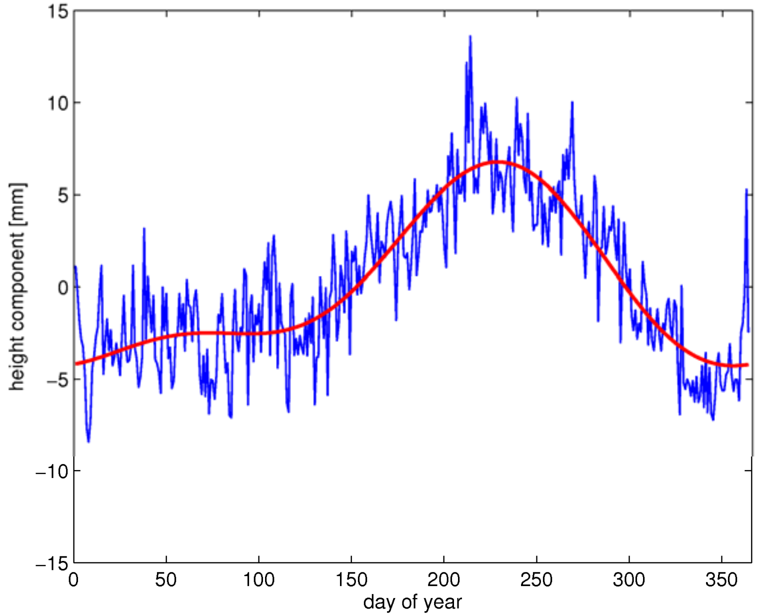
TRF computation per technique (6/6)

How is the shape of the “averaged” seasonal signal ?

Brasilia



Ankara



Shape of seasonal signals can be mathematically approximated by sine/cosine annual and semi-annual functions

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Computation of the TRF (1/4)

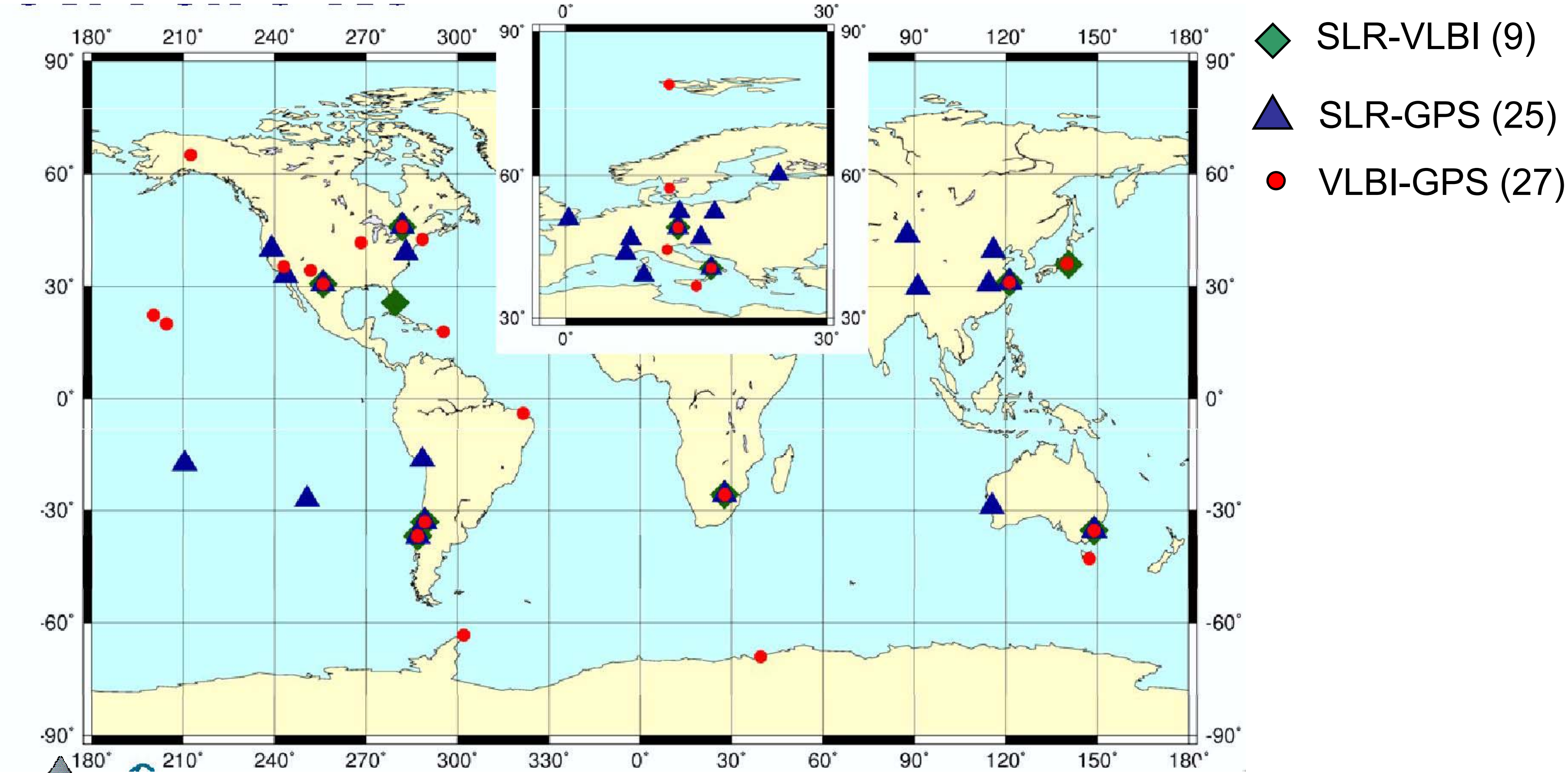
The combination of different techniques is done by:

- ✓ Relative weighting between techniques
- ✓ Selection of terrestrial difference vectors (local ties)
- ✓ Combination of the technique-specific NEQ's
  (without estimating similarity transformations)
- ✓ Realization of the geodetic datum

Datum parameters	ITRF2005D (DGFI Solution)	GGOS-D
Origin	SLR	SLR
Scale	SLR + VLBI	SLR + VLBI + GPS
Orientation	NNR conditions w.r.t. ITRF2000	NNR conditions w.r.t. ITRF2005
Orientation time evolution	NNR conditions w.r.t. horizontal motions by using the Actual Plate Kinematic and Deformation Model (APKIM)	

Computation of the TRF (2/4)

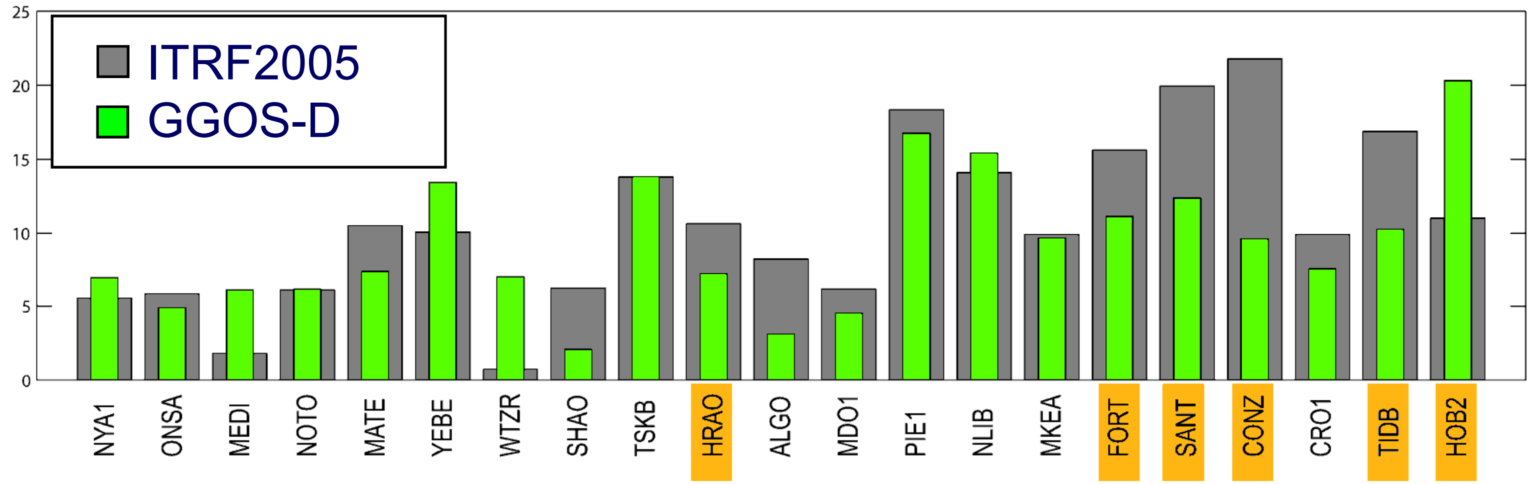
Selection of local ties at co-location sites



Computation of the TRF (3/4)

Selection of terrestrial difference vectors (1)

Three-dimensional differences between space geodetic solutions (GPS and VLBI) and terrestrial difference vectors [mm]



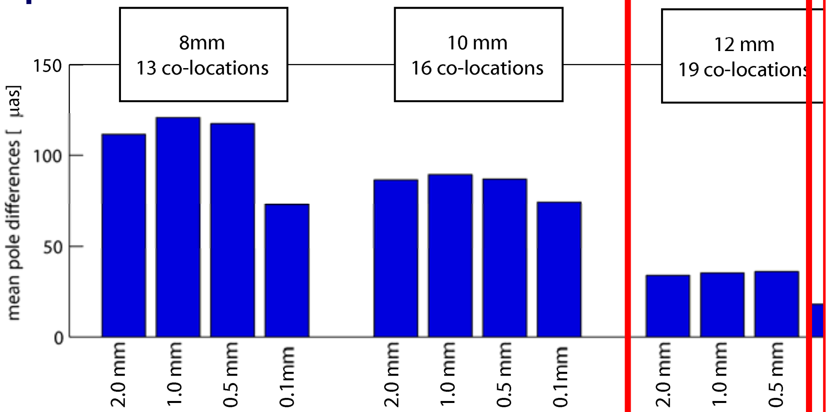
= stations in southern hemisphere

Krügel et al. 2007: Poster presented at AGU Fall Meeting 2007

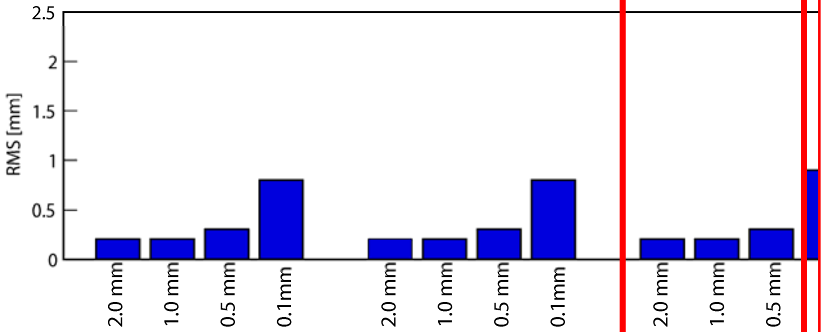
Computation of the TRF (4/4)

Selection of terrestrial difference vectors (2)

Mean pole difference



Network deformation



Mean pole difference:
35 µas (≈1 mm)

Network deformation:
≤ 0.3 mm

Number of
co-locations: 19

<u>ITRF2005:</u>

Pole difference: 41 µas

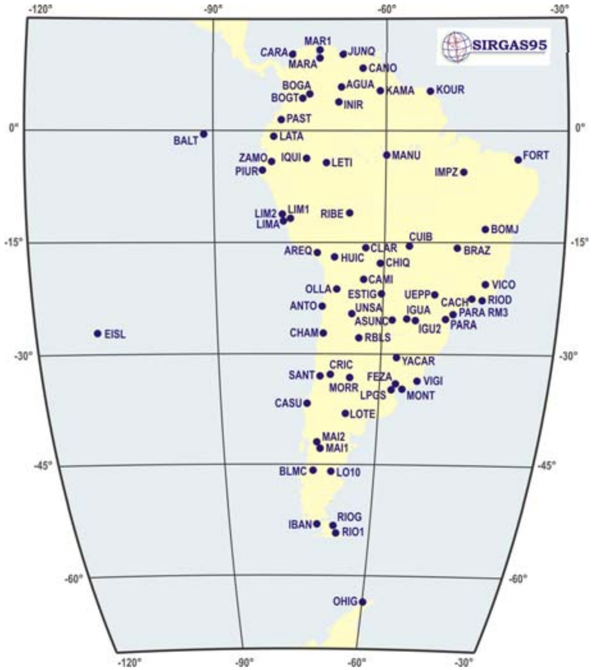
Deformation: 1.0 mm

No. co-locations: 13

SIRGAS realizations (1/2)

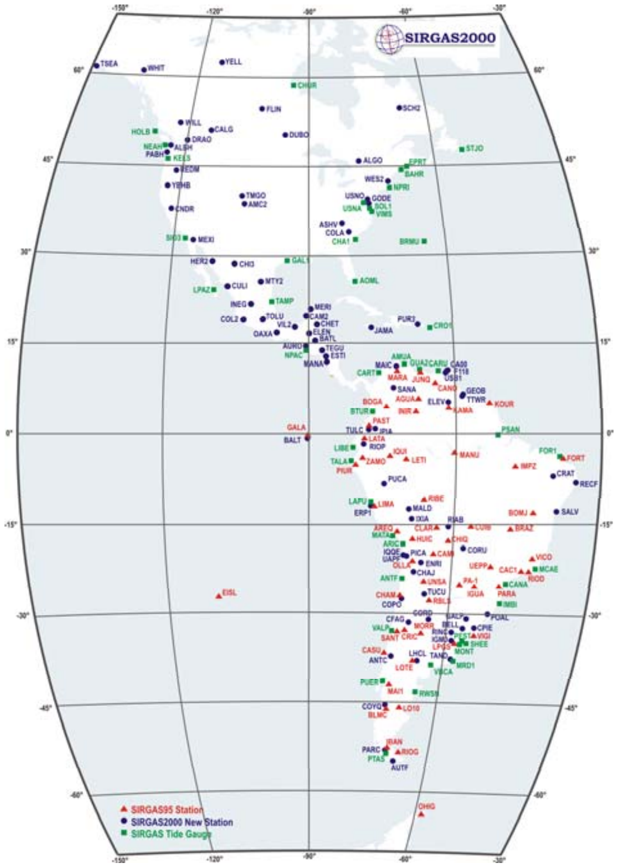
SIRGAS is the Sub-Commission 1.3b of IAG Commission 1

3 SIRGAS Realizations: **SIRGAS95**, **SIRGAS2000**, and **SIRGAS-CON**



✓ **SIRGAS95: ITRF94, epoch 1995.4**: 58 stations over South America.

Please visit **www.sirgas.org**



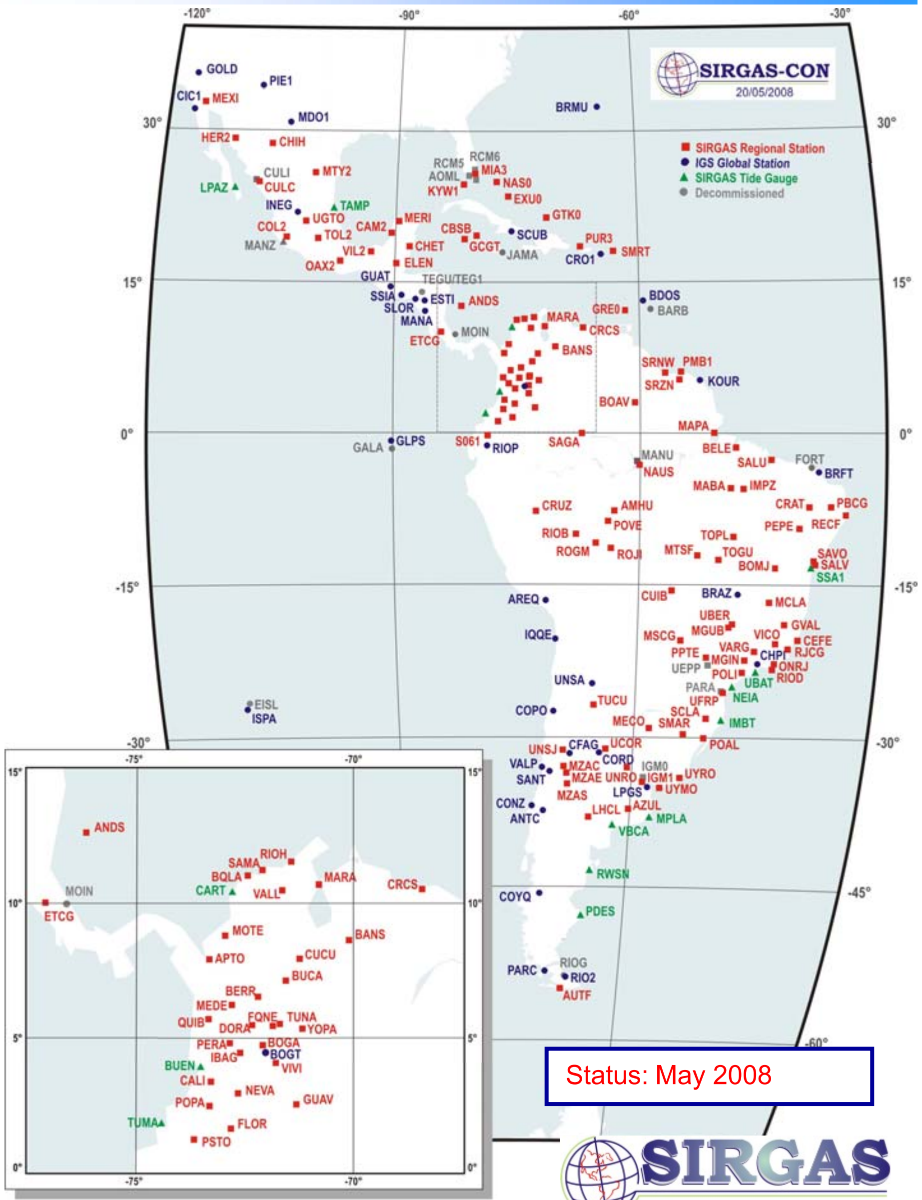
✓ **SIRGAS2000: ITRF2000, epoch 2000.4**: 184 stations over the Americas: North, Central and South America

SIRGAS realizations (2/2)

SIRGAS Continuously Observing Network (**SIRGAS-CON**)

Year	IGS Stations	Regional Stations	Sum
1996	15	0	15
1997	15	6	21
1998	19	10	29
1999	24	14	38
2000	32	16	48
2001	35	17	52
2002	41	18	59
2003	47	19	66
2004	47	28	75
2005	48	55	103
2006	48	72	120
2007	48	128	176
present	48	141	189

IGS-RNAAC-SIR contributions to IGS polyhedron



SIRGAS-CON: Multi-year solution DGF08P01-SIR

- Bernese GPS Software 5.0 is used for the processing.
- Absolute PCVs are applied since GPS week 1400 (GPS weeks 1200-1399 are being reprocessed using absolute PCVs).
- Satellite orbits, clocks and EOPs are fixed to the combined IGS solutions.
- Accumulation of free normal equations (daily resolution) and analysis of the time series to identify discontinuities and outliers.
- The geodetic datum is defined by NNT + NNR conditions by using 17 IGS05 stations.
- The multi-year solution (DGF08P01-SIR) contains station positions (epoch: 2004.4) and velocities w.r.t. IGS05.
- Coord. / vel. precision: ± 2.2 mm (hor), ± 4.5 mm (up); ± 1-2 mm/a (vel).

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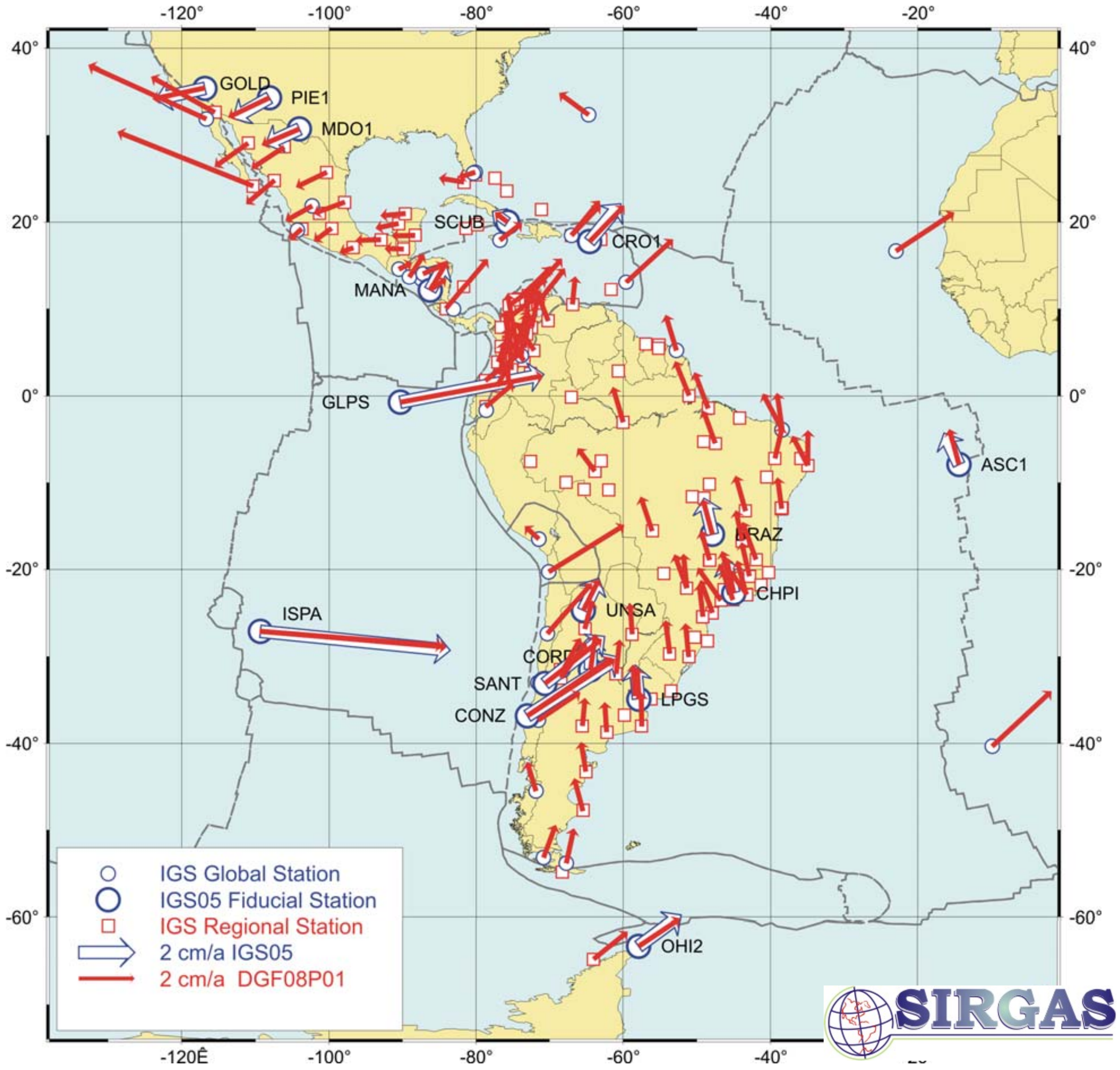
SIRGAS-CON station velocities

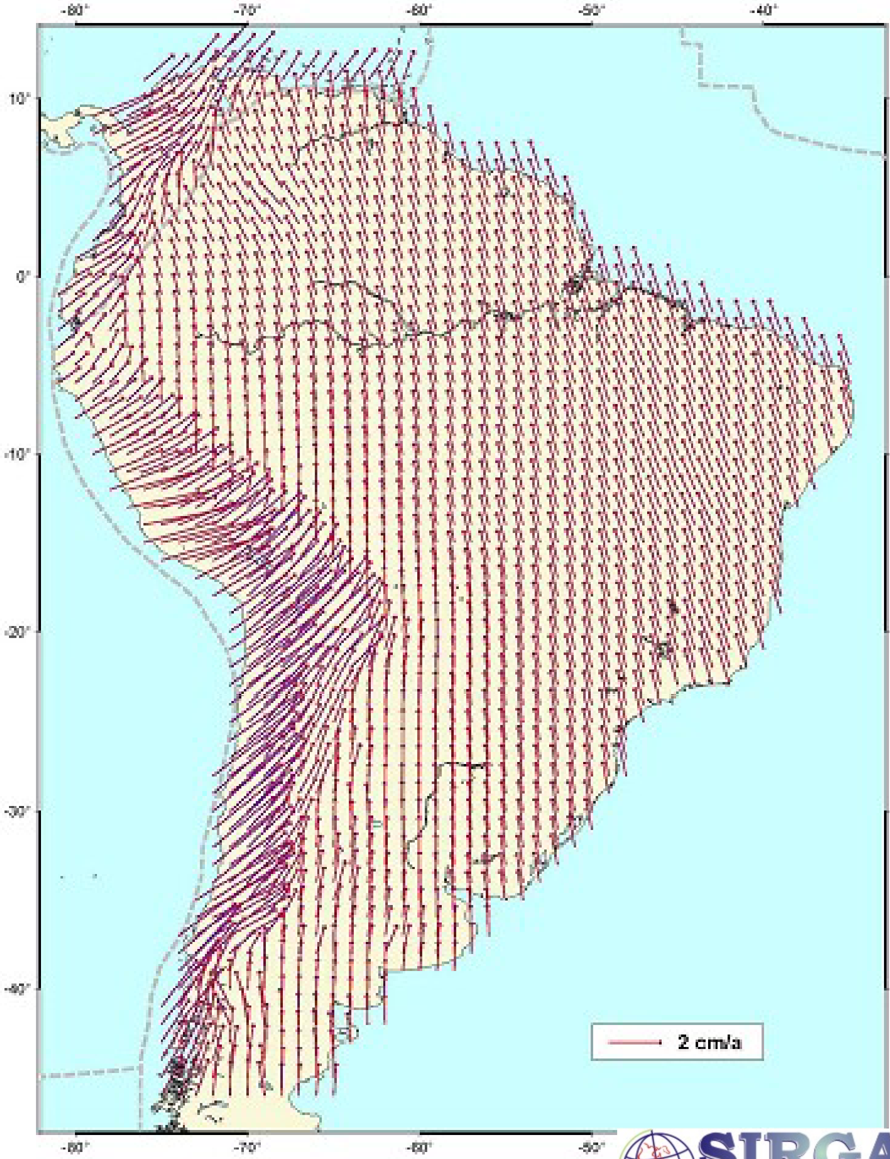
SIRGAS-CON:

Horizontal station velocities of DGF08P01 solution compared to IGS05



Velocity model for SIRGAS

- Released in November 2003 (available at www.sirgas.org)
- Input data
  - ✓ SIRGAS95 coordinates
  - ✓ SIRGAS2000 coordinates
  - ✓ IGS RNAAC-SIR velocities
  - ✓ Other velocities from geodyn. projects in South America (CAP, CASA, SAGA, SNAPP)
- The continuous velocity field is expressed in the **global** frame.
- Efforts are currently done in order to improve the velocity model.



(Drewes and Heidbach 2005)

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Transformations between different SIRGAS realizations

Reference Frame

SIRGAS95 (ITRF94, t_0=1995.4)

SIRGAS2000 (ITRF2000, t_0=2000.4)

GNSS Positioning at the epoch t_i, referred to the reference frame t_k

Transformation $t_0 \rightarrow t_i$, t_k

$$\mathbf{X}(t_i) = \mathbf{X}(t_0) + \Delta T + \mathbf{R} \cdot \mathbf{X}(t_k - t_0) + \frac{d\mathbf{X}}{dt}(t_i - t_0)$$

Processing of the new coordinates $X'(t_i)$, referred to t_k

Coordinates related to the reference frame $X(t_0)$

Transformation t_i, $t_k \rightarrow t_0$

$$\mathbf{X}'(t_i) = \mathbf{X}'(t_0) - \Delta T - \mathbf{R} \cdot \mathbf{X}'(t_k - t_0) - \frac{d\mathbf{X}'}{dt}(t_i - t_0)$$

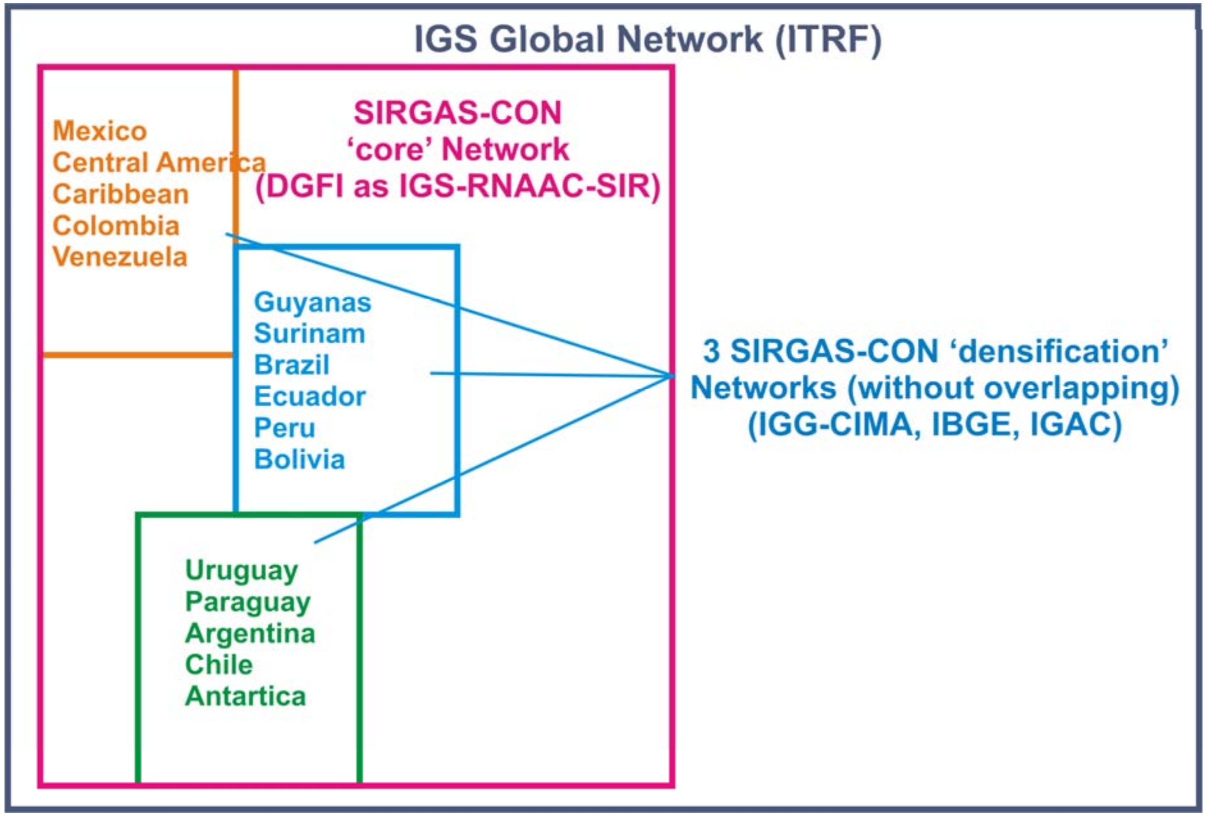
National densifications of SIRGAS

Country	Official national reference frame
Bolivia	SIRGAS95, epoch 1995.4
Brazil	SIRGAS2000, epoch 2000.4
Chile	SIRGAS2000, epoch 2002.0
Colombia	SIRGAS95, epoch 1995.4
Costa Rica	ITRF2000, epoch 2005.8
Ecuador	SIRGAS95, epoch 1995.4
El Salvador	ITRF2005, epoch 2005.0
French Guyana	ITRF93, epoch 1995.0
Mexico	ITRF92, epoch 1988.0
Panama	SIRGAS2000, epoch 2005.0
Peru	SIRGAS95, epoch 1995.4
Uruguay	SIRGAS95, epoch 1995.4
Venezuela	SIRGAS95, epoch 1995.4

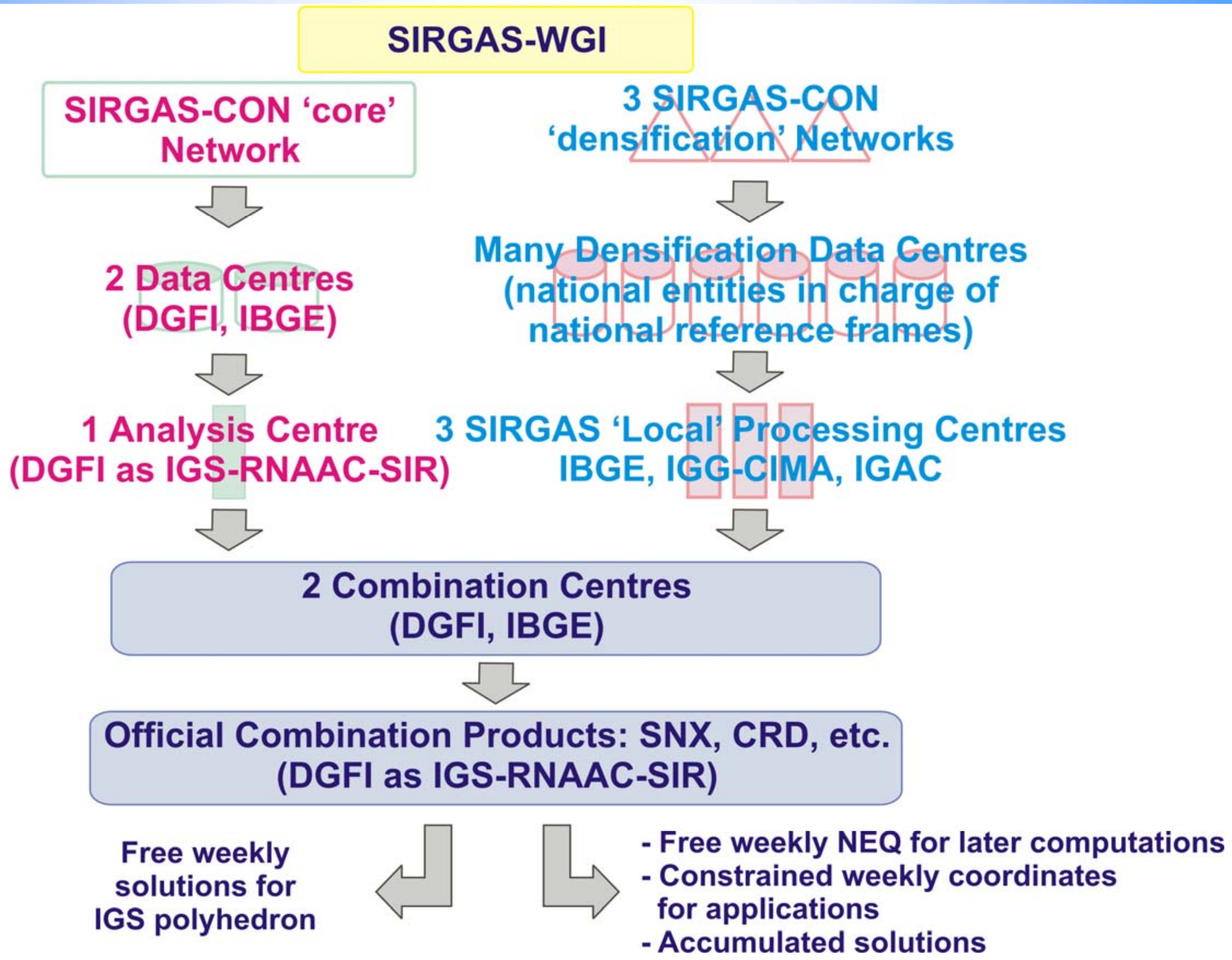
- **13 of the 18 SIRGAS member countries have introduced SIRGAS as the official national reference system.**

Future developments of SIRGAS (1/2)

- SIRGAS-CON Core Network (~ 100 stations)
- 3 SIRGAS-CON Densification Networks
- Combination of Densification Networks with SIRGAS-CON Core Network



Future developments of SIRGAS (2/2)



Conclusions

- The GGOS-D reference frame is more consistent than ITRF2005:
  - Reduced number of discontinuities due to homogeneous re-processing
  - Smaller discrepancies between space geodetic solutions and local ties
- A suitable parameterization of annual signals is necessary for future reference frame computations (to achieve **few-mm** accuracy).
  - Better representation of the „real“ station motions
  - Better alignment of epoch solutions to the reference frame
- Conclusions for the processing of regional networks:
  - Homogeneous reprocessing will provide more consistent results
  - Discontinuity tables must be consistent with the ITRF
  - Coordinates at defined epoch instead of fixing to „stable plate“
  - Definition of the velocity field in the ITRF frame (NNR datum) has major advantages (e.g., simple transformation between different realizations, station coordinates are consistent with GPS orbits)

DGFI SIRGAS GGOS-D http://www.ggos-d.de