Geodetic control of vertical movements at tide gauges

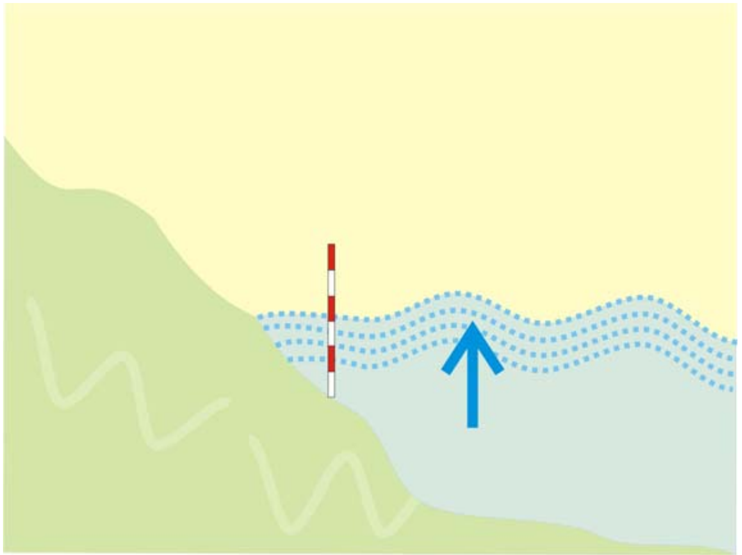
Laura Sánchez

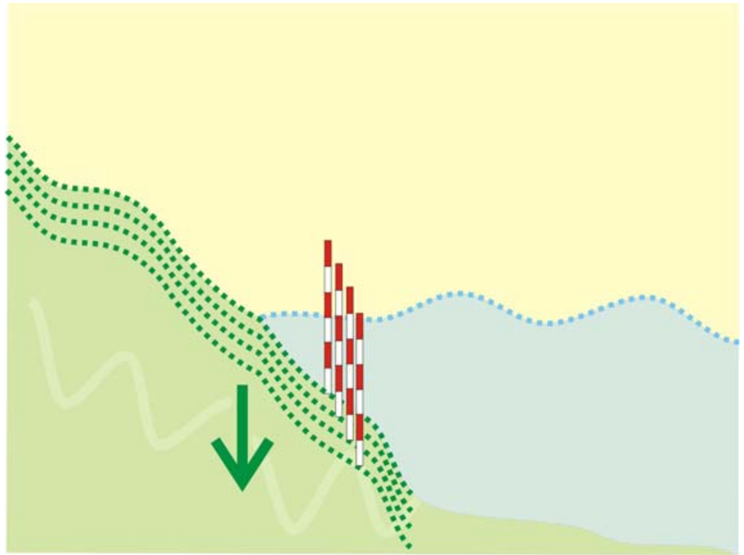
Deutsches Geodätisches Forschungsintitut

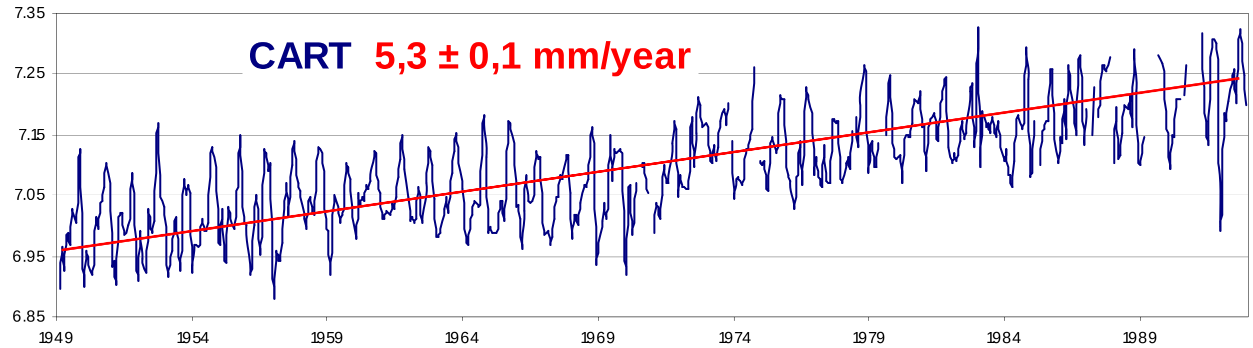
SIRGAS 2008 General Meeting
May 28-29, 2008. Montevideo, Uruguay

Motivation

Vertical displacement of the continental crust or sea level variation?







Objectives

To distinguish sea level variations from vertical crustal movements

Vertical velocities derived from GPS at coastal sites

Sea level trends derived from tide gauge records

Absolute sea level trends

Sea surface trend obtained from satellite altimetry in the marine areas surrounding the tide gauge sites.

Comparison absolute sea level trends derived from satellite altimetry data and from the combination of GPS positioning and tide gauge records

Tide Gauge Benchmark Monitoring Project

It aims at monitoring of vertical motions of tide gauge sites (http://adsc.gfz-potsdam.de/tiga/)

DGFI participation:

i) Starts 2003;

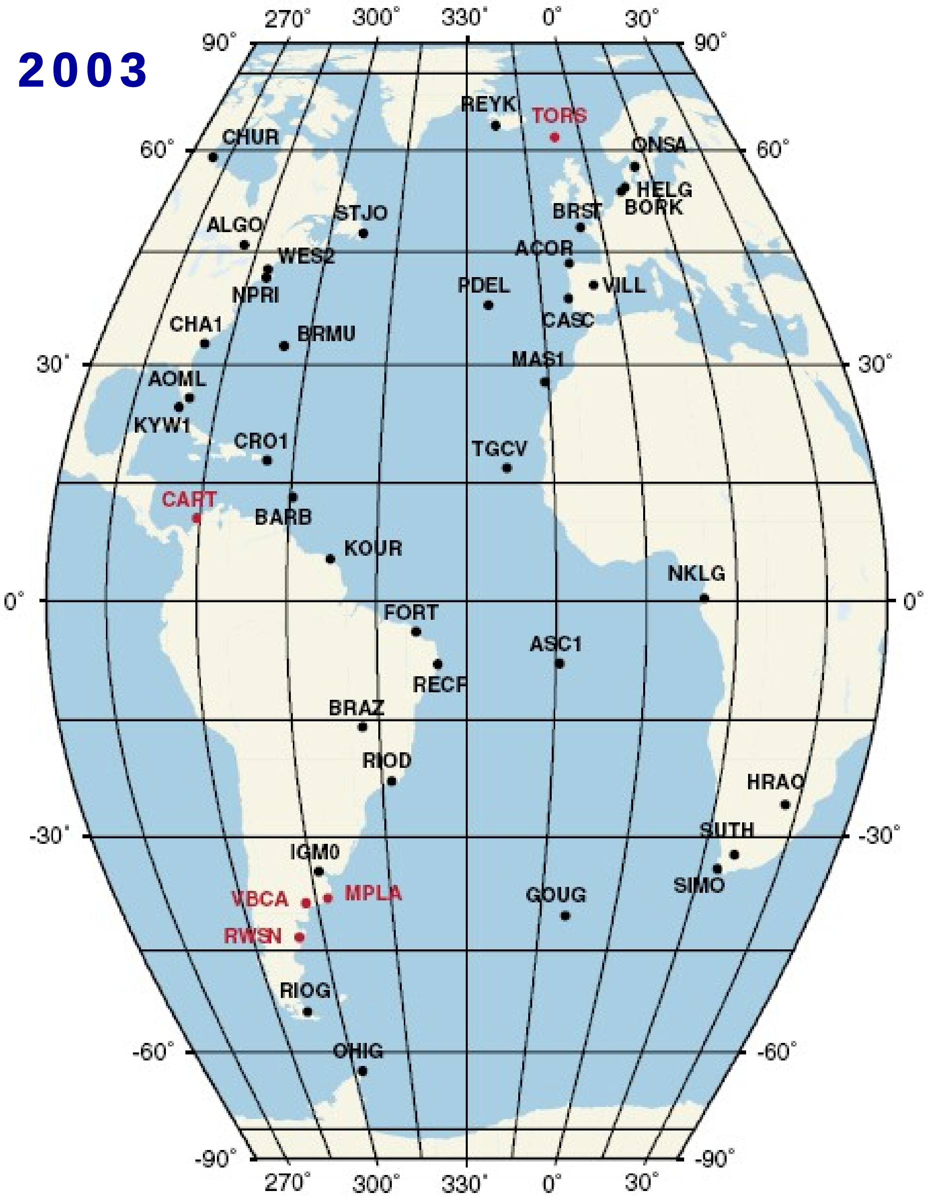
i) Operating continuously observing GPS stations at six tide gauges in the Atlantic Ocean;

ii) Processing a network of about sixty GNSS sites as a TIGA Analysis Centre.

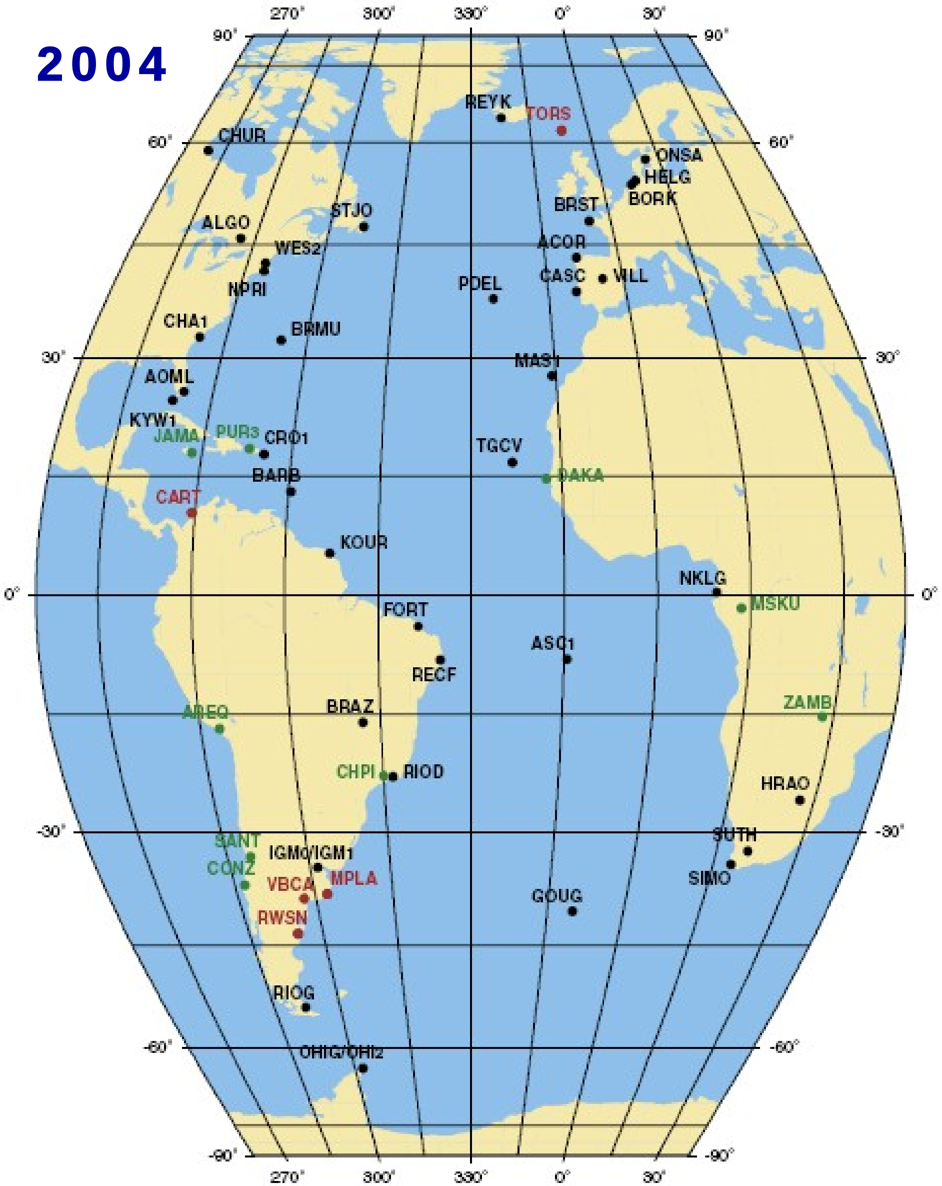
DGFI

TIGA Network processed by DGFI

2003

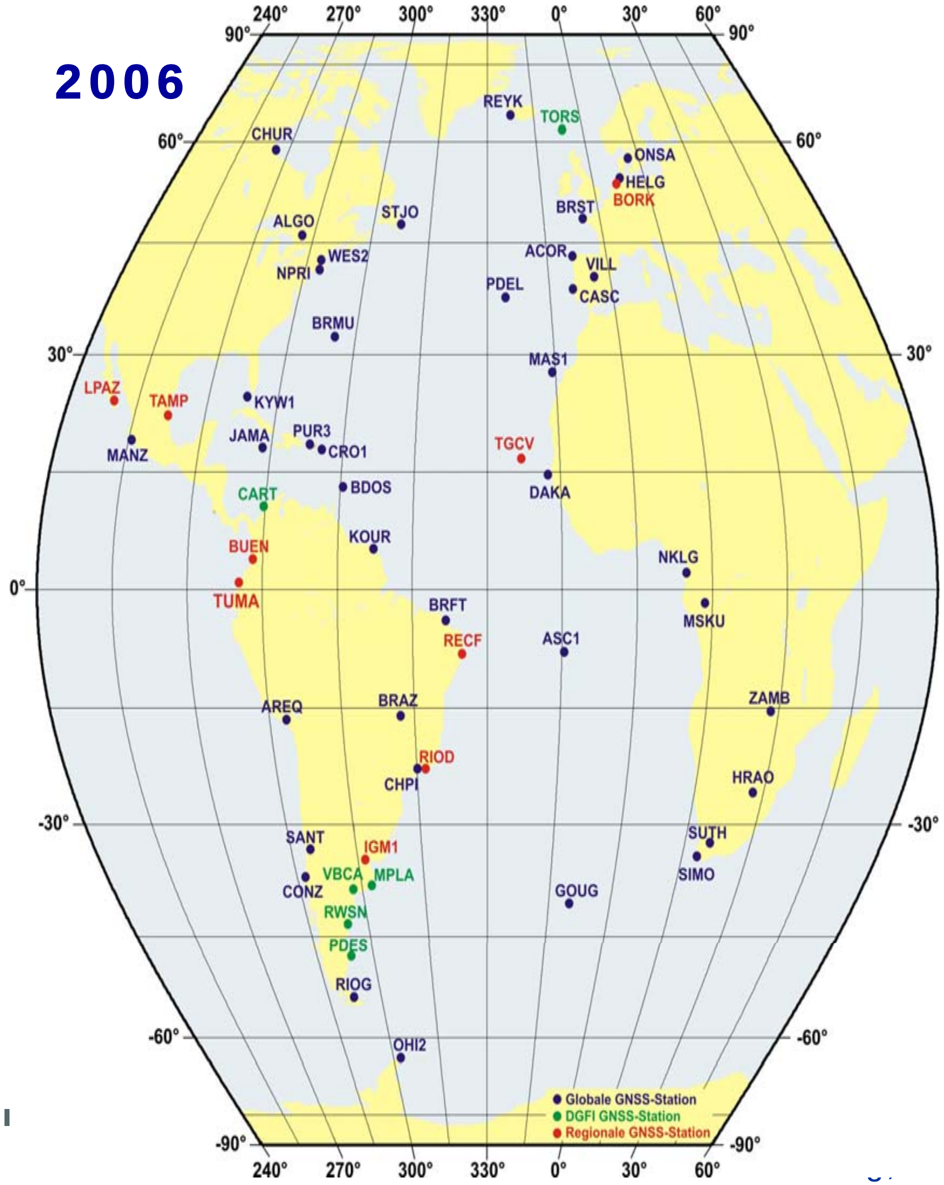


2004

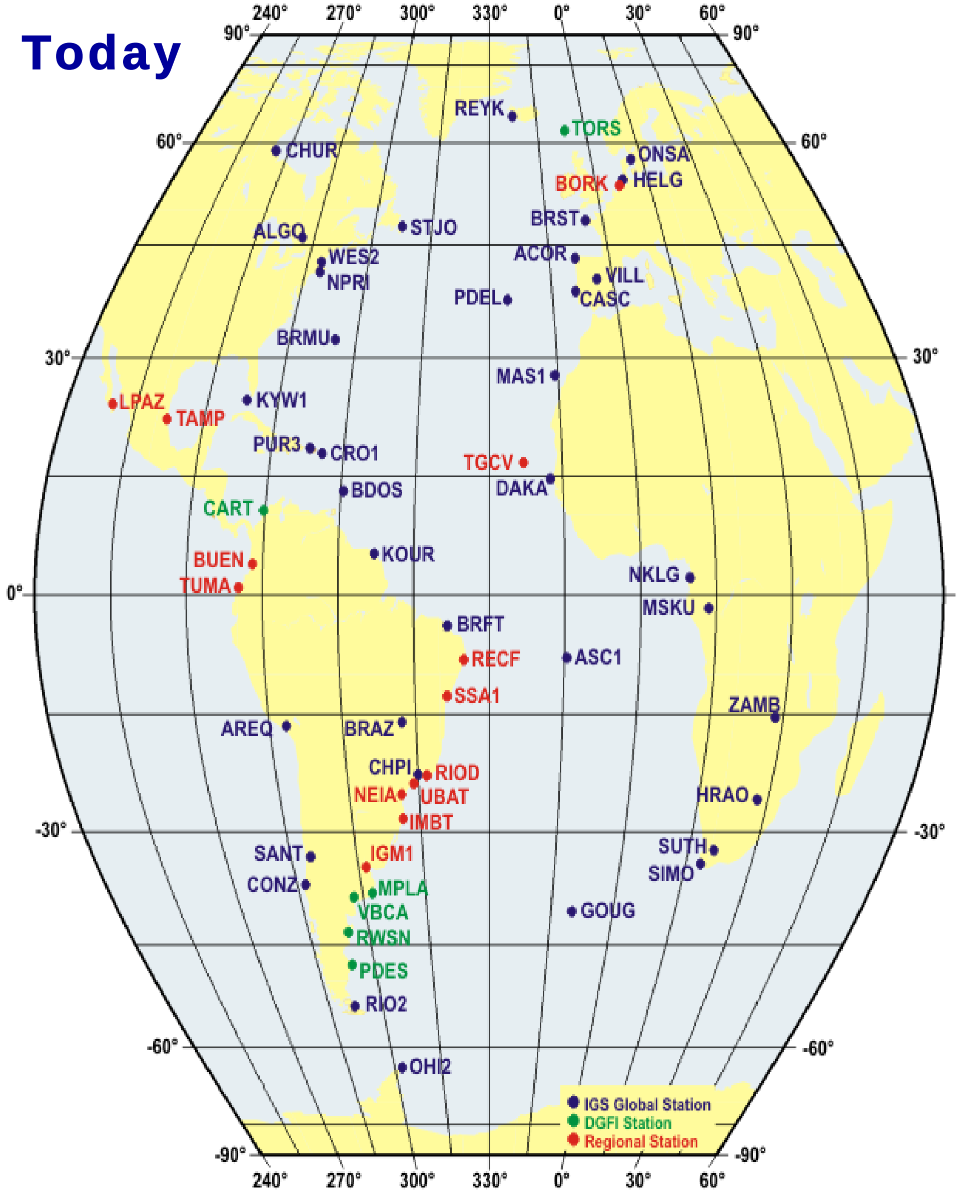


TIGA Network processed by DGFI

2006



Today



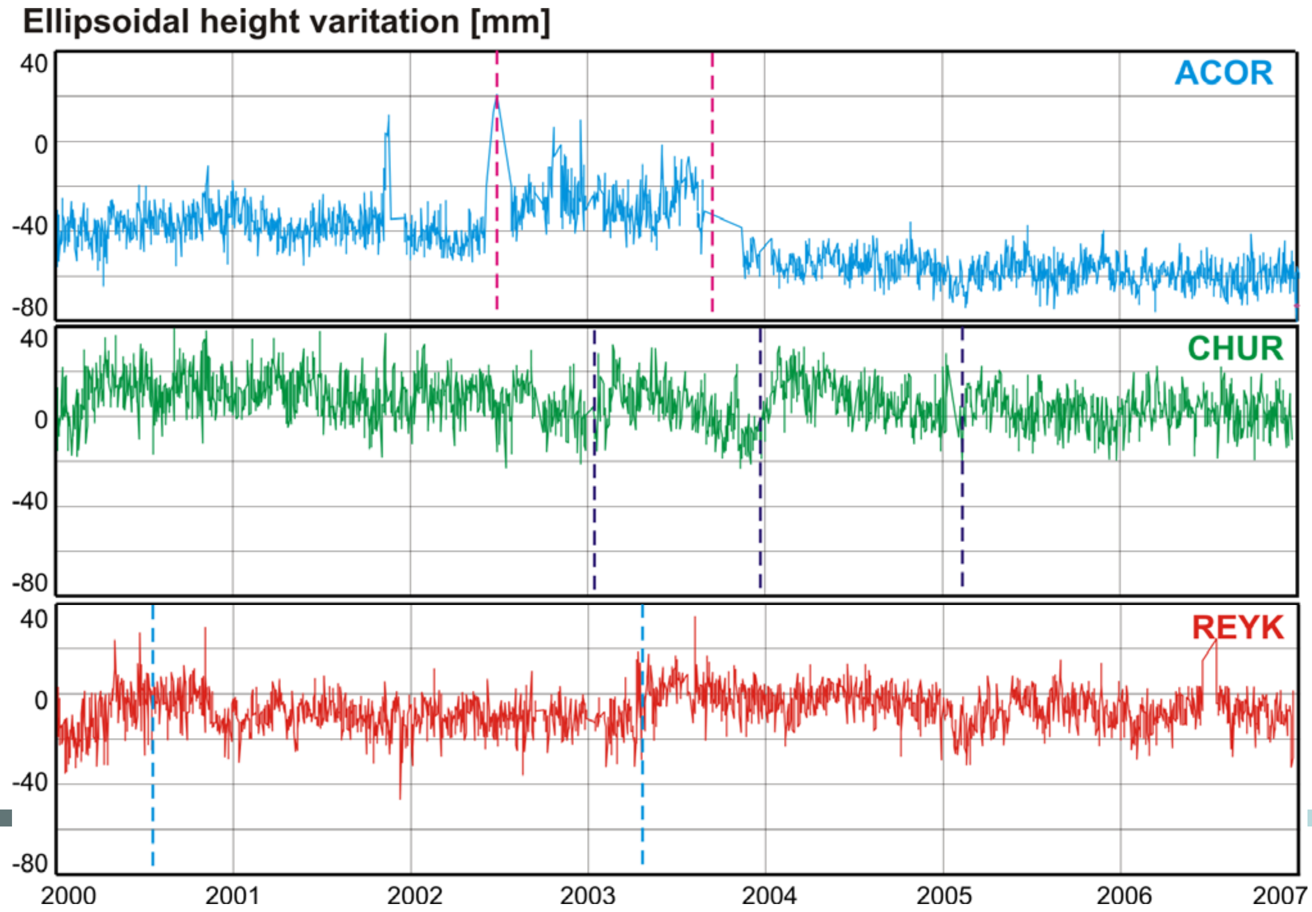
Vertical crustal trends

1. GPS positioning a coastal sites;
2. A multi-year solution (DGF07P01-TIGA) obtained from the accumulation of daily free network normal equations from 1 January 2000 to 31 December 2007;
3. Double difference approach;
4. Bernese software, version 5.0 (Hugentobler, et al. 2004);
5. The elevation mask 3°; data sampling rate 30 s;
6. The absolute calibration values for the antenna phase centre corrections published by the IGS are applied (http://igscb.jpl.nasa.gov/igscb/ station/general/igs05.atx);
7. Satellite orbits, satellite clock offsets, and Earth orientation parameters are fixed to the combined IGS solutions. The earlier satellite orbits are transformed from ITRF97 or ITRF2000 to IGS05.

DGFI

8. The quasi ionosphere free (QIF) strategy is applied for solving the L1 and L2 phase ambiguities. The applied a priori ionosphere models correspond to the daily global ionosphere maps derived at the CODE analysis centre (http://www.aiub-download.unibe.ch/ CODE).
9. The periodic site movements due to ocean tide loading are modelled according to the FES2004 ocean tide model. The corresponding values are provided by M.S. Bos and H.-G. Scherneck at http://www.oso.chalmers.se/~loading/.
10. The zenith delay due to the tropospheric refraction (wet part) is estimated at a 2 hours interval within the network adjustment. The Niell (1996) dry mapping function is applied to the total delay.
11. The free normal equations generated by the daily network adjustments are combined to determine an accumulative solution with epoch site coordinates and linear velocities.
12. The SINEX files of the weekly free net adjustment are provided to the TIGA Associated Analysis Centres (TAAC) and to other users through the web site http://adsc.gfz-potsdam.de/tiga/index_TIGA.html.

13. The possible discontinuities or systematic effects to be modelled in the combination are pre-analysed by generating time series of stations coordinates. These series are derived from the transformation of each daily solution to the cumulative one.



Vertical crustal trends

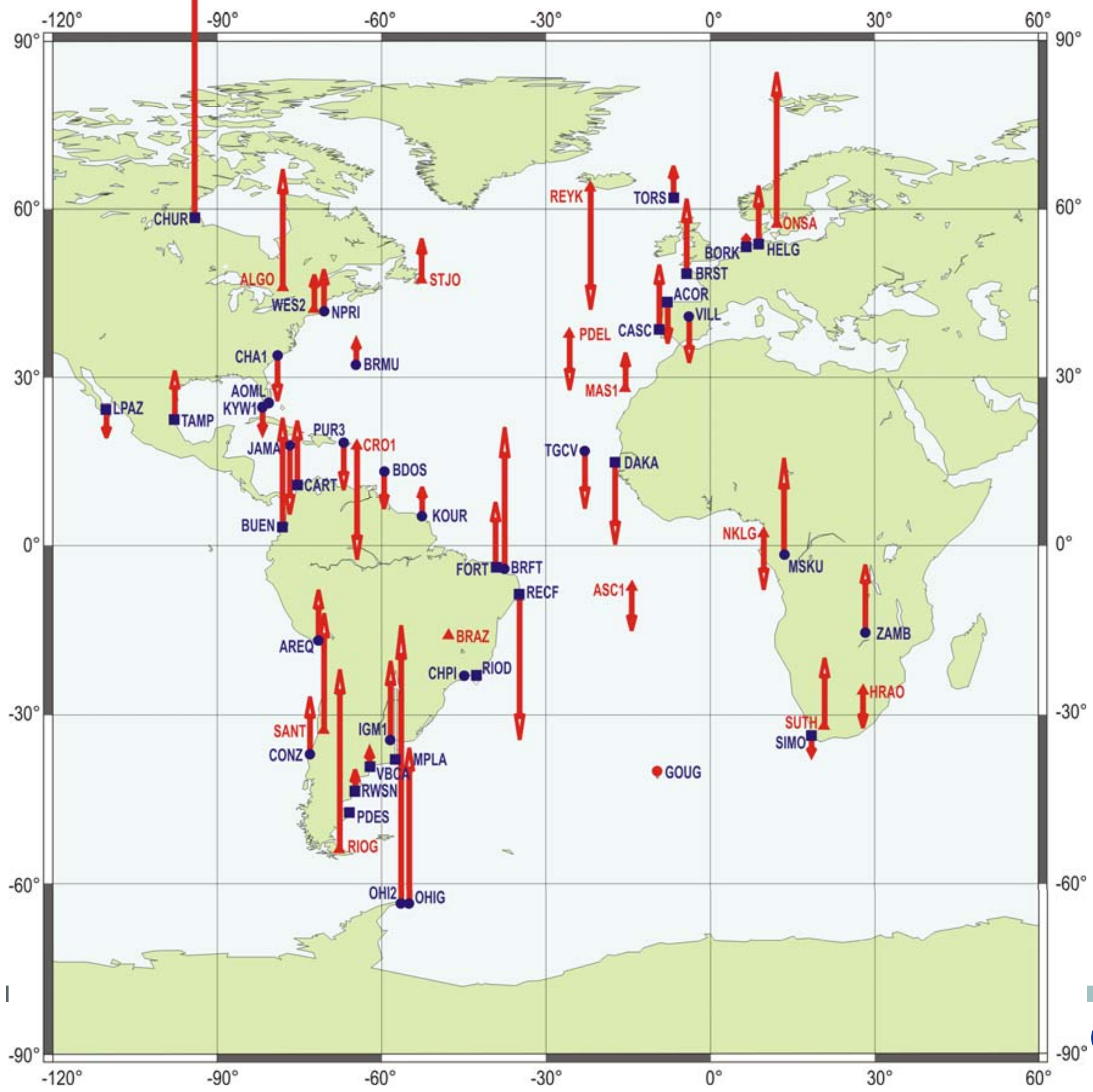
14. Regional stations with short time series (less than one year) are not included in the cumulative solution.
15. The geodetic datum is defined by constraining coordinates and velocities of fourteen IGS05 stations The final solution (DGF07P01-TIGA) refers to the IGS05 frame, epoch 2000.0.

Station	North [mm/y]	East [mm/y]	Up [mm/y]
CHUR	-0,1	-1,2	-3,6
CONZ	-0,3	0,3	0,9
OHI2	0,7	-0,1	-0,9
VILL	-0,7	-1,9	-0,7
WES2	-1,2	-0,5	-3,2
Mean	**-0,3 ± 0,7**	**-0,7 ± 0,9**	**-1,5 ± 1,9**

Differences between the velocities obtained from the DGF07P01-TIGA Solution and the IGS05 Reference Frame for IGS05 stations that were not included as reference sites.

DGFI

Vertical crustal trends



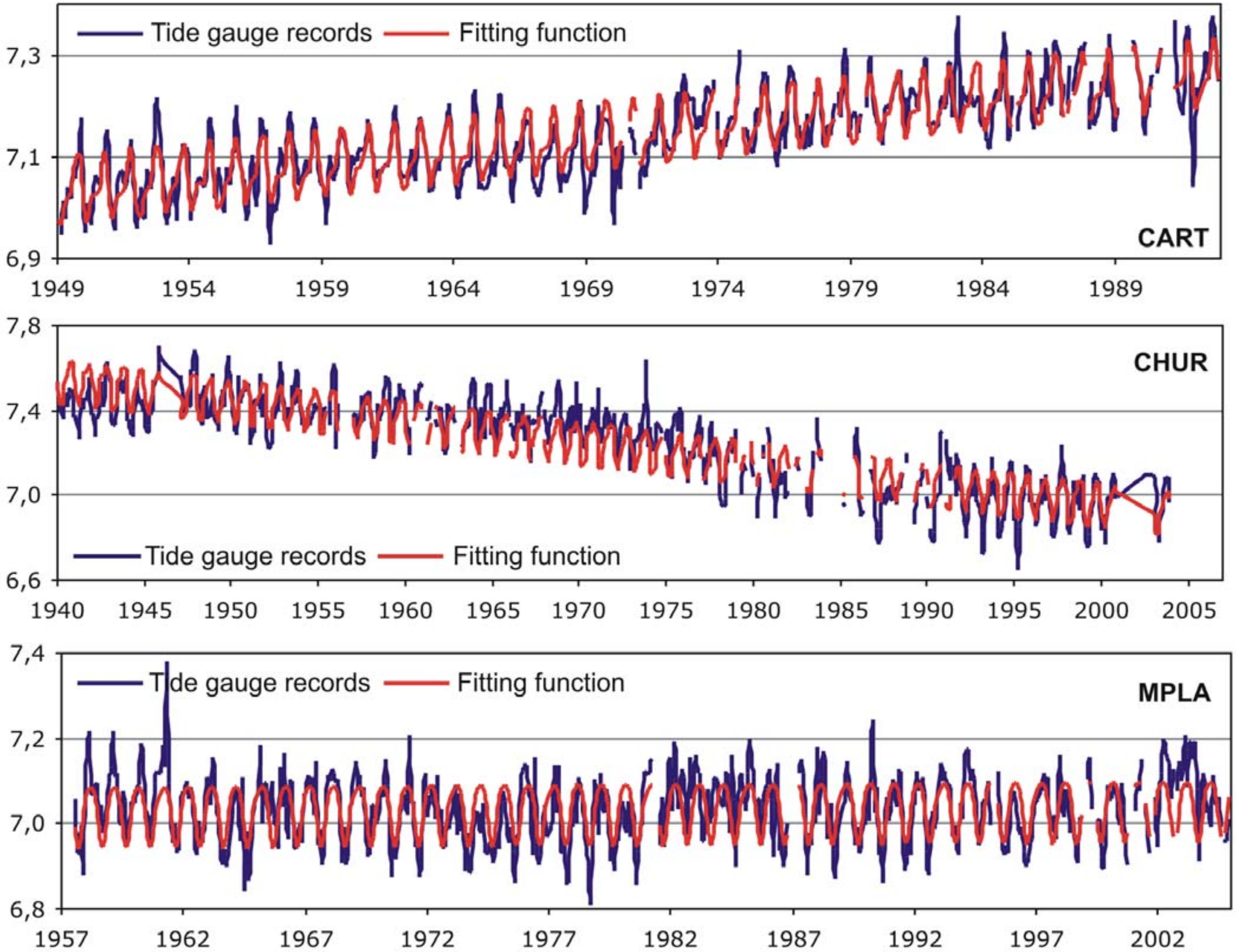
Vertical velocities of the DGF07P01-TIGA solution

Sea level trends from tide gauge records

1. Determination of lineal sea level trends over the full length of tide gauge records available at the Permanent Service for Mean Sea Level (PSMSL, http://www.pol.ac.uk/ psmsl/)
2. Monthly mean values of the so-called RLR (Revised Local Reference) data base, which contains tide gauge registrations reduced to a common datum of tabulation (Woodworth and Player 2003). So, it is possible to generate time series of sea level measurements at each tide gauge.
3. The trends derived here should be considered representative only for a region near the tide gauge site with uniform vertical land motion, i. e. the vertical crustal velocities of the DGF07P01-TIGA solution are assumed constant over the time span covered by the tide gauge registrations.
4. The secular sea level change is computed through a least squares adjustment of a harmonic oscillator with a mean trend and two frequencies: one annual and one semi-annual.
5. This approach adequately represents averaged seasonal cycles in the sea level variations at each tide gauge site, but it does not take into account multi-year cycles or regional effects generated by anomalous temperatures, ocean currents or winds.

Sea level trends from tide gauge records

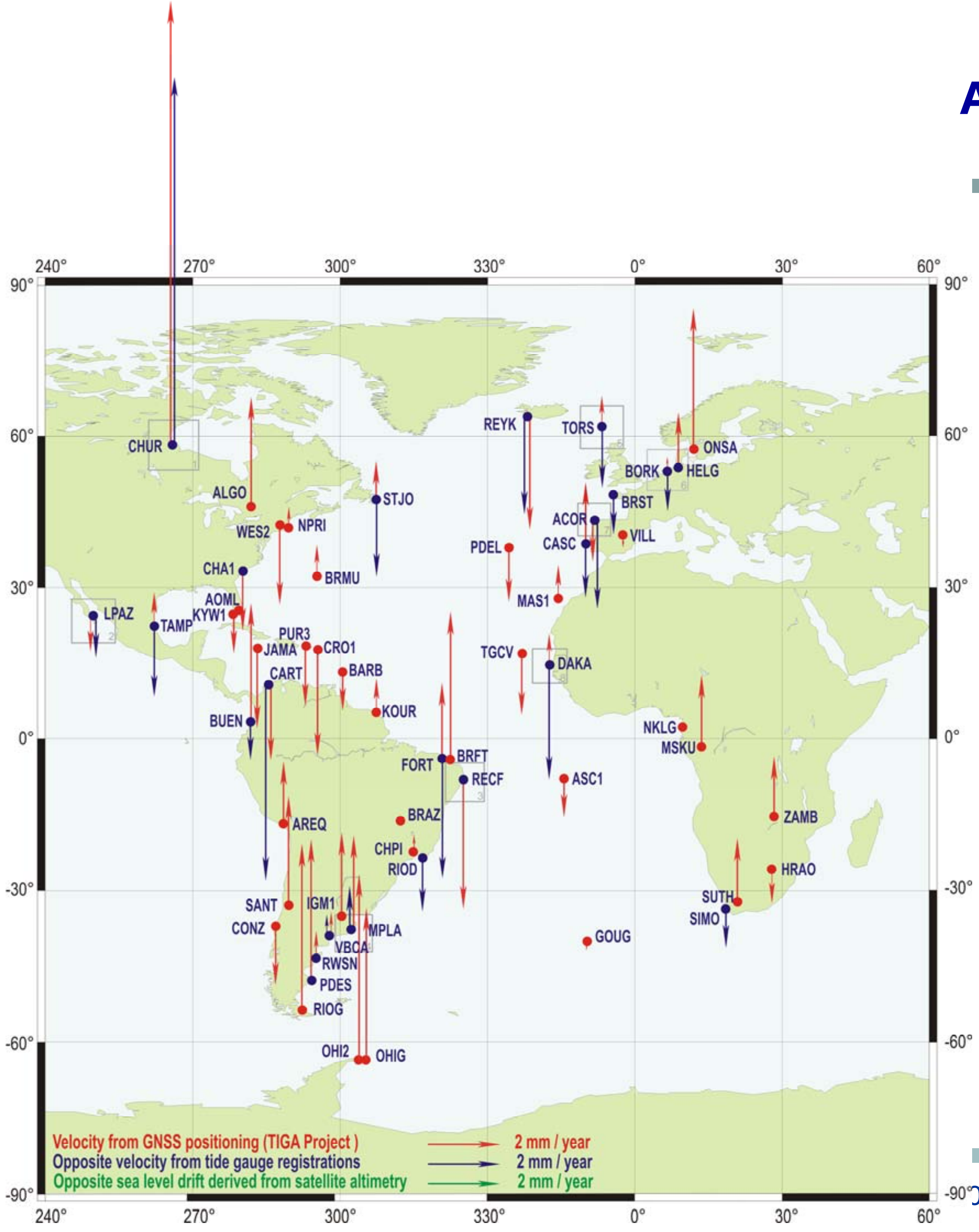
Tide gauge registrations represented by a harmonic oscillator function with two frequencies



Sea level trends from tide gauge records

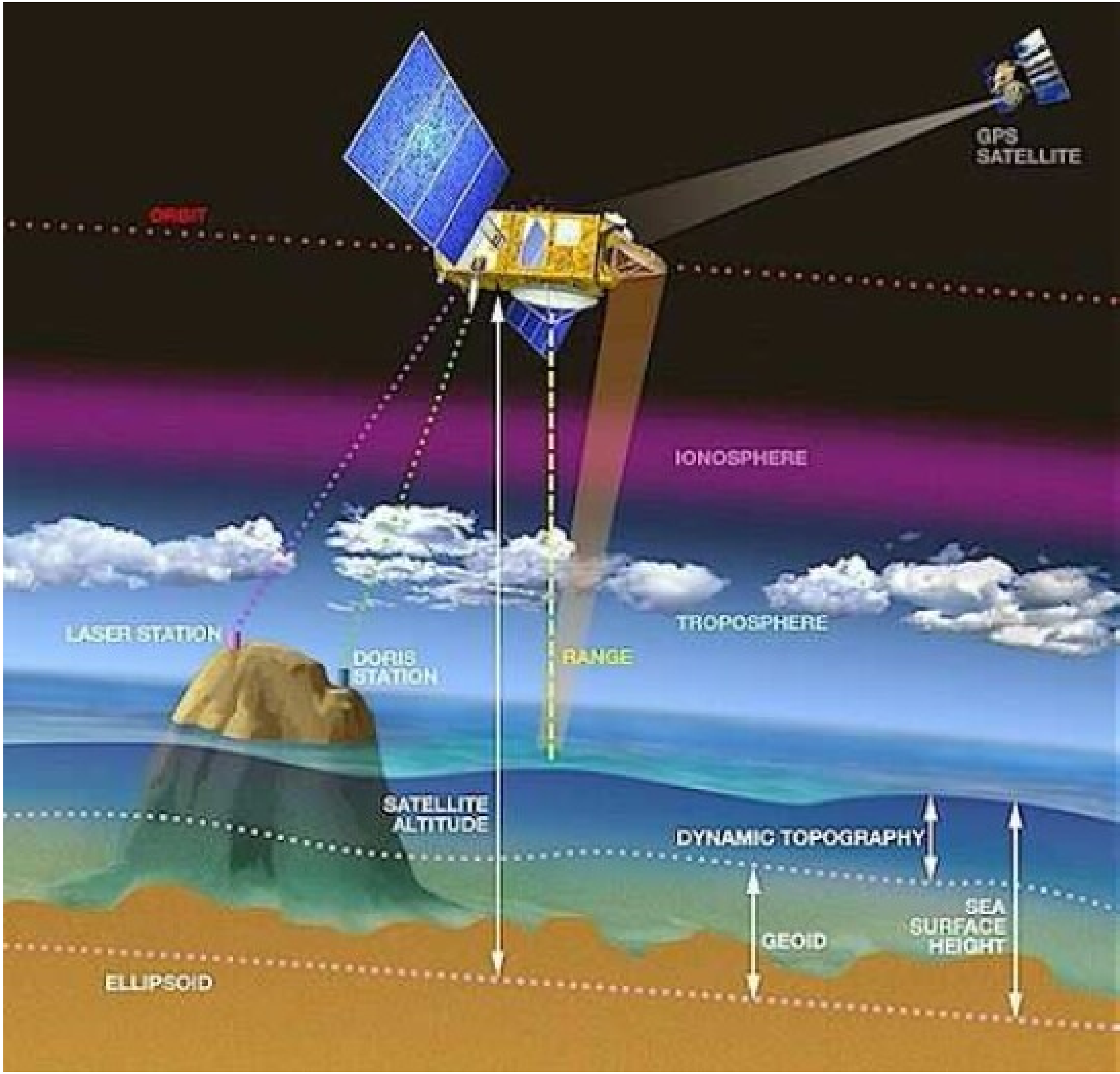
Station	Harmonic oscillator function		PSMSL values		
	Trend [mm/y]	Time span	Trend [mm/y]	Time span	Diff. [mm/y]
ACOR	2,3 ± 1,8	1992- 2004	5,0 ± 4,0	1993- 2004	2,7
BORK	1,2 ± 0,5	1949- 1987	4,9 ± 0,7	1963- 2002	3,7
BRST	1,0 ± 0,0	1807- 2005	1,0 ± 0,1	1807- 2000	0,0
BUEN	1,0 ± 0,3	1941- 1970	1,0 ± 0,7	1941- 1969	0,0
CART	5,3 ± 0,1	1949- 1993	5,2 ± 0,2	1949- 1992	0,0
CASC	1,3 ± 0,1	1882- 1993	1,2 ± 0,1	1882- 1993	-0,1
CHUR	-9,7 ± 0,2	1940- 2004	-9,6 ± 0,5	1940- 2003	0,1
FORT	3,3 ± 0,7	1949- 1969	3,5 ± 1,8	1949- 1968	0,2
LPAZ	1,3 ± 0,3	1952- 1982	1,1 ± 1,0	1954- 1976	-0,2
MPLA	0,3 ± 0,2	1957- 2005	0,0 ± 0,5	1958- 1997	-0,3
RECF	-0,2 ± 0,4	1949- 1969	-0,2 ± 1,0	1949- 1968	0,1
REYK	2,5 ± 0,2	1956- 2004	2,0 ± 0,5	1957- 2001	-0,5
RIOD	1,4 ± 1,0	1950- 1969	3,7 ± 2,2	1950- 1967	2,3
STJO	2,1 ± 0,2	1936- 2004	2,8 ± 0,2	1929- 1996	0,7
TORS	1,6 ± 0,2	1957- 2003	1,5 ± 0,3	1958- 2001	-0,1
Mean					**0,4 ± 1,1**

Absolute sea level change



The sea level change referred to the ITRS/ITRF is obtained by adding the vertical crustal velocities derived from GPS to the sea level trend determined from the tide gauge records.

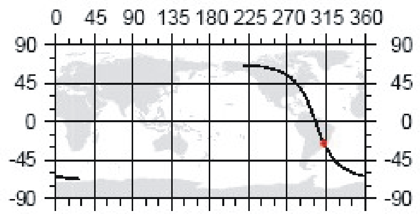
Satellite altimetry



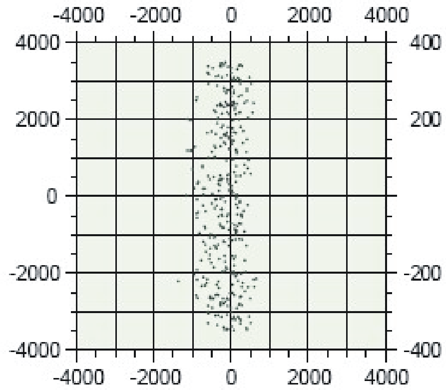
ay

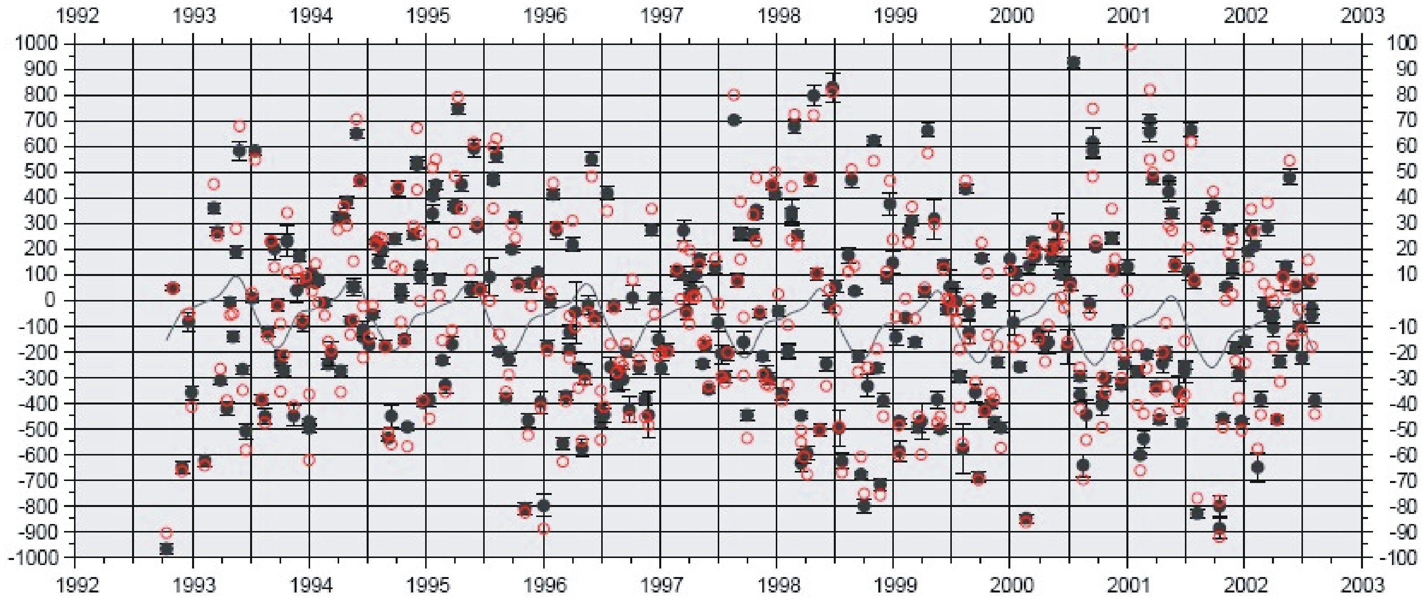
Sea level trends from satellite altimetry

BIN structure

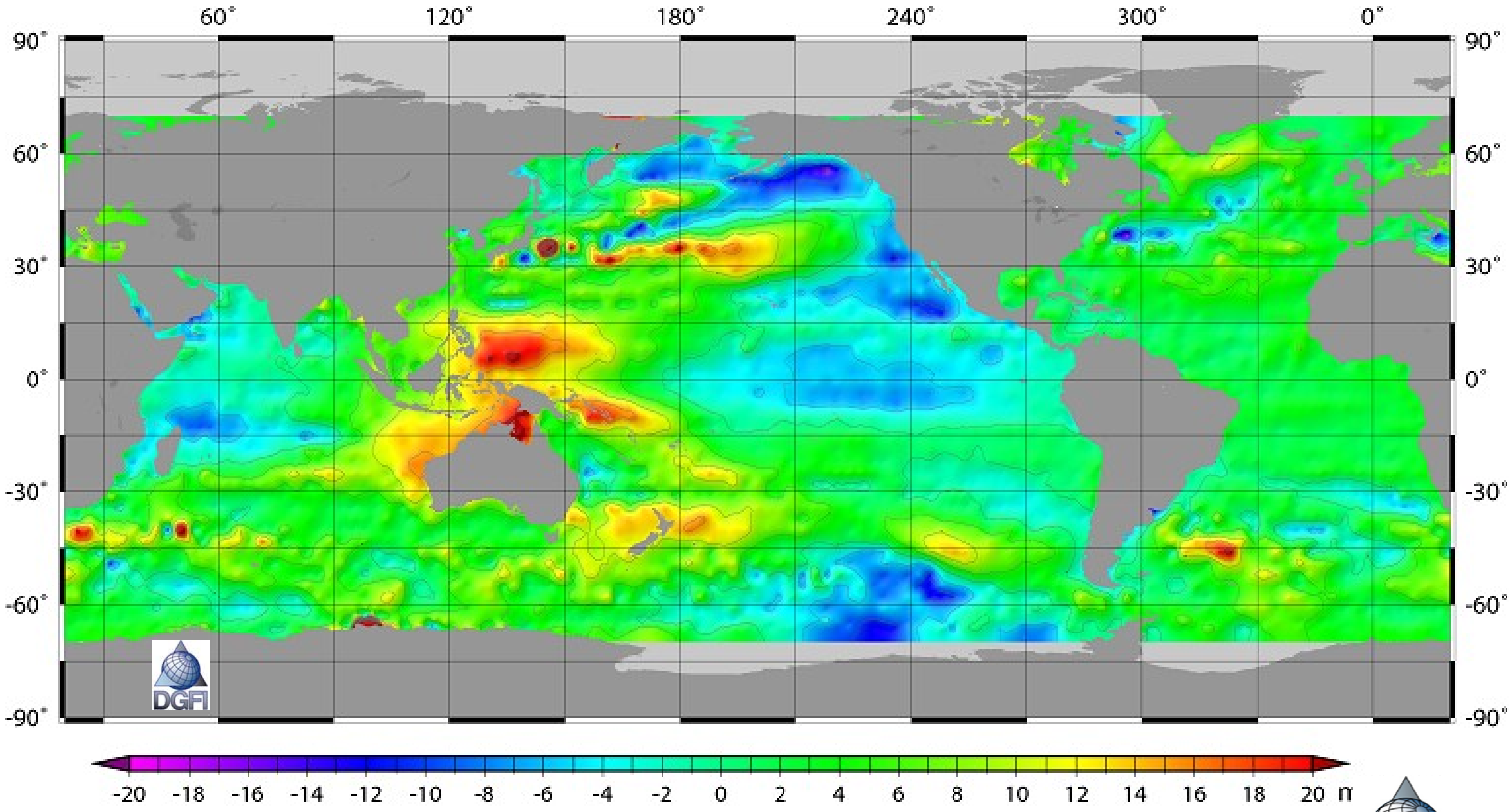


topex 0228d.ssha2bins.03 432

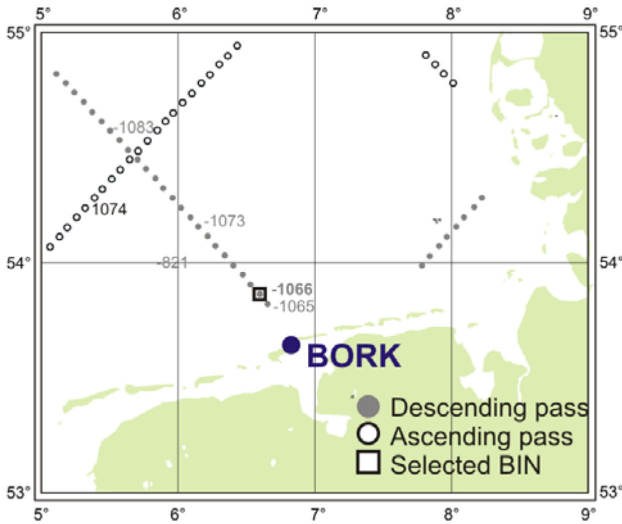




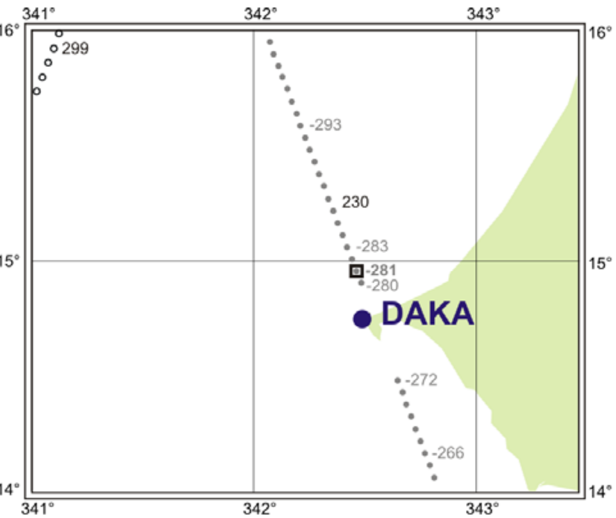
Sea level trends from satellite altimetry



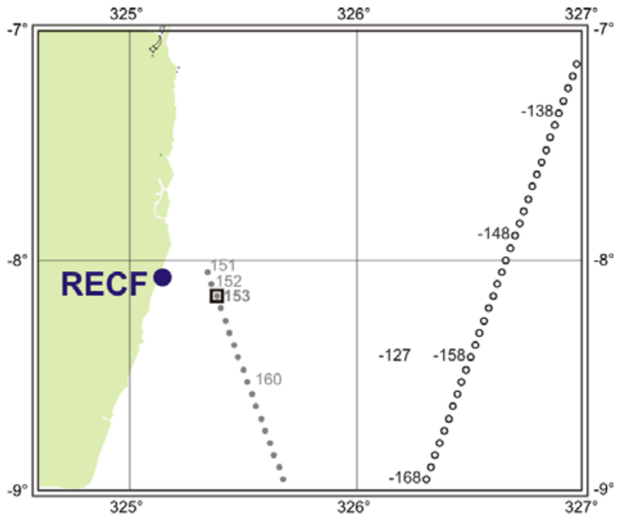
Sea level trends from satellite altimetry



BIN No.	No. Obs.	Trend [mm/y]
-1065	228	-2,7 ± 5
-1066	**319**	**1,6 ± 4,2**
-1067	320	2,3 ± 4,3
-1068	323	5,3 ± 4,3



BIN No.	No. Obs.	Trend [mm/y]
-272	247	3,3 ± 2,1
-280	93	7,0 ± 1,7
-281	**322**	**4,4 ± 0,9**
-282	327	5,5 ± 0,8



BIN No.	No. Obs.	Trend [mm/y]
151	229	2,2 ± 0,9
152	318	2,8 ± 0,9
153	**326**	**1,6 ± 0,8**
154	333	3,4 ± 0,7

Comparison of vertical trends derived from GPS, tide gauge registrations and satellite altimetry

Station	GPS processing		Tide gauges records (TG)		Satellite altimetry (SatAlt)		GPS+TG [mm/y]	(GPS+TG) -SatAlt [mm/y]
	Trend [mm/y]	Time span	Trend [mm/y]	Time span	Trend [mm/y]	Time span		
ACOR	-1,0 ± 0,1	2003.7-2007.0	2,3 ± 1,9	1992.5-2004.0	2,3 ± 1,5	1993.0-2005.0	1,3	-1,0
BORK	0,3 ± 0,1	2000.8-2007.0	1,2 ± 0,5	1949.0-1987.0	1,6 ± 4,2	1993.0-2005.0	1,5	-0,1
BRST	1,8 ± 0,1	2004.5-2006.1	1,0 ± 0,0	1807.0-2005.0	3,3 ± 1,6	1993.0-2005.0	2,8	-0,5
BUEN	2,7 ± 0,2	2005.8-2007.0	1,0 ± 0,3	1941.0-1970.0	-0,2 ± 1,5	1993.0-2005.0	1,0	1,2
CART	1,6 ± 0,2	2003.5-2007.0	5,3 ± 0,1	1949.0-1993.0	1,3 ± 1,0	1993.0-2005.0	6,9	5,6
CASC	1,6 ± 0,1	2000.4-2007.0	1,3 ± 0,0	1882.0-1994.0	3,6 ± 0,9	1993.0-2005.0	2,9	-0,7
CHUR	12,0 ± 0,1	2000.4-2007.0	-9,7 ± 0,2	1940.0-2004.0	2,6 ± 5,0	1993.0-2005.0	2,3	-0,3
DAKA	-2,0 ± 0,1	2002.2-2004.5	2,9 ± 1,0	1992.7-2003.4	4,4 ± 0,9	1993.0-2005.0	0,9	-3,5
HELG	1,4 ± 0,1	2000.4-2007.0	0,1 ± 0,5	1951.0-1987.0	1,6 ± 4,2	1993.0-2005.0	1,5	-0,1
LPAZ	-0,7 ± 0,2	2005.0-2007.0	1,3 ± 0,3	1952.0-1982.4	-1,9 ± 1,8	1993.0-2005.0	0,6	2,5
MPLA	2,2 ± 0,1	2002.7-2007.0	0,3 ± 0,2	1957.5-2005.0	1,6 ± 2,6	1993.0-2005.0	2,5	0,9
RECF	-3,6 ± 0,1	2000.4-2007.0	-0,2 ± 0,4	1948.8-1969.0	1,6 ± 0,8	1993.0-2005.0	-3,8	-5,4
RIOD	-0,2 ± 0,1	2001.6-2007.0	1,4 ± 1,0	1949.8-1969.0	0,6 ± 1,4	1993.0-2005.0	1,2	0,6
TAMP	1,2 ± 0,2	2005.0-2007.0	1,9 ± 3,1	1952.0-1961.0	3,1 ± 1,4	1993.0-2005.0	3,1	0,0
TORS	0,8 ± 0,1	2001.2-2005.5	1,6 ± 0,2	1957.1-2003.0	2,2 ± 1,1	1993.0-2005.0	2,4	0,2
Mean							**1,8 ± 2,2**	**-0,1 ± 2,4**

Closing remarks

1. The sea level changes derived form the GPS+TG values present discrepancies, in general, less than 1 mm with respect to the absolute sea surface variations provided by satellite altimetry.
2. However, the residual variability of the trends derived from satellite altimetry is considerably large, and the precision estimates of the vertical variation from GPS are too optimistic.
3. The large discrepancies at some tide gauges are a consequence of the well-known problems associated to
   - the tide gauge records because of their regional locations (bays, creeks, etc.),
   - the uncertainties of the altimetry observations in coastal areas,
   - the dis-location (no coincidence) between tide gauge and altimetry observations, and
   - the different time periods covered by the various data sources (GNSS positioning, tide gauge registrations, and satellite altimetry).