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Comment

Interactive comment on “Reprocessed height time series of GPS stations at tide gauges” by S. Rudenko et al.

S. Rudenko et al.

rudenko@gfz-potsdam.de

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Authors Comment to the Referee Comment by Jim R. Ray

The authors are grateful to the Referee Jim R. Ray for very careful reading the manuscript and his valuable comments that notably improved the quality of our paper. The purpose of the paper is to describe the algorithm and models used to reprocess GPS data obtained at GPS stations located worldwide and to derive time series and vertical motions at these stations. Some examples of geophysical interpretation of the results obtained are given in the paper, however, the use of the derived land rates for the correction of the colocated tide gauge trends is out of the scope of this paper and can be investigated in other papers. Here are our answers to the detailed remarks. The referee remarks start with symbol ">" followed by the authors comments.

Full Screen / Esc

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Interactive Discussion

Discussion Paper



> * title "for GPS" would be better than "of GPS"

The title of the paper will be changed to "Reprocessed height time series for GPS stations", since the paper contains the results not only for the GPS stations located at tide gauges.

> * p. 1026, l. 2 "at the time" -> "for the time" or "over the time"

It will be replaced by "for the time".

> * l. 3-4 "used processing algorithm and models" -> "processing algorithms and models used"

It will be modified accordingly.

> * l. 17 "totally" -> "totaling"

It will be replaced.

> * l. 26 "switch" -> "the switch"

It will be corrected.

> * p. 1027, l. 3 Is it really correct to say "made possible a reprocessing within the TIGA project" rather than to say "made possible a reprocessing within the IGS"? I am not aware of any real TIGA reprocessing effort, whereas the IGS Analysis Centers have done so in a fairly consistent and coordinated way in the context of the IGS core products. Quite honestly, the TIGA project seems more like a virtual organization that is mostly concerned with operations at tide gauge stations rather than anything related to data analysis, at least in terms of visible results.

Various TIGA analysis centers provided their solutions of weekly station coordinates in 2002 - 2006. However, these solutions were obtained using a relative model for antenna phase centre variations. Three TIGA analysis centres, namely, a consortium of University of Canberra, University of Tasmania and Australian National

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Discussion Paper



University (CTA), German Research Centre for Geosciences (GFZ) and University La Rochelle (ULR) took part in the reprocessing campaign mentioned in our paper by providing solutions computed using an absolute model for antenna phase centre variations. The information on TIGA project is available at http://adsc.gfz-potsdam.de/tiga/index_TIGA.html and in particular, in the TIGA Reports to the IGS Governing Board at this web page.

The following sentences will be added after the words "made possible a reprocessing within the TIGA project": "Within this reprocessing three TIGA analysis centres (a consortium of University of Canberra, University of Tasmania and Australian National University (CTA), German Research Centre for Geosciences (GFZ) and University La Rochelle (ULR)) computed global station network solutions. The GFZ and ULR TIGA analysis centres contributed also to IGS reprocessing and ITRF2008 (Altamimi et al., 2011)".

The following reference will be added: Altamimi, Z., Collilieux, X., and Metivier L.: ITRF2008: an improved solution of the international terrestrial reference frame, J. Geodesy, 85, 457–473, doi:10.1007/s00190-011-0444-4, 2011.

> * I. 4 "Different authors" -> "Various authors"

It will be replaced accordingly.

> * I. 6 After "globally", I would be add a 2nd reference to Woepplermann et al., 2007, Global and Planetary Change, 57, 396-406, due to the significance of this paper.

The reference to the following paper will be added, as suggested by the referee: Woepplermann, G., Martin Miguez, B., Bouin, M.-N., and Altamimi, Z.: Geocentric sea-level trend estimates from GPS analyses at relevant tide gauges world-wide, Global Planet. Change, 57, 396-406, 2007.

> * I. 6 "King et al., 2010" -> "2010". However, there is no transition from the previous sentence to this one, which shifts from past work related to sea level monitoring to

sources of error in GPS time series. Concerning the latter topic, probably a great deal more could be said than just mentioning the work by King and Watson, which is mostly simulation. For instance, several studies have been made of colored noise errors and how this affects the accuracy of vertical velocity estimates. Other research has also been done on various types of systematic errors affecting station position estimates (e.g., troposphere and ionosphere modeling errors). It seems strange to pick just one item to mention here.

The following sentences will be added before the sentence "King and Watson (King et al., 2010) recently showed..." "Recently, several studies have been made to investigate the influence of various types of systematic errors on station position and vertical velocities estimates. Thus, Munekane and Boehm (2010) investigated troposphere-induced errors in GPS-derived geodetic time series. Effects of azimuthal multipath asymmetry on long GPS coordinate time series were studied by (Goebell and King, 2011). (King et al., 2012) examined simulated effect of the electromagnetic coupling of a GPS antenna-monument on GPS coordinate time series longer than 2,5 years. (Fu et al., 2012) have found coordinate differences of ~ 0.3 mm between solutions using ocean tidal loading (OTL) computed in center of mass of the Earth system and OTL computed in the center of mass of the solid Earth. The influence on non-tidal ocean loading effects on geodetic GPS heights has been recently studied by (Williams and Penna, 2011)."

The following references will be added:

Fu, Y., Freymueller, J. T. and van Dam, T.: The effect of using inconsistent ocean tidal loading models on GPS coordinate solutions, *J. Geodesy*, 86, 409–421, doi:10.1007/s00190-011-0528-1, 2012.

Goebell, S., and King, M. A.: Effects of azimuthal multipath asymmetry on long GPS coordinate time series, *GPS Solut.*, 15, 287–297, doi:10.1007/s10291-011-0227-7, 2011.

King, M. A., Bevis, M., Wilson, T., Johns, B., and Blume, F.: Monument-antenna ef-

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Interactive Discussion

Discussion Paper



fects on GPS coordinate time series with application to vertical rates in Antarctica, J. Geodesy, 86, 53–63, doi:10.1007/s00190-011-0491-x, 2012.

Munekane, H., and Boehm, J.: Numerical simulation of troposphere-induced errors in GPS-derived geodetic time series over Japan, J. Geodesy, 84, 405–417, doi:10.1007/s00190-010-0376-4, 2010.

Williams, S. D. P. and Penna, N. T.: Non-tidal ocean loading effects on geodetic GPS heights, Geophys. Res. Lett., 38, L09314, doi:10.1029/2011GL046940, 2011.

> * l. 12 "(Bouin and Woepplmann, 2010)" -> "(2010)"

This will be corrected.

> * l. 12-15 This part makes it seem as though corrections of tide gauge rates using colocated GPS vertical velocity measurements is not needed since there is such good agreement to begin with.

The following words will be added at the beginning of the sentence "Bouin and Woepplmann (2010) found agreement within 2 mm/yr...": "From the recently reprocessed ULR solution, ".

> * l. 20-21 "at about" -> "for about a"

This will be replaced.

> * p. 1028, l. 2 "the obtained results" -> "the results obtained"

This will be changed accordingly.

> * l. 17 "Terrestrial" -> "The terrestrial"

This will be added.

> * l. 20 "using NNR-NUVEL1A" -> "using the NNR-NUVEL1A"

This will be added.

> * I. 21 "the rest" -> "the remaining"

It will be corrected, as suggested.

> * p. 1029, I. 8 The satellite antenna offsets are really adjusted every day? This does not seem correct or wise, without some rather tight apriori constraint.

The GPS satellite phase center offsets are not estimated. They are put into the normal equations, but are constrained to get the solution ZERO. They are provided in the SINEX files to be used for later scale adaptations. So, the words "and GPS satellite phase center offsets" will be deleted from the sentence.

> * I. 9 Fixing of UT1 only for the 1st day of the week must imply that the daily LOD estimates are required to be continuous between days, right? If so, then this needs to be made explicit, as well as any other over-constraints on other parameters.

The phrase "UT1 is fixed for the first day and estimated for the remaining days" will be written in more clear way: "UT1 is fixed for the first day of the week and the daily estimates for UT1 and LOD are constrained to obtain a continuous Earth rotation throughout the week".

> * I. 22-24 Is it really correct to say that AS was turned off (NOTE: not "of") in May 2005, or is the intent to say that Selective Availability was turned off in May 2000? I would not agree that it is "clear" that the stability improvements can be correlated with any abrupt event. The dU performance looks relatively stable from 2001 onward, whereas the horizontal stabilities gradually improved over the entire data span. It does appear that the results became markedly less noisy at about 2004.0; is there any event in the data analysis that might explain this?

The sentence will be written in more clear way: "It is clear visible that the North and East coordinate solutions improve over the entire time span and reach even a level of 1 mm. The Up component looks relatively stable from 2001 onwards and reach a level of 3 mm in 2007."

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Interactive Discussion

Discussion Paper



> * l. 25 "eqiupment" -> "equipment"

It will be corrected.

> * l. 27 The cited reference to Dow et al. does not mention anything about the IGS combined Repro1 solution.

The reference (Dow et al., 2009) will be replaced by words "available at <ftp://cddis.gsfc.nasa.gov/gps/products/repro1/>".

> * p. 1030, l. 1-2 "The accuracy of North ..." -> "The accuracy of weekly North ...". However, use of the strong term "accuracy" is not justified on the basis of the comparison shown in Fig. 4. For one thing, this just shows how GT1 compares with the IGS combined solution, which include GT1. All common mode errors are invisible in such a comparison. It would be much better to use the term "precision" though this is probably an overstatement too.

The words "The accuracy of North" will be replaced by "The accuracy of weekly North". The use of word "accuracy" is correct from our opinion, because of the absolute quality assessment.

> * l. 6 "Lenght" -> "Length"

This will be corrected.

> * l. 15-16 It is well known that the formal standard deviations from GPS data analyses do not accurately reflect that actual measurement errors, which tend to follow flicker noise statistics. While use of the formal standard deviations might be OK for weights to estimate linear trends, they would definitely not be OK to compute accurate errors for the velocities.

The terms "vertical trend" and "vertical velocity" are identical in the content of this paper. The seasonal component was removed from the time series before estimating the trend leading to small error estimates. We agree, that taking into account for corre-

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Interactive Discussion

Discussion Paper



lated measurement errors would result in larger errors. The sentence "The seasonal component was removed from the time series before estimating the trend leading to small error estimates given in Tables 2-3 for our solution." will be added after the words "Vertical velocities of GPS stations located at tide gauges and some IGS stations are given in Table 2."

> * l. 16-19 Does the trend change detection also find discontinuities in the position time series? If so, this should be mentioned; if not, then the procedure used to find such breaks should be explained, whether supported by known station events or unknown.

The following explanation will be added after the words "Trend changes were determined using the BFAST package (Verbesselt et al., 2010).": "The BFAST algorithm uses a four-step iterative procedure to detect breakpoints in time series. First, the ordinary least squares (OLS) residuals-based MOving SUM (MOSUM) test is used to detect whether break points do occur in the time series. If the test shows a significant change (at $p < 0.05$), the break points are estimated from the seasonally adjusted data. In the second step, the trend is estimated using robust regression. The OLS-MOSUM test is then applied again in the third step to test for breakpoints in the seasonal component of the time series. In the final step, the seasonal component is estimated from the detrended data. The above steps are iterated until the number and position of breakpoints are unchanged. Details regarding the procedure are described in (Verbesselt et al., 2010)."

> * p. 1031, l. 1 Does "No atmospheric corrections" mean "No atmospheric loading corrections"? Some further elaboration is needed to explain exactly how the results for BRAZ, VAAS, and MAR5 were "corrected". It should be explained that these are special cases that are considered in detail in section 4.

The words "No atmospheric corrections" will be replaced by the words "No atmospheric loading corrections". The sentence has been added: "BRAZ, VAAS, and MAR5 stations were corrected for atmospheric loading using Green's functions as described in

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Interactive Discussion

Discussion Paper



detail in section 4. The analysis of these stations requires that the atmospheric loading is taken into account."

> * l. 6 "(Blewitt et al., 2002)" -> "(2002)"

This will be corrected.

> * p. 1034, section 4.3.1 Most commonly, post-seismic trends are modeled with exponential functions rather than linear segments. The proposed rate change in 2005 might just be an artifact of using linear segments.

The sentence "From 2005 on, a slight reduction of the trend can be observed, but a connection with a seismic event could not be established." will be written as "From 2005 on, a slight reduction of the trend can be observed. This is consistent with exponential behaviour which can be expected for a post-seismic event."

> * l. 18 Need a reference for "Sato".

The following reference will be added: Sato, T., Mochizuki, K., Kasahara, J., Fujie, G., Nishisaka, H., and Koresawa, S.: Depth variation of the crustal structure of the subducting plate along the Nankai Trough, off Kii Channel, Japan, *Geophys. Res. Lett.*, 25, 21, 4011-4014, doi:10.1029/1998GL900104, 1998.

> * p. 1035, l. 7 "(Emery et al., 1991)" -> "(1991)"

This will be replaced, as suggested.

> * l. 11-13 The trends discussed here presumably refer to trends in some tide gauge > data, though this is not stated explicitly.

The words "Another example of a trend change is Aburatsu, located at Nichinan, Miyazaki prefecture, Japan. One trend change" will be replaced by the words "Another example of a trend change is Aburatsu tide gauge, located at Nichinan, Miyazaki prefecture, Japan. One trend change (Fig. 11, upper panel)".

> * p. 1037, l. 16 "utilises" -> "that utilises"

This will be corrected.

> Note that Table 3 also shows that the formal velocity errors from this study are much, much more optimistic than those of Bouin and Woepplmann, which is most likely because no account was made of correlated measurement errors here.

The sentence "The seasonal component was removed from the time series before estimating the trend leading to small error estimates given in Tables 2-3 for our solution." will be added after the words "Vertical velocities of GPS stations located at tide gauges and some IGS stations are given in Table 2."

> * l. 19 "at 10 yr" -> "over the 10 yr"

This will be replaced.

> * l. 26 "comparion" -> "comparison"

It will be corrected.

> * references CDEW (1990) is mentioned several times in the article but is not listed in the reference section.

The reference "CDEW (1990)" will be replaced by "Utsu (1990)" through the paper. The reference has been corrected to: Utsu, T., 1990, Catalog of Damaging Earthquakes in the World (Through 1989), Utsu, Tokuji, Tokyo, 243 pp. (in Japanese).

> * p. 1043, caption, l. 2 "larger than" -> "longer than"

This will be changed, as suggested.

Interactive comment on Solid Earth Discuss., 4, 1025, 2012.

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