BERNESE GNSS Data Analysis Strategy and Products Summary

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SOFTWARE USED	BERNESE Version 5.2
SITE TIME SERIES SSSS = site ID MR = mon/rec ID CCC = country code AC = analysis c. RS = ref. system	http://4.232.136.103/data-analysis-and-product/ SSSSMRCCC_AC_RS.pos final daily x,y,z,e,u,n
SITE VELOCITIES	http://4.232.136.103/data-analysis-and-product/
FORMAT README FILES	http://4.232.136.103/data-analysis-and-product/ README.txt
PRODUCTS USED YYYY = year	Final, daily MGEX products from CODE archive: ftp://ftp.aiub.unibe.ch/ Including: CODE_MGEX/CODE GNSS multi-satellite orbit position estimates CODE earth orientation parameters /BSWUSER52/GEN IGS antenna calibration files GNSS receiver type codes GNSS observation selection priority GNSS satellite problem history GNSS satellite-specific information GPS-UTC leap seconds history General constants for Bernese SW Ellipsoids datum definition file Subdaily ERP model, IERS conventions 2010 Solid Earth tide coefficients, IERS2000 Nutation model IAU 2006 Earth gravitational model EGM2008 /CODE/YYYY CODE'S global ionosphere for higher order ion calibrations CODE P1-P2, P1.C1 differential code biases (DCB) VMF1 gridded ECMWF tropo parameters from TU Vienna from: http://vmf.geo.tuwien.ac.at/trop_products/GRID/2.5x2/VMF1/VMF1_OP/ JPL DE405 planetary ephemeris from: ftp://ssd.jpl.nasa.gov/pub/eph/planets/ascii/de405 Atmospheric tidal model (Ray and Ponte, 2003) from: https://geophy.uni.lu/uploads/ggfc/atmosphere/s1_s2_def_ce.dat.Z BLQ FES2004 ocean tidal loading coefficients at sites data from Chalmers University, Sweden: http://holt.oso.chalmers.se/loading/

GPS DATA USED:	RINEX files from various archives, including: RING ftp://bancadati2.gm.ingv.it UNAVCO ftp://data-out.unavco.org CDDIS ftp://cddis.gsfc.nasa.gov EUREF ftp://ftp.epncb.oma.be VENETO https://retegnssveneto.cisas.unipd.it FREDNET https://frednet.crs.ogs.it GEODAF ftp://geodaf.mt.asi.it SPINGNSS https://www.spingnss.it ...and many more
MEASUREMENT MODELS	
Preprocessing	RINEX header: - approximate XYZ replaced with internal database values - antenna, receiver and antenna eccentricities are replaced with station-information file derived from MGA database (url) Apply CA-P1 biases Delete short observation arcs < 5 minutes
Basic Observable	Double difference ionosphere-free (L3) combination: GPS L1-L2 GALILEO L1-L5 GLONASS L1-L2 --- Elevation angle cutoff: 3 degrees Sampling rate: 3 minutes Data weight, LC: 0.001 m Elevation weighting: Sigma^2=cos(e)^2
Marker -> antenna ARP eccentricity	dN, dE, dU eccentricities from station log-files or RINEX header (from MGA database, url) applied to compute station marker coordinates
Ground antenna phase center cal.	PCV model from igs14 applied Receiver antenna and radome types from MGA database
Troposphere	A priori model: Dry interpolated from VMF1 grid Mapping Function: Vienna Mapping Function VMF1 (Boehm et al. 2006) Estimation: Zenith delay every 1 hour, gradient every 24 hours
Ionosphere	1st order effect: Removed by LC combinations 2nd order effect: Modeled using IONEX data
Plate motions	Not applied to apriori positions

Tidal	Solid earth tide: IERS 2010 Conventions --- Permanent tide: coordinates are corrected for permanent tide --- Solid Earth pole tide loading: applied (IERS 2010 Conventions) --- Ocean pole tide loading: applied (IERS 2010 Conventions) --- Ocean Tide Loading: Ocean Tide Model: FES2004 Elastic Green Functions (Farrell, 1972) Station displacements computed by hardisp.f (IERS2010) Surface deformations computed with respect to the solid Earth center of mass
Non-tidal loading	Atmospheric Pressure: Not applied --- Ocean Bottom Pressure: Not applied --- Surface Hydrology: Not applied --- Other Effects: None applied
Earth Orientation Parameter (EOP) Model	IERS 2010 Conventions for diurnal, semidiurnal, and long period tidal effects on polar motion and UT1
Satellite center of mass correction	Phase centers offsets from igs14 model applied
Satellite antenna phase variations	PCV model w.r.t. phase center from igs14 model applied
Relativistic corrections	tbd
GNSS Attitude model	not applied, during eclipses the observations are typically excluded in the pre-processing procedure
ORBIT MODELS (IGS and MGEX-CODE ORBIT PRODUCTS)	
Orbit Arc	24 hours
Geopotential	EGM2008 12x12 C20, C30, C40, C21, S21 from IERS2010 standards --- GM = 398.6004415x10^12 m^3/sec^2 --- AE = 6378137.0 m
Third-body	Sun, Moon, Jupiter, Venus, and Mars --- Ephemeris: JPL DE405
Solar radiation pressure	Estimate GPS "Y-Bias" and solar radiation pressure(SRP) coefficient as described in Arnold et al. (2015).
Tidal forces	Solid earth tides: IERS2000 (CODE) --- Ocean tides: FES2004 to degree and order 8 --- Solid Earth Pole tide: IERS 2010 conventions --- Ocean Pole tide: IERS 2010 conventions

Relativity	tbd
Numerical Integration	Numerical integration using the collocation method (Dach et al., 2015. --- Arc length: 24 hours centered at 12:00 of each day

ESTIMATED PARAMETERS (APRIORI VALUES & SIGMAS)

Adjustment	Least Squares Parameter Estimation
Station coordinates	Daily station positions in a loosely constraint reference frame (apriori sigma 10 m)
Troposphere	Zenith delay: hourly corrections w.r.t. the apriori model Horizontal delay gradients: daily values Mapping function: VMF1
Ambiguity	Ambiguities resolution using the following scheme: Code-Based Melbourne-Wuebenna wide-lane for baselines shorter than 6000 km, Phase-Based wide-lane for baselines shorter than 200 km, Quasi-Ionosphere-Free on the remaining real-valued ambiguities for baselines shorter than 2000 km and direct L1/L2 ambiguity resolution on very short baselines (shorter than 20 km)

REFERENCE FRAMES

Inertial	J2000 Geocentric
Terrestrial	Daily transformed coordinates into ITRF2014
Interconnection	Precession: IAU 2006 Precession Theory --- Nutation: IAU 2006 Nutation Theory --- A priori EOP: EOPC04 updated daily, with polar motion and length of day estimated daily

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SOFTWARE USED	Developed at JPL: GipsyX Version 1.0 Developed at UNR: pppZap, pppTrop, wet2vapor, pppKenv pppQA, pppCluster, ppp2Products, tenv3Plate, midas Developed at UNAVCO: teqc Version 2018Oct15
NGL SITE TIME SERIES SSSS = site ID PP = plate ID YYYY = year DDD = day of year YYMMMDD = date	http://geodesy.unr.edu/gps_timeseries/ txyz/IGS14/SSSS.txyz2 final daily x,y,z tenv3/IGS14/SSSS.tenv final daily e,n,v tenv3/plates/PP/SSSS.PP.tenv final plate e,n,v kenv/SSSS/SSSS.YYYY.kenv.zip final 5-min e,n,v qa/SSSS.qa.gz final QA time series trop/SSSS/SSSS.YYYY.trop.zip final tropo SINEX rapids/tenv3/FID/SSSS.FID.tenv3 rapid daily e,n,v rapids_5min/kenv/by_sta/SSSS.kenv.tar rapid 5-min e,n,v ultracombo/kenv/YYYY/DDD/YYMMMDDSSSS_fix.kenv ultra-rapid 5-min e,n,v
NGL SITE VELOCITIES PP = plate ID	http://geodesy.unr.edu/velocities/ midas.IGS14.txt IGS14 midas.PP.txt Plate-fixed
FORMAT README FILES	http://geodesy.unr.edu/ gps_timeseries/README.tenv3.txt gps_timeseries/README.txyz2.txt gps_timeseries/README.kenv.txt gps_timeseries/QA.pdf README_trop.txt velocities/midas.readme.txt

PRODUCTS USED	Final, NNR daily Repro3.0 products from JPL archive: https://sideshow.jpl.nasa.gov/pub/ JPL_GNSS_Products/Final/ Including: GPS satellite orbit position/velocity estimates GPS satellite clock estimates GPS satellite attitude parameters WLPB estimates (widelane & phase biases) Daily transformation parameters from NNR to IGS14 Time-pole parameter estimates GPS satellite eclipse shadow times Name of IGS antenna calibration files IONEX data from JPL for higher order ion calibrations https://sideshow.jpl.nasa.gov/pub/iono_daily/ IONEX_final/ VMF1 gridded ECMWF tropo parameters from TU Vienna http://vmf.geo.tuwien.ac.at/trop_products/GRID/ 2.5x2/VMF1/STD_OP/ Auxiliary data updated periodically from JPL: https://sideshow.jpl.nasa.gov/pub/gipsy_products/ gipsy_params/ IGS ANTEX antenna calibration file JPL DE431 planetary ephemeris CODE CA-P DCB (differential code biases) GPS receiver type codes GPS constellation configuration history IERS/BIH leap seconds history IERS earth orientation parameters NOAA IGRF12 Earth magnetic field model Auxiliary data updated from IGS Central Bureau: https://igscb.jpl.nasa.gov/igscb/station/general/ igs_with_former.snx IGS station receiver/antenna configuration history Auxiliary data from Chalmers University, Sweden: http://holt.oso.chalmers.se/loading/ FES2004 ocean tidal loading coefficients at sites Custom data (from NGL/UNR) http://geodesy.unr.edu/NGLStationPages/steps.txt Step discontinuity database http://geodesy.unr.edu/NGLStationPages/llh.out Approximate latitude, longitude, height at sites Internal: antenna+radome and receiver type aliases
GPS DATA USED:	RINEX files from various archives, including: UNAVCO ftp://data-out.unavco.org CDDIS ftp://cddis.gsfc.nasa.gov CORS ftp://cors.ngs.noaa.gov/cors SIO ftp://garner.ucsd.edu EUREF ftp://igs.bkg.bund.de/EUREF GEONET ftp://ftp.geonet.org.nz GREF ftp://igs.bkg.bund.de/GREF IGN ftp://rgpdata.ign.fr AUSTRALIA ftp://ftp.ga.gov.au GSI ftp://terras.gsi.go.jp SONEL ftp://ftp.sonel.org ...and many more
PREPARATION DATE	2019-12-17 for NGL's GipsyX/IGS14 products
MODIFICATION DATES	2019-12-17 initial creation
EFFECTIVE DATE FOR DATA ANALYSIS	2019-11-28 updated website http://geodesy.unr.edu w/NGL GipsyX/IGS14 products using JPL Repro3 products
MEASUREMENT MODELS	

Preprocessing	RINEX header must be interpretable - approximate XYZ replaced with NGL database values - alias table replaces antenna type with IGS standard - algorithm attempts to fix formatting errors - require antenna type has IGS ANTEX calibrations - non-calibrated radome set to "NONE" (IGS standard) Require minimum file size, typically ~18 hr/day Apply CA-P1 biases Fix non-compliant time-tags for older receiver types Remove non-GPS GNSS data (e.g., GLONASS) Remove L2C and C2 data Cycle slip detection and correction using TurboEdit Delete phase connected arcs < 20 minutes Carrier Phase: Decimated to 5 minutes Pseudorange: Carrier-aided smoothing to 5 minutes
Basic Observable	Undifferenced ionosphere-free carrier phase, LC Undifferenced ionosphere-free pseudorange, PC --- Elevation angle cutoff: 7 degrees Sampling rate: 5 minutes Data weight, LC: 0.01 m Data weight, PC: 1 m Elevation weighting: Sigma^2=1/sin(e)
Modeled observable	Undifferenced LC and PC combinations CA-P1 biases from CODE applied
RHC phase rotation corr.	Applied
Marker -> antenna ARP eccentricity	dN, dE, dU eccentricities from IGS SNX or RINEX header applied to compute station marker coordinates
Ground antenna phase center cal.	PCV model from igs14_wwww.atx applied Receiver antenna and radome types from RINEX header
Troposphere	A priori model: Wet and Dry interpolated from VMF1 grid Nominal gradients are zero Mapping Function: Vienna Mapping Function VMF1 Estimation: Zenith delay and gradients as random walk every 5 minutes Integrated water vapor: from wet zenith delay using Bevis et al. (1994) refractivity coeffs, SI units: k1=0.776, k2=0.704, k3=3739.0, Rv = 461.5 and k2'=k2-k1*m where ratio m = 18.0152/28.9644 and using VMF1 interpolated mean atmospheric temperature
Ionosphere	1st order effect: Removed by LC and PC combinations 2nd order effect: Modeled using IONEX data with IGRF12
Plate motions	Not applied to apriori positions Reference velocities for plate-fixed time series use rotation pole vectors from Kreemer et al. (2014)

Tidal	Solid earth tide: IERS 2010 Conventions --- Permanent tide: Not removed from model --- Pole tide: IERS 2010 Conventions --- Ocean Tide Loading: Diurnal, Semidiurnal, MF, and MM Model: FES2004 Semiannual: Self-consistent equilibrium model hardisp.f from IERS2010 Surface deformations computed with respect to instantaneous center of mass --- Ocean Pole Tide Loading: Applied
Non-tidal loading	Atmospheric Pressure: Not applied --- Ocean Bottom Pressure: Not applied --- Surface Hydrology: Not applied --- Other Effects: None applied
Earth Orientation Parameter (EOP) Model	IERS 2010 Conventions for diurnal, semidiurnal, and long period tidal effects on polar motion and UT1
Satellite center of mass correction	Phase centers offsets from igs14_wwww.pcm applied
Satellite antenna phase variations	PCV model w.r.t. phase center from igs14_www.atx applied
Relativistic corrections	Periodic Clock Corrections, (-2*R*V/c): Applied Shapiro Delay: Applied
GPS Attitude model	GYM95 nominal yaw rate model from Bar-Sever (1996) and yaw rates estimated for Block II satellites
ORBIT MODELS (JPL ORBIT PRODUCTS)	
Orbit Arc	30 hours
Geopotential	EGM2008 12x12 C20, C30, C40, C21, S21 from IERS2010 standards --- GM = 398600.4415 km**3/sec**2 --- AE = 6378.1363 km
Third-body	Sun, Moon, and All Planets --- Ephemeris: JPL DE421

Solar radiation pressure	Block II/IIA/IIF/IIR/III: JPL empirical model, GSPM-13 Bar-Sever and Kuang, (2004) Sibois et al, 2014 --- Estimate GPS "Y-Bias" and solar radiation pressure(SRP) coefficient as constant with no a-priori constraint. Make small time-varying (stochastic) adjustments to SRP coefficients in spacecraft body-fixed X and Z directions (1% process noise sigma with 1 hr 11 sec updates and 4-hour correlation time.) Estimate tightly constrained time-varying empirical acceleration in spacecraft Y direction (0.01 nm/s^2 process noise sigma with 1 hr 11 sec updates and 4-hour correlation time.) --- Earth shadow model: conic model with oblate Earth, umbra and penumbra --- Earth albedo: applied (Knocke, 1989) --- Attitude Model: GYM95 yaw model from Bar-Sever (1996)
Tidal forces	Solid earth tides: IERS 2010 Conventions --- Ocean tides: GOT4.8ac to degree and order 30 with convolution formalism of Desai and and Yuan (2006) --- Solid Earth Pole tide: IERS 2010 conventions --- Ocean Pole tide: IERS 2010 conventions
Relativity	Applied Acceleration due to point mass of Earth Acceleration due to geodesic precession Acceleration due to Lense-Thirring precession
Numerical Integration	Variable high order Adams predictor-corrector with direct integration of second-order equations --- Integration step: variable --- Starter procedure: RKF --- Arc length: 30 hours centered at 12:00 of each day

ESTIMATED PARAMETERS (APRIORI VALUES & SIGMAS)

Adjustment	Stochastic Kalman filter/smoother implemented as square root information filter with smoother
Station coordinates	Daily PPP estimates for all sites Apply daily transformation into IGS14
Satellite clock	Fixed to JPL clock products, which are given every 5 minutes relative to reference clock
Receiver clock	Estimate every 5 minutes relative to satellite clocks
Orbital	Fixed to JPL ECEF orbit products interpolated to 5 min
GPS Attitude	Fixed to JPL products: yaw rates when in eclipse

Troposphere	Zenith delay: random walk 5.0d-8 km/sqrt(sec) Horizontal delay gradients: random walk 5.0e-9 km/sqrt(sec) --- Mapping function: VMF1
Ionosphere	1st order effects removed by LC and PC combinations and 2nd order effects modeled
Ambiguity	Resolve ambiguities using WLPB products from JPL
Earth Orientation Parameters	Fix to JPL products: polar motion, polar motion rate, and LOD, where UT1 is integrated from estimated LOD

REFERENCE FRAMES

Inertial	J2000 Geocentric
Terrestrial	Daily transformed coordinates into IGS14 and relevant plate-fixed frames using plate rotation model
Interconnection	Precession: IAU 2006 Precession Theory --- Nutation: IAU 2006 Nutation Theory --- A priori EOPS: EOPC04 updated daily, with polar motion and length of day estimated daily

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