IGS ANALYSIS STRATEGY SUMMARY

(template version 2.0, 01 May 2006)

Analysis Center	[center name] [ACN = Analysis Center code] [address] [group phone number] [group fax number]
Contact people	[name 1] [e-mail 1] [phone 1] [name 2] [e-mail 2] [phone 2] [name 3] [e-mail 3] [phone 3]
Software used	[name/version], [developer], [YYYY-MM-DD implemented]
GNSS system(s)	GPS
IGS products generated for GPS Week 'wwww' day of Week 'n' (n=0,1,...,6)	ACNwwwwn.sp3 daily orbit files ACNwwww7.erp weekly ERP file of daily values ACNwwwwn.clk daily station & SV clock files ACNwwww7.sum weekly summary file ACNwwww7.snx weekly SINEX file ACNwwwwn.tro daily tropo files (???) ACNGDDD0.YYI daily ionosphere maps (???) [ACN = Analysis Center code] [wwww = GPS week number] [n = GPS day of week number] [DDD = day of year] [YY = year of century]
Preparation date	YYYY-MM-DD
Modification dates	YYYY-MM-DD: ... [items changed & summary] YYYY-MM-DD: ... [items changed & summary]
Effective date for data analysis	YYYY-MM-DD

MEASUREMENT MODELS

Preprocessing	RINEX files pre-screened using TEQC metrics to reject small/incomplete files (<85%), excessive phase slips (>500), or high multipath (>1.2 m); outliers edited & cycle slips detected/fixed; 1 ms RINEX clock jumps fixed using clockprep; code biases corrected to P1/P2 using cc2noncc; [examples shown here; summarize any such preprocessing steps]
Basic observables	undifferenced carrier phases & pseudoranges [or carrier phase only for double-differencing]
	elevation angle cutoff: 10 degrees sampling rate: 5 minute (decimated) weighting: (for raw obs *before* iono correction) carrier phase= 1 cm sigma (nominally) pseudorange= 1 m sigma (nominally) sigmas increase with decreasing elevation angle by factor (1/sin(elev)) deweighting: ... [summarize algorithm, if any] smoothing: ... [summarize procedure, if any] code biases: C1 & P2' corrected to P1 & P2 using cc2noncc tool depending on receiver type
Modeled observables	undifferenced, corrected for 1st order ionosphere effect to LC & PC
*Satellite antenna -center of mass offsets	SV-specific z-offsets & block-specific x- & y-offsets (from manufacturers) from file igs05_wwww.atx based on GFZ/TUM analyses using fixed ITRF2000 coordinates [refer to IGS Mail #5189, 17 Aug 2005]
*Satellite antenna phase center corrections	block-specific nadir angle-dependent "absolute" PCVs applied from file igs05_wwww.atx; no azimuth-dependent corrections applied [refer to IGS Mail #5189, 17 Aug 2005]
*Satellite clock corrections	2nd order relativistic correction for non-zero orbit ellipticity (-2*R*V/c) applied [NOTE: other dynamical relativistic effects under Orbit Models]
GPS attitude model	GPS satellite yaw attitude model: applied (Bar-Sever, 1995); yaw rates adjusted as described below
*RHC phase rotation corr.	phase wind-up applied according to Wu et al. (1993)
*Ground antenna phase center offsets & corrections	"absolute" elevation- & azimuth-dependent (when available) PCVs & L1/L2 offsets from ARP applied from file igs05_wwww.atx [refer to IGS Mail #5189, 17 Aug 2005]

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|*Antenna radome   | calibration applied if given in file igs05_wwww.atx;  |
| calibrations     | otherwise radome effect neglected (radome => NONE)    |
|----------------------------------------------------------------------------|
|*Marker -> antenna| dN,dE,dU eccentricities from site logs applied to     |
| ARP eccentricity | compute station coordinates                            |
|----------------------------------------------------------------------------|
| Troposphere      | met data input: latitude, height, DOY climate model   |
| a priori model   |                 from T. Herring (private comm.);      |
|                  |                 rel. humidity set to 50% for all sites |
| (parameter       |--------------------------------------------------------|
| estimation is    | zenith delay: Saastamoinen (1972) "dry" + "wet"       |
| below)           |--------------------------------------------------------|
|                  | mapping function: NMF for dry & wet parts (Niell, 1996)|
|                  |--------------------------------------------------------|
|                  | gradient model: ...                                   |
|                  | [NOTE: hydrostatic troposphere has equatorial bulge]  |
|----------------------------------------------------------------------------|
|*Ionosphere       | 1st order effect: accounted for by dual-frequency     |
|                  |                   observations in linear combination  |
|                  |--------------------------------------------------------|
|                  | 2nd order effect: no corrections applied              |
|                  |--------------------------------------------------------|
|                  | other effects:    no corrections applied              |
|----------------------------------------------------------------------------|
|*Tidal            |*solid Earth tide: IERS 2003 (dehanttideinel.f routine) |
| displacements    |--------------------------------------------------------|
|                  |*permanent tide: zero-frequency contribution left in   |
| (IERS Conventions|                 tide model, NOT in site coordinates   |
| 2003, Ch. 4, eqn |--------------------------------------------------------|
| 11)              |*solid Earth pole tide: IERS 2003; mean pole removed   |
|                  |                 by linear trend (Ch. 7, eqn 23a & 23b) |
|                  |--------------------------------------------------------|
|                  | oceanic pole tide: not applied (no model available yet)|
|                  |                 [IERS model under development]        |
|                  |--------------------------------------------------------|
|                  |*ocean tide loading: consistent with IERS 2003 (Ch. 7), |
|                  |                 site-dependent amps & phases from Bos |
|                  |                 & Scherneck website for FES2004 tide  |
|                  |                 model; NEU site displacements computed |
|                  |                 using hardisp.f from D. Agnew         |
|                  |                                                        |
|                  | [NOTE: IERS model is not well specified; see NOTES    |
|                  |  below]                                                |
|                  |--------------------------------------------------------|
|                  |*ocean tide geocenter: coeffs corrected for center of  |
|                  |                 mass motion of whole Earth            |
|                  |                                                        |
|                  | [NOTE: IERS Conventions are ambiguous; geocenter motion|
|                  |  should also be included in translation of sp3 orbits |
|                  |  from inertial to terrestrial frame using whole-Earth |
|                  |  coefficients for each tide model given at Bos-       |
|                  |  Scherneck website.]                                   |
|                  |--------------------------------------------------------|
|                  | atmosphere tides: corrections for S1 & S2 tidal       |
|                  |                 pressure loading not applied (no model |
|                  |                 available yet)                        |
|                  |                 [IERS model under development]        |
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|---------------------------------------------------------------------------|
|*Non-tidal         | atmospheric pressure:  not applied                    |
| loadings          |-------------------------------------------------------|
|                   | ocean bottom pressure: not applied                    |
|                   |-------------------------------------------------------|
|                   | surface hydrology:     not applied                    |
|                   |-------------------------------------------------------|
|                   | other effects:         none applied                   |
|---------------------------------------------------------------------------|
|*Earth orientation| ocean tidal: diurnal/semidiurnal variations in x,y, &  |
| variations        |        UT1 applied according to IERS 2003 (ortho_eop.f)|
|                   |-------------------------------------------------------|
| (near 12 & 24 hr  | atmosphere tidal: S1, S2, S3 tides not applied        |
| only; longer      |        [no IERS model specified yet]                  |
| period tidal      |-------------------------------------------------------|
| corrections       | high-frequency nutation: prograde diurnal polar motion |
| should not be     |        corrections (IERS 2003, Table 5.1) applied     |
| applied)          |        using IERS routine PMsdnut.for                 |
|                   |-------------------------------------------------------|
|                                                                           |
| [NOTE: effects should be included in observation model as well as in the  |
|  transformation of orbits from inertial to terrestrial frame]             |
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REFERENCE FRAMES

Time argument	GPS time as given by observation epochs, which is offset by only a fixed constant (approx.) from TT/TDT [NOTE: Please specify which general relativistic timescale is the underlying basis for the time argument used in the analysis. For instance, geocentric time, TCG, is recommended by the IAU but is not generally used in practice; see NOTES below.]
Inertial frame	geocentric; mean equator and equinox of 2000 Jan 1.5 (J2000.0)
Terrestrial frame	ITRF2000 reference frame realized through the set of up to 99 station coordinates and velocities given in the IGS internal realization IGS03P33_RS106.snx [NOTE: update to ITRF2005 expected in mid 2006]
Tracking network	use all available stations of the 99 IGb00 set, plus add others based mostly on geometry up to a total of 150 stations; data are processed in double-difference subnets and combined at the normal equation level; a core net ensures interconnection of the subnets
Interconnection	precession: IAU 1976 Precession Theory
(EOP parameter estimation is below)	nutation: IAU 1980 Nutation Theory, with daily offset corrections applied from IERS Bulletin A [NOTE: Errors in 1980 model are sufficiently large that observational corrections should be applied; even with more recent nutation models, observational corrections are still needed to account for time-varying free core nutation effects, which are not predictable.]
	a priori EOPs: polar motion & UT1 interpolated from IERS Bulletin A, updated weekly, with the restoration of subdaily EOP variations using IERS models (see MODELS above)

ORBIT MODELS

Geopotential (static)	JGM-3 to degree & order 12; C21 & S21 modeled according to polar motion variations (IERS 2003, Ch. 6)
	GM=398600.4415 km**3/sec**2 (for TT/TDT time argument) [NOTE: see Relativity Notes below.]
	AE = 6378136.6 m
Tidal variations in geopotential	*solid Earth tides: procedure given in IERS Conventions 2003, Chapter 6.1, including anelastic effects and step 2 frequency-dependent corrections to Love number k(2,1)
	ocean tides: procedure given in IERS Conventions 2003, Chapter 6.4 applied
	*solid Earth pole tide: IERS 2003, Chapter 6.2
	oceanic pole tide: new model of S. Desai applied for C21 and S21 terms only [NOTE: see IERS Conventions updates]
Third-body forces	Sun, Moon, Mercury, Venus, Mars, Jupiter, Saturn (regarded as point masses)
	ephemeris: JPL DE405
	GM_Sun 132712442076.0000 km**3/sec**2 Moon-Earth mass ratio 0.0123000383 Sun-Mercury mass ratio 6023600. Sun-Venus mass ratio 408523.71 Sun-Mars mass ratio 3098708. Sun-Jupiter mass ratio 1047.3486 Sun-Saturn mass ratio 3497.898
Solar radiation pressure model (parameter estimation is below)	a priori: GSPM_EPS model of Bar-Sever (private comm.) parameterized for variations in direct & orthogonal forces
	Earth shadow model: umbra & penumbra included
	Earth albedo: not applied
	Moon shadow: not applied
	satellite attitude: model of Bar-Sever (1995) applied; yaw rates estimated as described below

*Relativitic effects	dynamical correction: IERS 2003, Ch. 10, eqn 1 (except Lense-Thirring & geodesic precession terms neglected)
	gravitational time delay: IERS 2003, Ch. 11, eqn 17
[NOTE: see NOTES ON RELATIVISTIC EFFECTS below.]	
Numerical integration	variable (high) order Adams predictor-corrector with direct integration of second-order equations
	integration step: variable
	starter procedure: RKF
	arc length: 3+24+3 hours [NOTE: multiple arcs are sometimes combined at the normal equations level for the parameter estimation.]

ESTIMATED PARAMETERS (& APRIORI VALUES & CONSTRAINTS)

Adjustment method	weighted least squares implemented as a Kalman filter [or weighted least squares and Helmert blocking used to process subnetworks separately and then combine]
Data span	30 hours used for each daily analysis, but results reported only for the central 24 hours [NOTE: multiple orbital arcs are sometimes combined at the normal equations level for parameter estimation.]
*Station coordinates	all station coordinates are adjusted, relative to the a priori values from IGS03P33_RS106.snx; a no-net-rotation condition is applied wrt the IGb00 frame using up to 99 reference frame stations; apriori sigmas are 1 m for each component [NOTE: update to ITRF2005 expected in mid 2006]
Satellite clocks	solved for at each epoch as white noise process with a steady state sigma of 1 sec --- sp3,clk files: frame for clocks corresponds to ITRF origin by constraining station positions and back-solving for clocks [or clocks consistent with apparent center-of-mass frame and determined simultaneously with station positions; this is not recommended for IGS products]
Receiver clocks	solved for at each epoch as white noise process with a steady state sigma of 1 sec; one station clock fixed & used as a timescale reference, usually USNO. Output .clk file of clock products has been "densified" using PPP with our own satellite orbit/clock files to generate clocks for stations not used in the orbit/TRF solution. Highest priority is given to stations with stable clocks and stations co-located at time labs.
Orbits	deterministic positions and velocities, y-bias, solar radiation pressure scale in direct direction; stochastic accelerations in SV x,y,z directions with steady state sigma of 0.125e-12 km/s/s and correlation time of 4 hrs solved for every 30 min, nominally; stochastic sigma increased for SV with poor fits based on prior preliminary solution or prior history; apriori values are based on solution for previous day [or whatever procedures are actually used ...] --- sp3 files: orbits transformed to crust-fixed (rotating) frame accounting for geocenter motions due to ocean tides and for subdaily tidal EOP variations [NOTE: see NOTES below for details]

Satellite attitude	deterministic yaw bias with yaw rates estimated as white noise for satellites which are eclipsing with a steady state sigma of 0.01 deg/sec, solved for every 6 hours
Troposphere	zenith delay: estimated for each observation as a random walk with process noise of 1.0 cm/sqrt(hr) [or if segmented model used give model form and segment interval]
	mapping function: partial is NMF wet (Niell, 1996)
	zenith delay epochs: reported for each observation epoch [if segmented model used, give epochs of tabulated values]
	gradients: one N-S and one E-W gradient parameter per day for each station, constrained to 10 mm at 10 deg elevation angle
Ionospheric correction	not estimated
Ambiguity	phase cycle ambiguities adjusted except when double-ambiguities can be resolved confidently (<2 cm uncertainty), in which case they are fixed; fixing is successful for 98% of obs on all baselines <2000 km
*Earth orientation parameters (EOP)	daily x & y pole offsets, pole-rates, and LOD at noon epochs; rates constrained to 32.2 mas/day; UT1 not estimated
Other parameters	... [explain]

NOTES ON RELATIVISTIC EFFECTS

Here is a brief summary of the relativistic effects involved in modeling satellite orbits to determine a terrestrial reference frame (TRF), etc:

* The dynamical formulation should be in an geocentric frame, applying the relativitistic corrections listed below for the effects on signal propagation and satellite dynamics.
* If the TDT time scale (i.e., no secular rate term included between TT = TAI+32.184s and the time coordinate used for the dynamics) is used, as is still common despite IAU/IUGG recommendations to use TCG, then the appropriate value for GM = 398600.4415 km**3/sec**2. However, this choice of modeling will result in a TRF which differs from TCG units; the TRF will need to be scaled upward by (1 + Ue) = (0.69... ppb) to be consistent with a TCG timescale.
* If the IAU-recommended TCG timescale is used (the secular rate term included between TT and the TCG time coordinate used for the dynamics), then the appropriate value for GM = 398600.4418 km**3/sec**2. For this choice of modeling, the TRF scale will be consistent with IAU/IUGG recommendations.
* The observation modeling should include the following relativistic effects:

[1] The 1st-order effects on GPS satellite clocks due to time dilation and gravitational potential shifts have been accounted for by offsets applied in the oscillator settings aboard the spacecraft, assuming nominal orbital elements. The 2nd-order effects due to non-circular orbits must be handled by applying a periodic time correction:

-2(R <dot> V)/c^2

where R is the satellite position, V its velocity, and c the speed of light.

[2] The coordinate time of propagation, including the gravitational delay ("gravitational bending"), as given in IERS Conventions 2003, Ch. 11, eqn 17.

[3] The "dynamical correction" to the acceleration of near-Earth satellites, as given in IERS Conventions 2003, Ch. 10, eqn 1. The 2003 version differs from earlier editions by the addition of terms for the Lense-Thirring precession (frame dragging) and geodesic (de sitter) precession, which are probably negligible for the short arcs used in most GPS analyses. The IERS formulation neglects the Earth's oblateness, an effect estimated by Kouba (2004) to be ~0.2 ns/day (same level as IGS clock accuracy) with periodic variations at 6 hrs and near 14 days.

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|        NOTES ON HANDLING OCEAN TIDAL LOADING DISPLACEMENT EFFECTS           |
|-----------------------------------------------------------------------------|
| There are three main parts involved in implementing model corrections for |
| ocean tidal loading (OTL) effects in GPS analyses to be fully self-        |
| consistent:                                                                 |
| [1] Site-dependent tidal coefficients                                       |
| Site-dependent amplitude & phase values for the 11 main tides (in BLQ      |
| format) are generated upon request by the Bos-Scherneck OTL service at     |
|   http://www.oso.chalmers.se/~loading/                                      |
| Users are advised to select one of the more modern ocean models from the  |
| list available, such as FES2004 models.                                     |
| For the option "Do you want to correct your loading values for the [center|
| of mass] motion?" the answer should be "YES" (but the default is "NO").    |
| [Note that for users of IGS orbits (in sp3 format) it is generally *not*  |
| necessary to consider the center of mass effect because this has already  |
| been taken into account by the IGS (see below).  That is, the IGS orbits  |
| are expressed with respect to the Earth's crust as a fixed frame.  So, for|
| such applications, site-dependent coefficients should be with the option  |
| "Do you want to correct your loading values for the motion?" set to the   |
| default "NO".]                                                              |
| [2] Site-dependent tidal displacements                                      |
| Given previously computed site-dependent amp & phase values for the 11     |
| main tides (in BLQ format), the hardisp.f routine, written by Duncan Agnew|
| (UCSD), determines local dU, dS, dW displacements.  The code can be found |
| at the IERS Conventions Update site at                                      |
|   ftp://tai.bipm.org/iers/convupdt/chapter7/hardisp.f                       |
| This routine considers a total of 141 constituent tides using a spline    |
| interpolation of the tidal admittances, achieving a precision is about 1%.|
| [3] Center-of-mass orbit correction                                         |
| After the Analysis Centers determine the GPS orbits in an inertial frame, |
| taking account of the OTL effects as described above, it is necessary as  |
| a final step in generating sp3 format orbit results to account for the    |
| crust-frame motions due to the ocean tidal mass.  This can be done by     |
| computing the net crustal frame translations dX(t), dY(t), and dZ(t)      |
| according to the method given by Scherneck at                              |
|   http://www.oso.chalmers.se/~loading/cmc.html :                            |
|                                                                             |
| dX(t) = SUM_i=1,11 { Xin(i) * cos(ANGLE(t,i)) - Xcr(i) * sin(ANGLE(t,i)) }|
| dY(t) = SUM_i=1,11 { Yin(i) * cos(ANGLE(t,i)) - Ycr(i) * sin(ANGLE(t,i)) }|
| dZ(t) = SUM_i=1,11 { Zin(i) * cos(ANGLE(t,i)) - Zcr(i) * sin(ANGLE(t,i)) }|
|                                                                             |
| where ?in(i) are the in-phase and ?cr(i) are the cross-phase amplitudes   |
| for the 11 main ocean tides.  ANGLE(t,i) is the angular argument returned |
| by the IERS subroutine ARG(YEAR,DOY,ANGLE) for YEAR being the (current    |
| year - 1900) and DOY being the day of year and fraction thereof.  The ARG |
| routine is available at the IERS Conventions Update website:               |
|   ftp://tai.bipm.org/iers/convupdt/chapter7/ARG.f                           |
| Scherneck has tabulated the center of mass motion in-phase and cross-phase|
| coefficients for the various ocean models at:                              |
|   http://www.oso.chalmers.se/~loading/CMC/                                  |
| Note that on each tidal constituent record, the entries are ordered as:   |
|   tide, model name, Zin, Zcr, Xin, Xcr, Yin, Ycr                            |
|   using the format (a,1p,t42,3(2x,2e12.4)).                                 |
| In order to correct the GPS inertial orbits (ORB_cm) to the moving        |
| crust-fixed frame (ORB_sp3), in addition to whatever other transformations|
| are applied, the following translations should also be made:               |
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|   ORB_cm(t) + dXYZ(t) --> ORB_sp3(t)                                       |
| where dXYZ(t) is the dX(t), dY(t), dZ(t) vector computed above.  Note that|
| this correction is exactly analogous to the rotational corrections that   |
| must be applied to create sp3 orbits whenever a sub-daily EOP tidal model |
| is used in the GPS data analysis.                                          |
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REFERENCES

Bar-Sever, Y.E., New GPS attitude model, IGS Mail #591, 1995, http://igscb.jpl.nasa.gov/mail/igsmail/1994/msg00166.html

Bos, M.S., & H.-G. Scherneck, website at www.oso.chalmers.se/~loading/

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Niell, A.E., Global mapping functions for the atmosphere delay at radio wavelengths, J. Geophys. Res., 101(B2), 3227-3246, 1996.

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Wu, J.T., S.C. Wu, G.A. Hajj, W.I. Bertiger, and S.M. Lichten, Effects of antenna orientation on GPS carrier phase, Manuscripta Geodaetica,18, 91-98, 1993.

* = strong consistency with IERS/IGS conventions is especially important for these items