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The GPS Data Reanalysis Campaign at the National Geodetic Survey

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1. Introduction

The National Geodetic Survey (NGS) has begun a GPS data reanalysis campaign in cooperation with the International GNSS Service (IGS). The NGS is using its own Program for the Adjustment of GPS EphemerideS (PAGES) as the heart of its data processing. Institut Geographic National's Combination and Analysis of Terrestrial REFerence Frames (CATREF) software will be used to form a long-term combined frame from weekly postioinal solutions.

In addition to computing global frame, orbit and Earth rotation soltuions for submission to the IGS, the NGS is reanalyzing GPS data from the U.S. Continuously Operating Reference Stations (CORS) network. CORS consists of 1187 GPS receivers, most located within the United States. These receivers are owned and operated by 192 orgnizations. The results of the reanalysis will make the reference frame of the United States consistent with the IGS reference frame, IGS05, and ultimately ITRF. The results will also be combined with the results of other organizations to form an updated North American REference Frame (NAREF).

To date,the NGS has submitted eleven (11) weeks of solutions to the IGS. Eight (8) of those submissions were in time to be included in the combinations.

2. NGS Data Analysis Strategy

Software

PAGES (Program for the Adjustment of GPS EphemerideS) performs a batch weighted least-squares estimation of a variety of parameter types. For efficiency, processing of large networks is usually done by first processing suitable subnetworks forming a set of reduced normal equations with PAGES, which are then combined (via Helmert blocking) to determine a variety of global parameters with the GPSCOM (GPS COMbination) software.

Measurement Models

- Basic observables - Double-differenced carrier phase network defined using an optimal Delaunay triangulation algorithm
  - code only used for receiver clock synchronization and to aid in fixing phase ambiguities using the Melbourne-Wuebbena widelane method
  - elevation angle cutoff: 10 degrees
  - sampling rate: 30 seconds
  - weighting model: elevation-dependent scaling
- Satellite antenna phase center models: "absolute" offsets and phase center variations (PCVs) applied from the IGS standards file, igs05_wwww.atx
- Ground antenna phase center models: "absolute" elevation & azimuth-dependent PCVs and L1/L2 offsets from antenna reference point (ARP) applied from the igs05_wwww.atx file
- Antenna radome calibrations: applied from igs05_wwww.atx
- Troposphere a-priori model:
  - pressures, temperatures from GPT; relative humidity = 0.5 for all sites
  - zenith delay: *Saastamoinen* [1972] "dry" + "wet"
  - mapping function: GMF [*Boehm et al.*, 2006] for dry & wet zenith delays individually
  - no horizontal a-priori gradient model is used
- Ionosphere model: only a 1st order effect is accounted for by dual-frequency observations in linear combination
- Tidal displacements: IERS Conventions 2003
  - solid Earth tide: IERS 2003
  - permanent tide: zero-frequency contribution left in tide model
  - ocean tide loading: using site-dependent amplitudes & phases for 11 main tides from Bos & Scherneck website for FES2004 model, computed using hardisp.f
  - ocean tide geocenter: site-dependent coefficients corrected by Earth's center of mass (i.e., CMC) motion; CMC corrections also applied to satellite orbits

Reference Frames

- Time argument: GPS time as given by observation epochs
- Inertial frame: geocentric - mean equator and equinox of 2000 (J2000)
- Terrestrial frame: IGS05 – an IGS realization (GPS only) of the ITRF2005 reference frame

Orbit Models

- Geopotential (static): GEM-T3 model up to degree and order 8:
  - GM=398600.4415 km3/sec2 and AE = 6378136.3 meters
- Third-body forces: Sun & Moon as point masses
- Solar radiation pressure model: presently the modified CODE operational version of their SRP model is applied (see Panel 3 for details)
  - Earth and Moon shadow models: umbra & penumbra included
- Numerical integration is a variable, high-order Adams-Moulton predictor-corrector with direct integration of second-order equations

Estimated Parameters

- Satellite and receiver clocks not estimated, eliminated by double-differencing
- Orbits: Geocentric positions and velocities; solar radiation pressure scaling terms in 3 orthogonal directions--3 constant offset and 2 once-per-rev terms; midday 3D constrained velocity discontinuities:
  - final orbits:
    - station coordinates are adjusted from a-priori values from IGS standards:
    - no-net-rotation condition imposed, w.r.t. IGS05, using up to 132 IGS fiducial stations
  - rapid orbits:
    - frame inherited by fixing the IGS fiducial stations
- Troposphere zenith delay: residual delays and horizontal gradients are adjusted for each station assuming the delays are mostly dominated by "wet" component.
- Real-valued double-differenced phase cycle ambiguities are adjusted except when they can be resolved confidently (<4.5 cm uncertainty), in which case they are fixed (approximately 95% are fixed)
- Earth orientation parameters (EOP):
  - daily x & y pole offsets, and UT1-UTC estimated at day boundaries
  - x and y pole estimated as piece-wise, linear offsets from IERS Bulletin A and IGS ERP a-prioris over each 1-day segment
  - estimates transformed to equivalent offsets and rates at noon epochs to be consistent with IGS

GPS Tracking network

The global network used to determine the global frame , orbit and Earth rotation solutions is composed of nearly 200 IGS global stations. In addition, 12 - 13 CORS stations are added to increase the density of the North American backbone for the CORS solution. A handful of non-IGS AUSLIG stations are added to improve the coverage in the southwest Pacific. The baselines are selected using Delaunay triangulation.

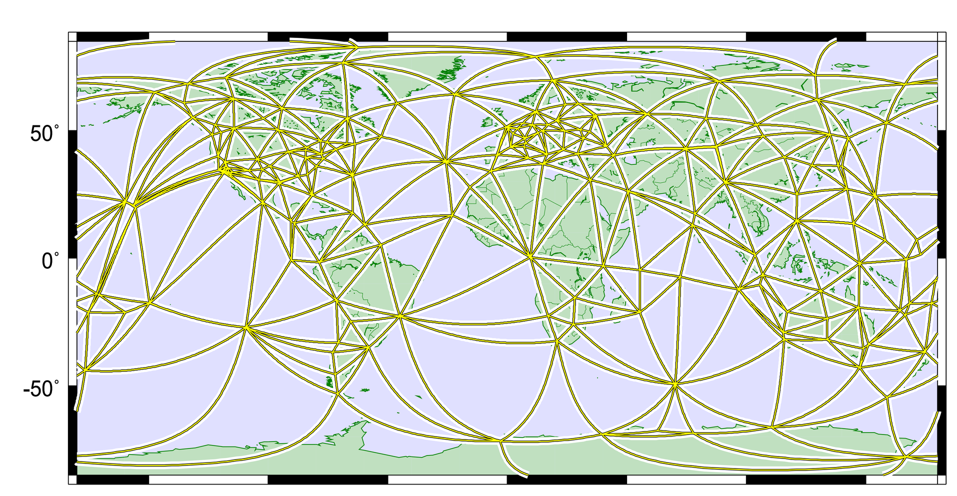

Fig. 1. The global network with baselines shown for 9 September 2007.

The CORS network is formed by attaching the CORS stations to the nearest station in the global network to form clusters. The data for each cluster are reduced using PAGES with orbits and Earth orientation parameters fixed from the previous global solution.The normal equations for all of the CORS clusters are combined and back-solved for the global + CORS network.

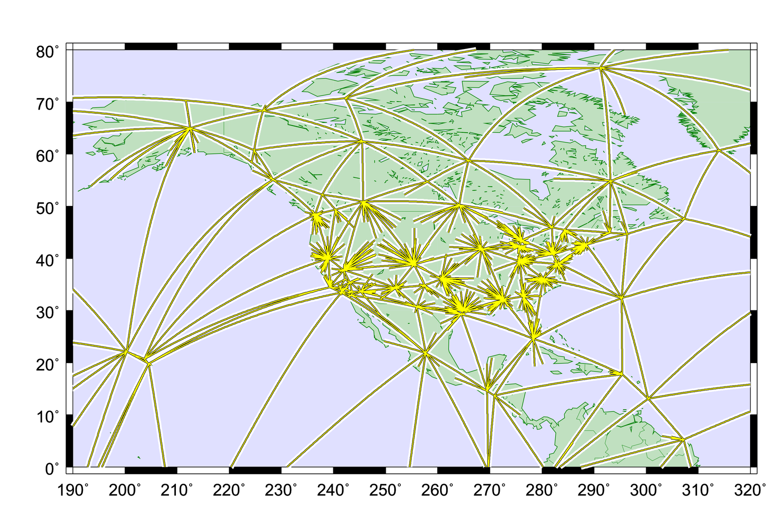

Fig. 2. The CORS network with baselines shown for 9 September 2007.

3. Relative Performance of NGS Orbits

With so few weeks processes and no combined reprocessed orbits with which to compare, it is difficult to access the quality of the NGS orbits. Comparisons can be made to the reprocessed orbits of the other ACs and to the IGS Final orbits. Figure 3 shows that the NGS orbits are comparable to the orbits of the other ACs.

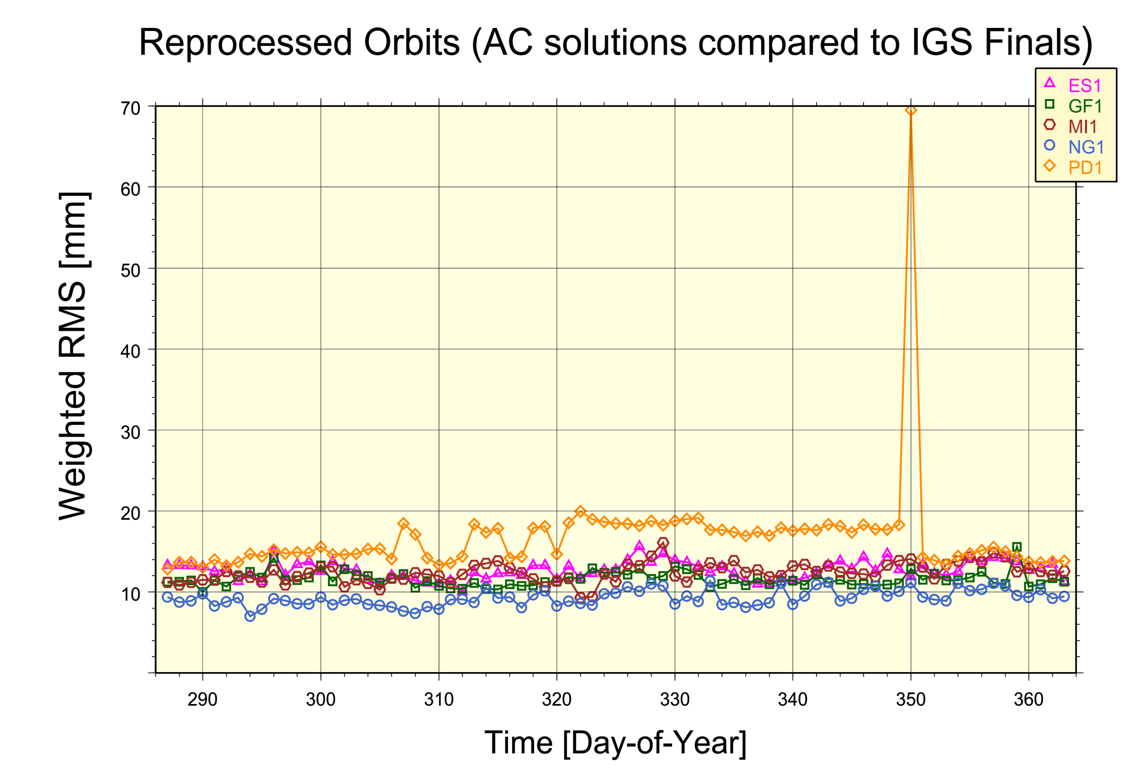

Fig. 3. Eleven weeks of weighted 1D RMSes from reprocessed orbits compared to IGS Final orbits.

4. Relative Performance in Weekly SINEX Combination

The NGS reference frame alignment compares favorably with the weekly SINEX combination and with the alignment of the other ACs. There however a down bias. The comparisons for weeks 1449 - 1451 were done in-house and the standard deviations are suspect. The comparisons for weeks 1452 - 1459 are from Remi Ferland.

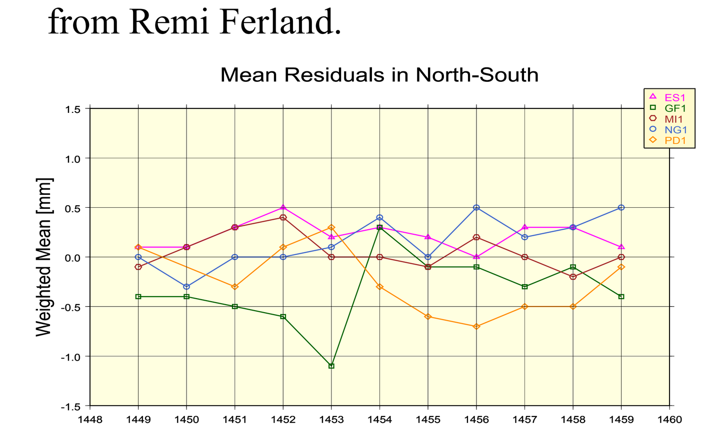

Fig. 4a. Mean north-south residuals from weekly SINEX combinations.

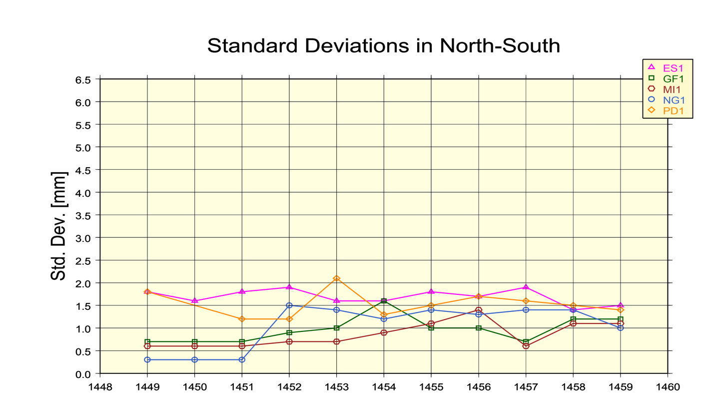

Fig. 4d. North-south std. dev. from weekly SINEX combinations.

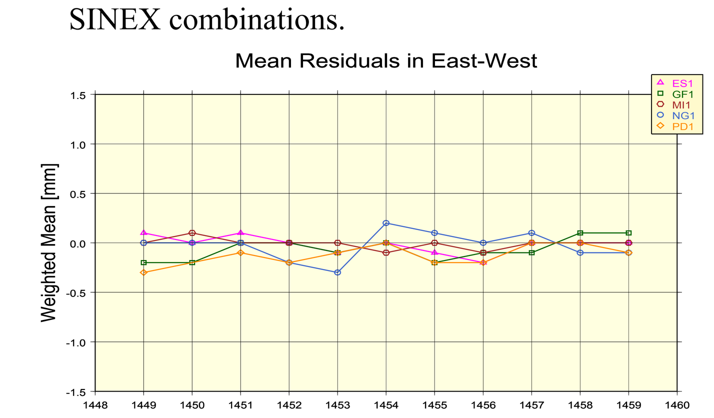

Fig. 4b. Mean east-west residuals from weekly SINEX combinations.

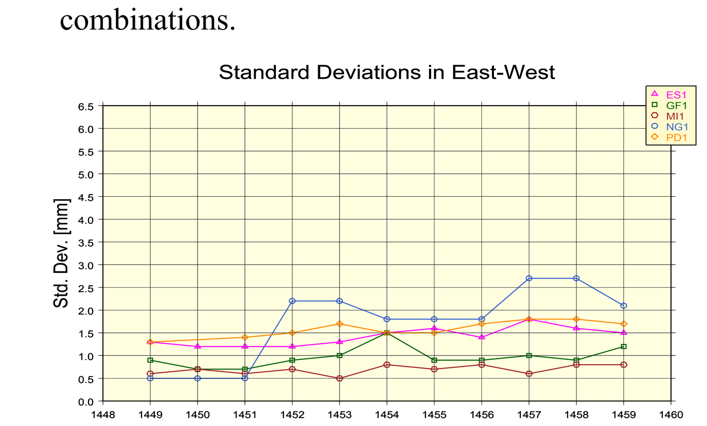

Fig. 4. East-west std. dev. from weekly SINEX combinations.

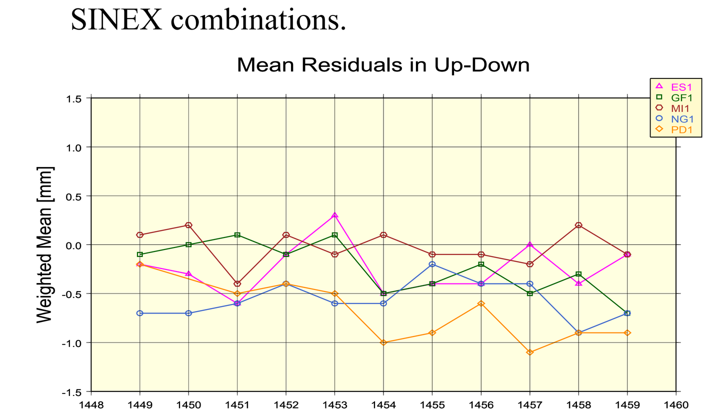

Fig. 4c. Mean up-down residuals from weekly SINEX combinations.

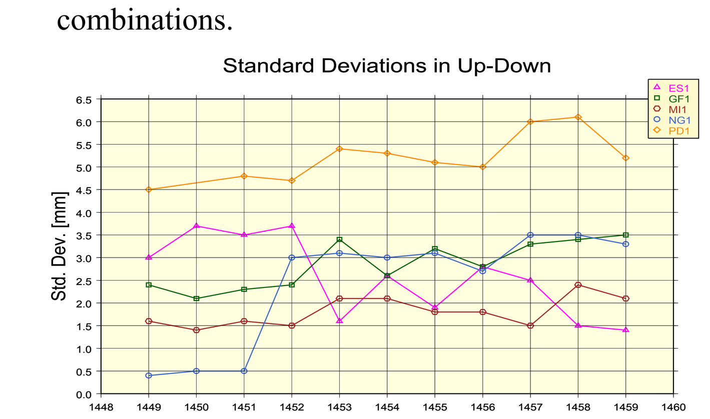

Fig. 4d. Up-down std. dev. from weekly SINEX combinations.