ABSTRACT
We discuss the analysis of the 1999 combined solutions generated from the SINEX files submitted by the IGS analysis centers. We highlight the changes to the analysis procedures reported in previous annual reports. Analysis of our combined solutions shows mean fits to the up to 43, and on average 41, ITRF97 reference sites of 3.7 mm. For the G-SINEX combinations the median root-mean-square (RMS) repeatability in north, east, and height are 1.9, 2.4 and 5.6 mm, respectively for 173 sites. For the P-SINEX combinations, the median RMS repeatabilities are 1.9, 2.1, and 5.9 mm, respectively for 230 sites. Estimates of daily pole position and length-of-day (LOD), now included in our G-SINEX analysis, deviate from IERS Bulletin A with RMS scatters of 0.16 and 0.19 milli-arc-seconds (mas) in X- and Y-pole position, and 0.023 milliseconds (ms) in LOD.

ANALYSIS PROCEDURE CHANGES
As reported previously [Herring, 1996,1997], two analyses are performed each week. One of these analyses uses the IGS Analysis Center (AC) weekly A-SINEX files to generate a combined G-SINEX file, and the other uses the Regional Analysis Center (RAC) R-SINEX files combined with the G-SINEX file to generate weekly P-SINEX files. In 1999, the G-SINEX files contain 173 sites that were used more than 10 times during the year and 65 sites that were used every week. The corresponding values for the P-SINEX files are 230 and 94 sites, respectively. The G- and P-SINEX analyses are performed 3 and 7 weeks delays.

The basic procedures we use are documented in the weekly summary files submitted with the combined SINEX files. The two changes of note are associated with (a) deconstraining SINEX files, and (b) incorporation of Earth rotation parameters in the weekly analyses. Also starting at the beginning of 1999 we began applying the pole-tide correction to the ESA, NGS and SIO SINEX files (the other analysis center already appear to be applying these corrections). We also adopted an automatic correction feature that reads the igs.snx file, and applies corrections to the analysis center SINEX files if there are differences. If the antenna type is correct, then this procedure should generate the same result as if the analysis center had used the correct information in the original processing. The corrections applied are reported each week in the summary file. Corrections were still needed even by the end of 1999 and into 2000. Typically, 3-4 station heights and 1-2 antenna phase offsets need correction per week.
Deconstraining AC SINEX files

All of the IGS analysis centers now submit either loosely constrained SINEX files (JPL, SIO) or SINEX files with minimum constraints applied (EMR, GFZ, NGS, COD and ESA). For this latter group of analysis centers we add to their covariance matrix a rotational deconstraint with variance of $(10 \text{ mas})^2$. This additional matrix is generated by computing the full covariance between station coordinates and Earth orientation parameters for rotations about each axis with $(10 \text{ mas})^2$ variance. Two analysis centers (ESA and GFZ) are applying constraints to the center of mass position. We are currently not removing these constraints because we have not implemented in our software the necessary algorithms to undo these types of constraints. As a result, our estimates of center mass motion can not be considered reliable indicators of true center of mass motions or of the quality of the GPS determinations.

Earth rotation parameter estimation

We now carry forward into the SINEX combinations the estimates of Earth rotation parameters. In our combination we allocate elements in the Kalman filter state vector for the Earth orientation parameters (value and rate of change) for each day of the week centered at 12:00 UTC. The stochastic variations in these parameters are treated as a combination of a random walk (process variance $1 \text{ mas}^2$/day for pole position, and $0.066 \text{ ms}^2$/d of UT1) and integrated random walk ($0.1 \text{ mas}^2$/day$^3$) for pole position and $0.007 \text{ ms}^2$/day$^3$ for UT1). The initial values at the start of the week are assumed to have variances of $(100 \text{ mas})^2$ for pole position, $(10 \text{ mas/day})^2$ for polar motion rate, $(6.7 \text{ ms})^2$ for UT1 and $(0.67 \text{ ms})^2$ for length of day. We ignore the values of UT1 given in the input SINEX files, i.e. the estimates of UT1 in our combined SINEX files are the IERS Bulletin A values at the start of week and integration of LOD for later days in the week.

We apply corrections to the submitted SINEX for some centers. For JPL, prior to January 1, 2000, we treat the input LOD as being regularized even through it is not given as LODR. For all dates, we reverse the sign of LOD since the submitted values appear to be the time derivative of UT1. For GFZ, we reverse the sign of UT1 since it appears to be given as UTC-UT1. (This latter change has little effect because we do not use the UT1 values).

ANALYSIS OF COMBINED SOLUTIONS

Our analysis of 1999 combined SINEX files examines the internal consistency of these combinations and their agreement with ITRF97. Figure 1 we show for each weekly combination in 1999, the RMS agreement between the ITRF97 reference sites (list of sites given in weekly summary files and the number of sites used in the realization. This RMS is computed from the combination of the north, east, and height differences after a translation, rotation, and scale are removed from the weekly combination. In computing the RMS, the height is down-weighted by a factor of 3, i.e., we construct a weight matrix with the heights given one-tenth the weight of the horizontal components.
Figure 1: RMS fit of the weekly combinations to the up to 43 ITRF97 reference sites. The mean RMS fit is 3.7 mm with a median of 41 stations form the reference site list used.

In Figure 2, we show the estimates of the differences between the G-SINEX estimates of pole position and LOD. Some of the systematic differences seen in the pole position differences arise from errors in the treatment of EOP parameters and changes in the analysis center data that were being used in the combination. Near the end of 1999 and continuing into 2000 the differences between our pole position estimates and IERS Bulletin-A are considerably reduced. From December 1999 forward, the RMS scatters of the pole position differences reduce to about 0.05 mas. The behavior of LOD remains unchanged in the latter part of the time series and this may be because we are not yet correctly fixing the problems in the analysis center EOP estimates (or the analysis center has fixed a previous problem but we are not aware that the change has been made). Overall the RMS scatter of the LOD differences are small compared to the magnitude of LOD variations (RMS 0.41 ms for the variations compared to 0.02 ms for the differences). For reasons that are not clear, the combination appears to underestimate the uncertainties of the EOP parameters by a much larger factor than station positions.

In Figure 3, we show the histograms for the repeatabilities of the sites in the G- and P-combinations. Although the RMS scatters are small, they are typically three-times larger than the standard deviations of the estimates. The time series of the position estimates also show systematic variations (see http://www-gpsg.mit.edu/~fresh/MIT_IGS_AAC.html). The median RMS scatters for the G- and P-SINEX solutions are similar with the P-SINEX being a little smaller in the East component suggesting that bias fixing in the P-SINEX files (which tend to contain sites with shorter intersite distances) may improve the East repeatability. The ratio of the scatter of the position estimates to their uncertainties is 10% larger for the P-SINEX files suggesting that the errors are underestimated by a larger factor than the G-SINEX files. Despite rescaling of the covariance matrices of individual centers to make $\chi^2$-per-degree of freedom ($\chi^2/f$) near unity, the scatter of the position estimates is 2-3 times larger than the error bars would suggest. Interestingly, the height errors appear closer to the scatter (ratio 2) than the errors horizontal errors do (ratio 3). Analysis of the power spectra of the site position residuals shows these spectra have red-noise characteristics which is consistent with $\chi^2/f$ being larger than unity.
Figure 2: Differences between the G-SINEX and IERS Bulletin-A estimates of pole position and length-of-day. The RMS differences are 0.16 and 0.19 mas in pole position and 0.023 ms in LOD.

REFERENCES
Figure 3: Histogram of the repeatabilities from the G- and P-SINEX combinations. The median values are 1.9, 2.4, and 5.6 mm for the north, east and height in the G-SINEX combinations and 1.9, 2.1, and 5.9 mm in the P-SINEX combinations. For horizontal components, the P-SINEX solutions have median ratios of the scatter to the standard deviations from the combination of 3.2 compared to 2.8 for the G-SINEX. For heights, the ratio medians are about 1.8 and 2.0 for the G- and P-SINEX files.